A Secure and Reusable Artificial Intelligence Platform for Edge Computing in Beyond 5G Networks

D2.4 KPIs, social-economic impact assessment and technoeconomic analysis

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Glossary	
AI	Artificial Intelligence
CA	Consortium Agreement
DMP	Data Management Plan
ETSI	European Telecommunications Standards Institute
FG-AN	Focus Group on Autonomous Networks
FRMCS	ETSI Future Railway Mobile Communication Systems
GA	General Assembly
IA	Infrastructure Association
IBN	Intent-Based Networking
IETF	Internet Engineering Task Force
IPR	Intellectual Property Rights
IRTF	Internet Research Task Force
ITU-T	ITU Telecommunication Standardization Sector
KPI	Key Performance Indicator
LCM	Latent Class Model
nGRG	Next Generation Research Group
NM	Network Management
NMRG	Network Management Research Group
SDA	Standards Developing Association
SDO	Standards Developing Organization
SNS	Smart Networks and Services
UC	Use-Case
WG	Working Group
WP	Work package

Executive Summary

Deliverable D2.4 presents a comprehensive update on the techno-economic analysis and key performance indicators (KPIs) initially introduced in Deliverables D2.1, D2.2, and D2.3. This report (Milestone 13) focuses on the advancements made in Task 2.3, dedicated to defining project KPIs, conducting techno-economic analysis, and assessing socio-economic impacts.

Chapter 2 builds on the foundational work established in Deliverables D2.2 and D2.3, offering a broader understanding of the project's technical objectives and criteria for evaluating them. It presents a detailed overview of the project's technical KPIs, emphasizing their relevance to the project’s goals and the importance of quantifiable, relevant measures in guiding technical advancements.

Chapter 3 explores the techno-economic analysis and impact of the AI@EDGE project. This chapter connects the project’s technological progress with economic viability, showcasing its practicality and sustainability in a market context. It goes beyond traditional analyses by incorporating an extensive review of business models, value networks, and the potential impacts of new technologies on business cases. The analysis encompasses insights into how AI@EDGE aligns with market realities and potentials.

Chapter 4 delves into the socio-economic impact assessment and the project's alignment with Sustainable Development Goals (SDGs), mirroring the approach used in the techno-economic analysis but with a broader societal perspective.

Chapter 5 provides an analysis of the socio-economic impact and techno-economic analysis, tailored to the specifics of each use case. This chapter offers specialized KPIs for each use case, complete with in-depth descriptions of how and where these values were measured.

Conclusively, the report offers a synthesis of the AI@EDGE project, combining its technical, societal, economic, and environmental dimensions. It provides a view of how these aspects interact and influence each other within the project's framework. By integrating the techno-economic analysis with a keen understanding of socio-economic impacts, the report demonstrates a multidisciplinary approach to technological development. This approach not only provides a technical contribution in edge computing and AI technologies but also emphasizes their relevance and responsibility towards societal needs and environmental sustainability.

1. Introduction

Deliverable D2.4 of the AI@EDGE project represents a comprehensive examination of the project’s technical Key Performance Indicators (KPIs), along with its socio-economic and techno-economic impacts. This document is structured to seamlessly integrate these critical aspects, providing a clear and detailed understanding of the project's multifaceted impact.

This introductory chapter provides a starting point for Deliverable D2.4 of the AI@EDGE project. Here, we set the stage for the detailed exploration of the project's Key Performance Indicators (KPIs) and its wider impacts on society and the economy. This chapter eases readers into the more detailed sections that follow, offering a clear and simple overview of what to expect in the rest of the document.

The second chapter provides the methodology used for defining and connecting the KPIs together with overview presentation of the project's technical KPIs. It aims to provide a broad understanding of the project’s technical objectives and the criteria for evaluating them.

Moving into the third chapter, we delve into the techno-economic analysis. This part of the report balances the technical advancements within AI@EDGE with their economic implications, offering insights into how the project’s innovations align with market realities and potentials. The chapter aims to connect technological progress with economic viability, showcasing the project's practicality and sustainability in a market context.

In the fourth chapter, the focus shifts to the socio-economic impact. Here, we explore the broader societal implications of AI@EDGE, particularly its contribution to the Sustainable Development Goals (SDGs). This chapter highlights the project’s commitment to positive societal change, emphasizing its role in addressing global challenges and contributing to a sustainable future.

The fifth chapter provides a detailed analysis of each use case within the AI@EDGE project. Building upon the methodologies and assessments discussed earlier, this section offers a nuanced view of how the project impacts various scenarios. It brings the earlier chapters full circle, illustrating the real-world applications and implications of the project’s innovations. Additionally, the fifth chapter offers a detailed exploration of the KPIs specific to each use case within the AI@EDGE project. Building upon the general KPI overview provided in the second chapter, this section delves into the nuanced, use-case-specific impacts of the project. It provides a more granular view of how the project's innovations are manifested and measured in different scenarios, illustrating the direct implications and achievements in each unique context.

Throughout this deliverable, the Sustainable Development Goals (SDGs) are a recurring theme, reflecting the commitment to integrating global sustainability efforts into the technological advancements. By aligning the project with these goals, we underscore the dedication to not just technological excellence but also to making a positive impact on society and the environment.

In essence, Deliverable D2.4 provides a comprehensive view of the AI@EDGE project, linking its technical achievements with economic and societal benefits. This document not only serves as an account of the project’s current status but also as a guidepost for its future trajectory, ensuring that AI@EDGE continues to be a benchmark project in both innovation and sustainability.

2. Methodology for Defining and Connecting KPIs

This Chapter 2 summarizes the process of exploring the different steps and components developed to define a set of Key Performance Indicators (KPIs) within the project. We also describe how the KPI Console, an add-on tool for the management of the KPIs defined for the AI@EDGE platform, could be used as a starting point for further developments and the addition of new functionalities for the AI@EDGE platform.

2.1 Methodology for KPI Definition

The methodology defines a common format for the KPIs description, which encapsulates all aspects and characteristics of KPIs, and introduces the KPI Matrix. Since issuing both deliverable D2.2 and D2.3, some changes were introduced to the KPI Matrix with the aim to better adjust the format to the evolving core characteristics of the AI@EDGE Platform and to align it with the 5GPPP template. (5G PPP, n.d.)

The AI@EDGE project proposed an initial template for KPIs description that contains essential information and data, i.e., the core characteristics of a specific KPI. The template takes the form of a KPI Matrix with the following domains:

- Name and Description.
- Use Case linked with each KPI (1 to 4).
- Threshold value: expresses the limit set in a KPI in order for the outcome to be acceptable and/or feasible.
- Achieved value: value obtained during the validation and evaluation at the end of the project.

Together with collecting and defining AI@EDGE KPIs, a collaboration has been established with the 5GPPP Test, Measurement and KPIs Validation Working Group (TMV WG), as its objectives bear close relation with the work already implemented by the AI@EDGE Project. Upon collaboration with the TMV WG, the KPI Matrix was enhanced with fields that were adopted in the template proposed by the 5G PPP TMV formula of collecting and defining KPIs. Therefore, the following columns were added to the AI@EDGE KPI Matrix (Technical):

- Where to measure the KPI
- Relevant components: parts of the platform that directly affect KPI
- Project enhancement: how meeting the target value for said KPI drives to innovation
- Comments: general remarks regarding the specific KPI

2.2 Final KPI Matrix (Technical)

In this section the general overview of the project's technical KPIs are provided. The KPI Matrix **Error! Reference source not found.** provides the list of AI@EDGE technical KPIs with achieved values measured during the final validations and evaluations in testbeds. Additional information regarding specific KPIs for each use case are provided in Chapter 5 with detailed descriptions on where and how that achieved values have been measured. Moreover, detailed descriptions on components of the AI@EDGE platform and project enhancements that affected achievements of specific KPIs are also provided.

The KPI Matrix provide clear and global overview about AI@EDGE projects s technical results in terms of measured technical KPIs, where almost all KPIs, present achieved values equal to or even better than threshold values. In particular:

- Networking Group of KPIs present a notable result in achieved value for Data Rate/Client for Streaming [TN4] of 60 Mbs much better than target of 15 Mbs, while Drone Range achieved value of 24 Km is quite better than target value of 20 Km.
- Computing Group of KPIs present almost all KPIs with achieved values equal to target values with Service Deployment Time KPI were achieved value of 15 s much better than threshold value of 180 s.
- Reliability Group of KPIs present almost all KPIs with achieved values equal to target values while Curated Content Delivery Time with achieved value of 2 s, much better than threshold value of 180 s.

Table 1 KPIs Matrix (Technical) – Final Version

Group [ID]	KPI Description [ID]	Use Case Nr / All / Generic	Threshold (Number / Qualitative Description)	Achieved Value	Where to Measure	Components Involved	Project enhancement	Comments
Networking [N]	Vehicle Density [TN1]	1	1200 vehicles/km 2	1200 vehicle/km2	- 5G network Emulators - Driving Simulators	AV/ADAS Vehicle simulators Network Simulators, MEC Platform	Development of cooperative perception AI Application (on-board Vehicle and on Edge)	N/A
	Drone Range [TN3]	3	> 20km	24km	Drone flight plans	Drone Fleet	Deployment in larger coverage surface	N/A
	Data Rate/Client for Streaming [TN4]	4	> 15 Mbps	> 60 Mbps	UEs connected to in-flight network	Edge Platform, 5G Networks	Providing high-end in-flight entertainment (IFE)	N/A
	Latency V2V [TC1]	1	< 160 ms	72.47 ms	Laboratory measurement on connection between TBM and AI@EDGE CCP	Vehicles	Fast V2V communication supporting the V2N-N2V protocol and complex decision making and path planning	N/A
Computing [C]	Latency V2N [TC1]	1	≤ 2000 ms	2000 ms	5G network Emulators Driving Simulators Network Simulators	AV/ADAS Vehicle simulators, Network Simulators, MEC Platform	Evaluation of the C-V2X simulation environment	N/A
	Control Signal Latency [TC3]	3	≤ 50 ms	≤ 50 ms	Both ends of 5G connection	5G Network	Deploy of drone operation in 5G connection	N/A

	Video Processing Latency [TC3]	3	≤ 100 ms	≤ 100 ms	Applications that deploy video streaming content	Multi-Media streaming services, 5G/6G Networks, Edge Computing	Ultra-fast services in regard to video streaming services	N/A
	False Alarm Rate ~~à possibly on AIF group~~ [TA2]	2	Rate: < 0.1 %	0.1%	Anomaly Detection Algorithms	ML Anomaly Detection algorithms, Datasets, Data output from UC2	Reliability, Robustness	N/A
	Known-Attack Detection ~~à possibly on AIF group~~ [TA2]	2	Detection Accuracy ≥ 97 %	97 %	ML Algorithms running on edge devices	ML Anomaly Detection algorithms, Datasets, Data output from UC2	Security, Robustness	N/A
	Service Deployment Time [TR4]	4	≤ 180 s	< 15s	SPI testrack	RDUs and SCU	Providing high-end in-flight entertainment (IFE	Tests for Seatback screen predictive failure AIF
Reliability [R]	Service Recovery Time [TR4]	4	≤ 180 s	~140s	SPI testrack	Providing high-end in-flight entertainment (IFE)	Providing high-end in-flight entertainment (IFE)	Tests for Seatback screen predictive failure GUI
	Curated Content Delivery Time [TR4]	4	≤ 180 s	<2s	SPI testrack	RDUs, SCU	Providing high-end in-flight entertainment (IFE)	Tests for recommen dation engine AIF
	Content Curation Precision of Recommendation [TR4]	4	≥ 80 %	0,79 (79%)	SPI testrack	RDUs, SCU, and SuperMicro	Providing high-end in-flight entertainment (IFE)	N/A

	Number Of Served Passengers [TR4]	4	12 for demonstration	6 (passenger GUI) 3 (Crew member) 4 (predictive failure)	Plane Cabin (experimental setup)	RDUs, SCU, and SuperMicro	Providing high-end in-flight entertainment and Connectivity (IFEC)	3 More RDUs are assigned for monitoring. (overall, 16 RDUs are in use)
	Communication Reliability [TR1]	1	99.9%	99.9999%	Dynamic Driving simulator	Dynamic Driving Simulator and microscopic traffic simulator, TBM, AIF	User Experience	N/A
	Control Signal Packet Loss [TR3]	3	≤ 1 %	1 %	Direct E2E links in Edge Computing Systems, eNBs, ground stations etc	Edge Computing Systems, 5/6G stations, 5G Core Network etc	Enhance communications reliability, improve edge platforms, build robust wireless links	N/A

2.3 KPI Console evolution towards KPI Monitoring Tool

In this section we describe the KPI Console, an add-on tool for the management of the KPIs defined for the AI@EDGE platform and how this tool could be used as starting point for the further developments with addition of new functionalities for the AI@EDGE platform.

The KPI Console is an open-source web application, designed to serve as a centralized hub for all KPIs defined, shared, and disseminated for the AI@EDGE project needs. The main functionalities are the following:

- KPI List: displays the section of the KPI Matrix containing every attribute regarding the KPIs
- Measurements: displays the section of the KPI Matrix containing the values of the attributes that provide measurements for the KPIs
- About specific KPI: implements a page containing the relevant information of one KPI
- Feedback: provides a contact form, through which a user can upload comments/observations/other useful information regarding KPIs.

KPI Console could be used as a starting point for the further developments and future enhancement of the AI@EDGE platform and use cases. New functionalities, such as KPI monitoring, could be added to improve the usage aspects of the AI@EDGE platform, both for the users operating AI@EDGE platform and for the business users that use the platform for specific use case. Some relevant aspects that should be addressed, depending on specific KPI under monitoring, include:

- Establishing a system for observability and collection of data on the KPIs: this may involve deploying observability features on relevant components of the platform to track and record data on the KPIs on a regular basis.
- Setting targets and thresholds for KPIs: using historical data or industry benchmarks to establish target and threshold values for the KPIs, to measure the performance against targets and goals.
- Reviewing measured values of the KPIs: continuous and/or periodic regular review of the data on the KPIs to identify trends and patterns, and to assess achieving, or not, the related targets, thresholds, and goals.
- Acting based on the measured KPIs values: upon reviewing KPIs, it's important to take action to address any issues or opportunities identified. This may involve implementing new configurations and/or new strategies, adjusting processes, or making other changes to improve performance.

Effective KPI monitoring involves establishing a system for collecting and analysing data on the indicators, setting targets, and using the insights gained to drive improvement. Given the fact that the KPI Console provides information regarding the AI@EDGE platform KPIs, it could be considered as starting point and enhanced to perform also monitoring over the same KPIs.

The KPI monitoring solution could use dashboard software or other data visualization tools, that allow users to create visualizations of their key metrics and display them on a single screen or dashboard, allowing decision makers and other stakeholders to monitor the performance of the KPI quickly and easily. Moreover, the KPI monitoring should include automatic alerts that notify when key metrics reach a certain threshold or deviate from expected values. This allows users to be notified immediately when there is a problem, anomaly, or potential issue, allowing timely actions to address the issue, preventing escalations. This is an essential tool for businesses and organizations that want to achieve their targets and goals, while improving their performance. Thanks to continuous tracking and monitoring key metrics, users can identify potential issues early and take timely action to prevent them from becoming major problems. This allows businesses and organizations to maintain a high level of performance and ensure that they are achieving their desired results.

This possible future enhancement of the KPI Console as a KPI monitoring tool could be provided as an individual component that can be dynamically plugged-in in the overall AI@EDGE system architecture. The identified parts of the AI@EDGE platform can feed measurement data regarding specific KPIs, and then the KPI Console could subsequently calculate and display the value of KPI in near real-time and/or rise an alarm in case of threshold passing.

3. Techno-Economic Analysis and Impact

The AI@EDGE project, focusing on integrating Artificial Intelligence (AI) and Machine Learning (ML) technologies across edge and cloud computing infrastructures, has significant techno-economic implications. AI@EDGE approach aims to enhance computational efficiency, data processing, and service deployment, making it a critical development in the realm of digital technology.

At its core, the project leverages on the strengths of edge computing – reduced latency, improved bandwidth utilization, and enhanced privacy features. By moving data processing closer to the source of data generation, AI@EDGE minimizes the need for constant, high-volume data transmission to centralized cloud servers. This shift not only speeds up data processing but also reduces the burden on network infrastructures, making the system more efficient and cost-effective.

The **techno-economic analysis** of AI@EDGE involves evaluating both a) the technological advancements it brings and b) their economic implications. For instance, the use of advanced AI algorithms in edge devices can lead to better decision-making capabilities at the local level. This decentralization of AI processing power reduces reliance on cloud resources, which can translate into lower operational costs due to reduced cloud server usage and maintenance.

Furthermore, the project incorporates innovative machine learning models designed to operate efficiently in edge environments. These models are optimized for lower power consumption and require less computational resources, which is crucial for sustainable and economically viable solutions. The project also explores the potential of 5G technologies in enhancing edge computing capabilities, offering faster data transmission rates and improved connectivity.

In terms of **model inputs** for the techno-economic analysis, several factors are considered. These include the cost of deploying and maintaining edge computing hardware, the expenses associated with developing and implementing AI and ML algorithms, and the potential savings from reduced cloud computing reliance. Additionally, the analysis considers the projected increase in data generation and consumption, as the world becomes increasingly connected and digitalized.

The **business case** for the AI@EDGE project is strengthened by the potential for new market opportunities and revenue streams. Businesses can leverage the enhanced capabilities of edge AI for various applications, such as real-time analytics, predictive maintenance, and personalized customer experiences. These applications not only provide competitive advantages but also open avenues for monetization, especially in industries like telecommunications, healthcare, and manufacturing.

Moreover, the **environmental impact** of the project is an essential component of the techno-economic analysis. By reducing the need for large-scale data centres and minimizing energy consumption through efficient processing at the edge, AI@EDGE aligns with global efforts towards sustainability and reduced carbon footprints.

3.1 Techno-Economic Analysis

The scope of Techno-Economic Analysis (TEA) is to evaluate the potential economic benefits and technical advancements proposed by the initiative. AI@EDGE aims to create new opportunities for enhancing the competitiveness of the European ICT sector, driven by innovative applications such as cooperative perception for connected cars, three-dimensional aerial photogrammetry, content curation, and Industrial Internet of Things (IoT). These applications are set to bring a level of efficiency and dynamism to the telecom industry, similar to what the IT sector currently experiences. Central to this analysis is the concept of Total Cost of Ownership (TCO), which is the main focus of our TEA. This analysis carefully examines costs, benefits, risks, and uncertainties, particularly focusing on the attributes of the technologies developed within the project. It evaluates the economic performance of these solutions from a life cycle perspective, which includes initial costs, operational expenses, maintenance, and replacements.

Our TCO model, along with revenue assumptions, is utilized to assess the viability of various business cases. By analysing the costs associated with different business models, we can identify and calculate the impact of performance-cost trade-offs. In addition, we take into account indirect benefits, such as non-monetary advantages for users and the wider economy or society. While the project does not fully explore these indirect benefits, they are approximated in our dialogues with external partners.

To appraise the economic viability of specific scenarios or use cases, we develop a generic TCO model that considers both Capital Expenditures (CapEx) and Operational Expenditures (OpEx), as well as overhead costs like marketing and customer support.

The TEA includes a thorough assessment of the CapEx needed to initiate the AI@EDGE project, which encompasses the costs of hardware, software, and infrastructure development. OpEx covers ongoing expenses such as maintenance, software updates, and energy consumption. For AI@EDGE, a significant portion of CapEx is allocated to setting up edge computing infrastructure, while OpEx may be influenced by the costs associated with continuous data processing, system upgrades, and security management. Understanding these financial aspects is essential for budgeting and financial planning.

In summary, CapEx includes investments in fixed infrastructure, which are depreciated over time, and includes expenses such as purchasing land, buildings, network infrastructure, and software. OpEx represents the cost to keep the company operational, which mainly includes rented and leased infrastructure and personnel wages. This financial classification is illustrated in Figure 1 and is crucial for understanding the total economic feasibility.

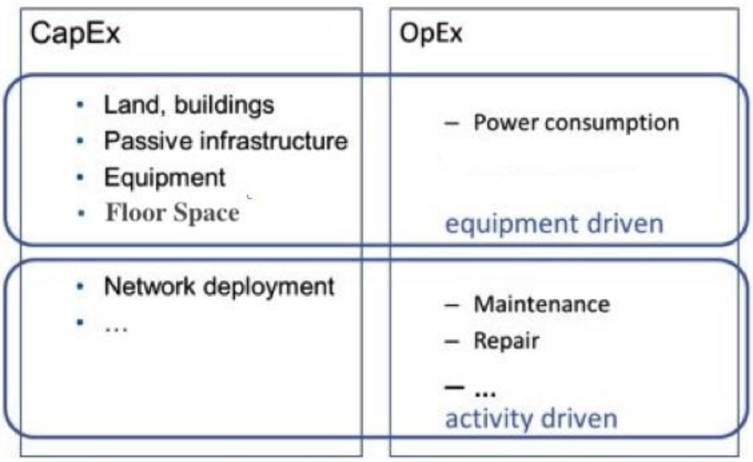


Figure 1 Cost classification

TCO analysis will be included for each use case in Chapter 5, in parallel with the development and testing of the use cases.

Economic restrictions (costs) include: the available budget, the human resources, and the expenses. Economic indicators for a techno-economic analysis are: Net Present Value (NPV), Internal Rate of Return (IRR), Return On Investment (ROI) and Dynamic Payback (DP). Moreover, it is important to identify the economic benefits and impacts of the outcomes of the project (for the whole economy).

Risks and uncertainties are related with the achieved values of the KPIs and how they close (or not) are with the target values. A risk mitigation analysis is to be carried out based on the findings and work done in the first twelve months. Finally, a timeframe and time plan are needed for the evaluation of the developed technologies.

One of the challenges would be to define a value proposition and identify where edge computing and AI are driving values for specific sectors and businesses. Different business models compared and concluded by a cost-benefit analysis for the most relevant use case should be investigated. The techno-economic analysis should identify the main reasons why edge computing and AI are playing a vital role in computing and Industrial IoT markets and analyse emerging architectures and edge platforms where industries need to agree on functions, interfaces, and technologies in order to realize digital products and services.

Environmental performance evaluation will also follow the life cycle approach, accounting for all products and flows through the whole lifetime of the system: equipment production and installation, operation including use, maintenance and replacement, and end of life.

3.1.1 *Techno-economic Analysis Methodology*

We have already introduced the parameter of Total Cost of Ownership (TCO) as the main cost element related with every techno-economic analysis. With a clear focus on business models and in the context of business analysis, we are proposing a general methodology for techno-economic analysis that consists of four main consecutive and iterative steps as shown in Figure 2. The proposed global methodology includes:

- Step 1. Business models and Value network identification: this can be achieved by firstly defining the different business roles and stakeholders involved, and secondly the interactions between them. Different ways of interactions result in different value network configurations, and accordingly in different individual business models for the stakeholders.
- Step 2. Business case viability study (TCO): A Total Cost of Ownership (TCO) model as well as revenue assumptions are used to judge the viability of the business cases. In addition, given the costs associated with different business models, performance-cost trade-offs can be identified, and their impact calculated. Finally, indirect benefits (i.e., non-monetary benefits for direct users or positive effects on the economy or society) should be included in the business case evaluation, especially for public stakeholders.
- Step 3. Impact of new technologies on business case: this step consists in investigating the impact of innovative technology on the business case. We are showing the benefits and advantages of the AI@EDGE proposed platform and relevant new technologies.
- Step 4. Sensitivity analysis: this step is elaborated to assess the degree of uncertainty (especially this period with high inflation) that links the model outputs to the inputs.

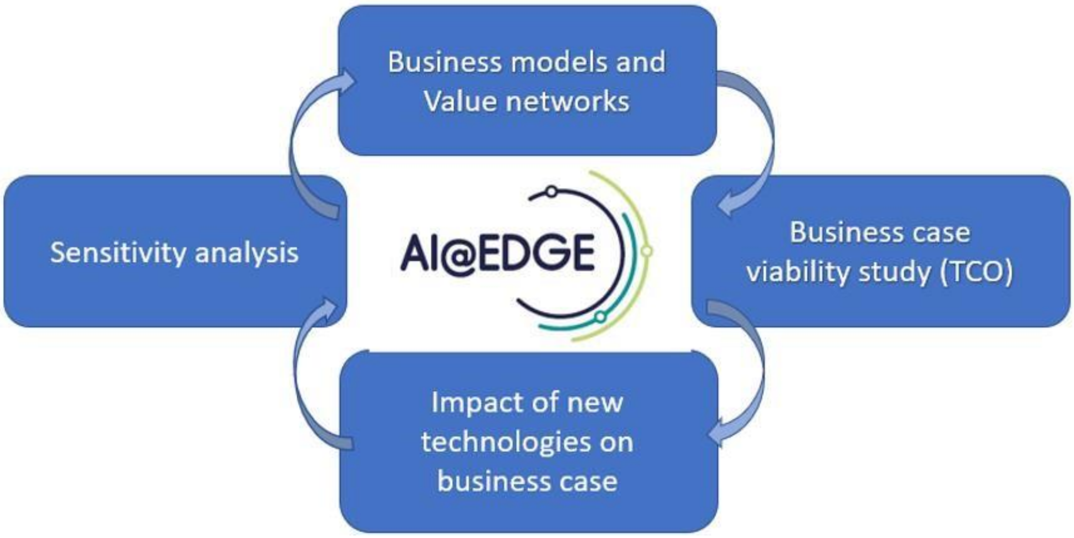


Figure 2 Global Methodology - Techno economics as part of business analysis

In the next sections we proceed with the description and analysis for each of the four steps/pillars of the proposed global methodology for techno economics analysis as part of business analysis.

3.1.1.1 Step 1 - Business models and Value network identification

3.1.1.1.1 Step 1a - Introduction to business models with a focus on 5G / Beyond 5G ecosystems

Business models have been proposed and developed for <u>both firms and ecosystems</u>. We begin with the definition of the business models for firm (and how it is related with the firm's strategic plan), then we define the 5G ecosystem and propose relevant models for the 5G ecosystem.

The b<u>usiness model definition of each firm</u> ideally is the result of a nested process evolution and development as illustrated in Figure 3. The process starts from a firm's strategic plan that explains which specific long-term goals a firm expects to achieve and how. From its strategic plan, the firm derives the business strategy, which sketches the steps needed to achieve the long-term goals. The next step in the process is the definition of a business model to identify value propositions, customer segments, and concrete steps for the execution of the business strategy and describes how a firm creates, delivers, and captures value in economic, societal and other contexts. Embedded in its business model each firm will define one or more business plans and formulate associated business cases that support the execution of the business strategy.

Figure 3 Business model as part of each firm's strategic plan

Within the scope of 5G PPP projects, the white paper (Gavras, Durkin, Fletcher, Hallingby, & Mesogiti, 2020) offers a business development pathway for firms in the 5G and beyond 5G ecosystems. This pathway, essential for firms participating in these projects, helps them establish their role within the value network of the 5G ecosystem. The approach, which is based on practical and efficient startup strategies, is divided into four distinct phases, as shown in Figure 4: Customer Validation, Solution Alignment, Business Model, and Growth Trajectory. These stages collectively form a strategic plan for each company. Notably, the business model is an integral part of this strategic framework, as highlighted in the upper layer of Figure 4. Therefore, in the area of H2020 vertical 5G use-cases, the business model is identified as one of the key pillars of business validation.

Figure 4 Business validation for H2020 vertical 5G use cases (Gavras, Durkin, Fletcher, Hallingby, & Mesogiti, 2020)

Similarly, we assume herein as well that no firm alone can deliver the full value to the customer. Therefore, before designing a business model, it is necessary to align the understanding with partner firms on how to jointly present a value proposition and deliver a solution to properly meets customer's expectations. When starting with the business model design, the single firm must have realised the dependency on other firms and ruled out the possibility of serving the customer alone.

Before we proceed with the business models for 5G ecosystem, we need first to define such an ecosystem. This white paper (6G – IA Whitepaper on 5G Ecosystem Business Modelling (discussions/calls November 2022)) provides definitions and early examples of 5G ecosystems, aiming at equipping 5G stakeholders in telecommunication and vertical industry sectors with better understanding of ecosystem dynamics, the processes that take an ecosystem from birth to maturity, and the kind of strategies that are necessary to kick off its evolution. Not the least, they wanted to emphasize that an ecosystem does not evolve and reach volume without potential tensions between stakeholders, which call for the need of balancing strategies and interests, hurdles mitigation and consensus creation. This white paper elaborated on the 5G ecosystem from two perspectives: the provisioning 5G ecosystem, and the 5G vertical ecosystem. In emerging 5G ecosystems, driving firms' strategies must focus on how to mobilize other contributors to take part in value creation. More specifically:

- 5G provisioning ecosystem encompasses those roles and actors who take part in developing, delivering, and providing AI/ML powered 5G services. Traditionally, the telecom industry is seen as a value chain where network operators source the resources necessary to provide fixed and mobile telecommunication services.
- 5G vertical ecosystem black boxes the 5G provisioning ecosystem and focuses on other actors who work closely together as part of vertical industries. While roles and actors from the telecommunication sector are still present in this ecosystem, the emphasis is on yet other roles which apply 5G services in their value creation and can be domain specific.

Since **AI@EDGE is mainly targeting (but not limited to) vertical industries**, we are focusing on 5G vertical ecosystem and the relevant roles. The roles of AI/ML in a 5G vertical ecosystem are part of disaggregation of the 5G Service Customer role in the 5G provisioning ecosystem (6G – IA Whitepaper on 5G Ecosystem Business Modelling (discussions/calls November 2022)). A first separation is between the role of the 5G Vertical enterprise customer that purchases 5G services, and the role which support the vertical enterprise customer to create and operate a solution in the vertical domain. While 5G Service Customer is a customer that only pays for the 5G services (ad hoc solution), the 5G Vertical enterprise is an enterprise that has adopted a 5G Solution, specialized for the needs of the (vertical) enterprise (permanent solution).

The 5G service provided by a 5G Service Provider is one component in such a solution. Thus, seen from the 5G Service Provider side, the supporting role complements a 5G service and the role may be referred to as a complementor. Furthermore, this complementing role consists of many more specific roles, and we therefore refer to the main role in plural – 5G Vertical complementors. It should be noted that the complementors are not only seen as providers of components in AI/ML and 5G empowered solutions; in an ecosystem context complementors are seen as critical holders and developers of knowledge which in turn is the basis for innovation in the vertical domain.

The first two proposed common business models are Security-as-a-Service and AI-as-a-Service.

- **Security-as-a-Service as a potential, common business model**

  The main goal of AI@EDGE is to build a platform and a set of accompanying tools for enabling secure and automated management, orchestration, and operation of AI-powered services over edge and cloud compute infrastructures, with close to zero-touch of the underlying heterogeneous MEC resources (network, storage, and compute resources).

  It is obvious that the overall security of the connect-compute (platform), based on elements with different security levels, should be evaluated at different stages of development. Based on different categories of the CCP (from low to high), different services based on different security levels might target to different potential customers. Such a business model, common to all use cases might be named as a Security-as-a service business model.

- **AI-as-a-Service as a potential, common business model**

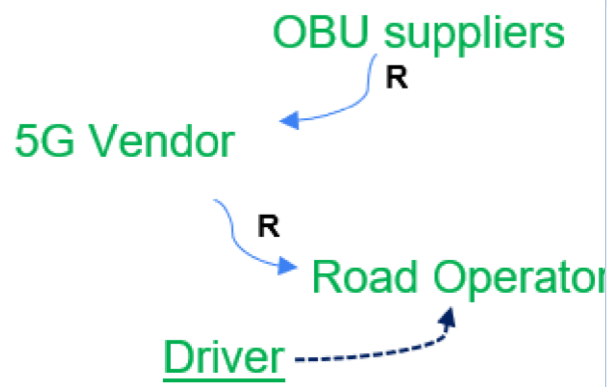
Additionally, to Security-as-a-Service business model, the AI@EDGE platform will be able to offer AI as serviced for business solutions targeting different type of customers depending on the AIFs which are offered to all use cases. In this case, the business model is called AI-as-a-Service.

3.1.1.1.2 Step 1b - Value network analysis and first models for Use Cases (Vertical Ecosystem)

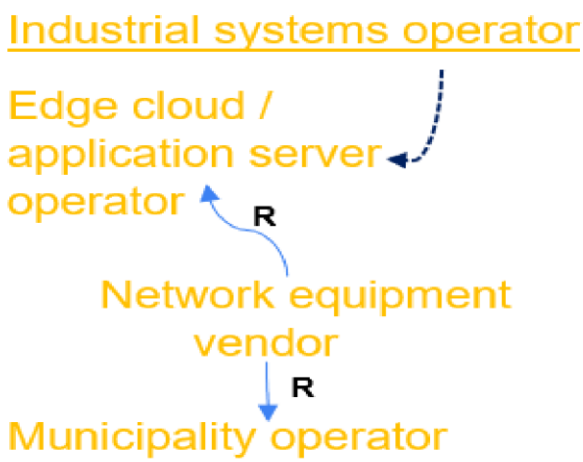
Value network analysis (VNA) is a methodology for understanding, visualizing, using, optimizing internal and external value networks and complex economic ecosystems (Allee, Value Network Analysis and value conversion of tangible and intangible assets, 2008). "*The methods include visualizing sets of relationships from a dynamic whole systems perspective. Robust network analysis approaches are used for understanding value conversion of financial and non-financial assets, such as intellectual capital, into other forms of value. The value conversion question is critical in both social exchange theory that considers the cost/benefit returns of informal exchanges and more classical views of exchange value where there is concern with conversion of value into financial value or price*". The proposed **e3value methodology** is a stepwise approach to develop business models for networked value constellations. These constellations are networks of enterprises who offer something of economic value to end users. Networks consist of end users (the customers), suppliers, and the suppliers of these suppliers. The e3value approach supposes an ideal network, in which all actors behave honestly and the e3fraud method can be used to analyse sub-ideal behaviour, e.g., actors committing a fraud. More specifically:

- Tangible and intangible value streams between all partners: The key point of Verna Allee's Value Network Analysis (VNA) is the shift from a linear value chain with only a few partners to a more complex value network (https://www.thevalueengineers.nl/tutorials/model-analyze-value-model/, n.d.). (Allee, Reconfiguring the value network, 2000) In these value networks intangible value streams are equally important as tangible value streams in order to create value. Tangible value streams are contractual like goods, services and money. Intangible value streams, however, are knowledge or intangible benefits which support a product and are not contractual. VNA visualizes both types of value streams between all involved partners. This is in contrast with the e3 value model, which mostly neglects intangible value streams (https://www.thevalueengineers.nl/tutorials/model-analyze-value-model/, n.d.)
- Activities or roles without value streams: Each actor can perform roles or activities in order to create value and the mapping of roles on their actors is referred to as a value network configuration. A value network configuration is not unique since different actors could take up different roles. We argue that the value streams in a value network configuration should be visualized between actors, as applied in VNA (Allee, Value Network Analysis and value conversion of tangible and intangible assets, 2008). In contrast to the e3 value model, value streams between internal activities are not depicted since they do not represent a transfer of ownership (https://www.thevalueengineers.nl/tutorials/model-analyze-value-model/, n.d.).
- Economic viability through scenarios: All the compared frameworks recognize the usefulness of scenarios to capture possible future changes of the value network. These scenarios represent different versions of a value network based on giving a value to one or more parameters. The e3 value model, however, solely uses these parameters to determine the economic viability of the network in quantitative numbers. This economic viability is determined by the actors' profitability, which is calculated by identifying their costs and revenues in the value network (Allee, Reconfiguring the value network, 2000).
- Two types of change: An examination of the e3 value model shows that there are two types of change in a value network: a change in the structure of the value network, such as actors (dis)appearing, and a change of its economic viability (Allee, Reconfiguring the value network, 2000).

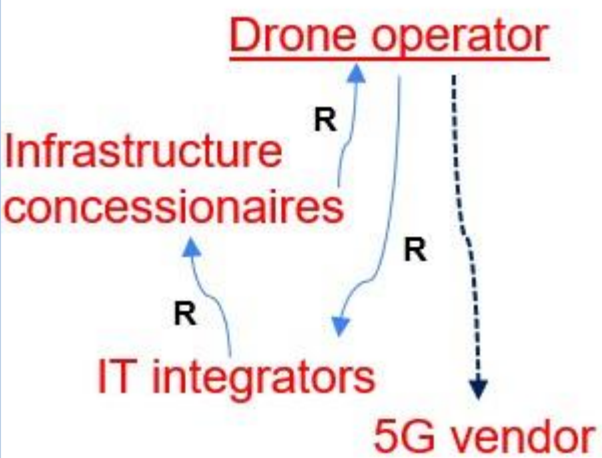
Following the methodology described above, we are proposing, in Figure 5, the value network models for each AI@EDGE use case. Solid line **R** denotes the relation between partners and dotted line shows the revenue stream from the customer to the supplier of the services. Underlined players correspond to customers, i.e., source of revenue.



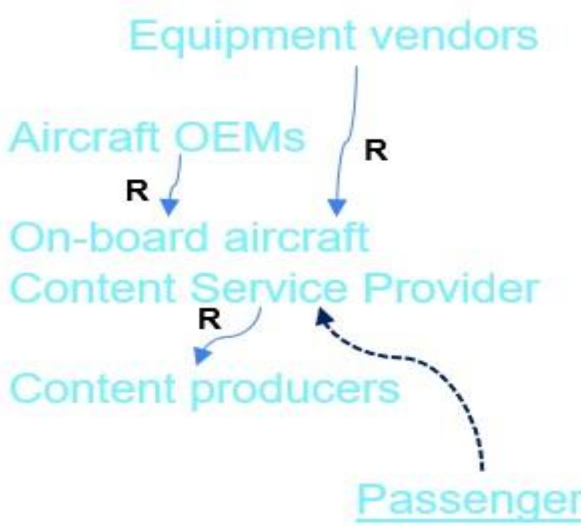
Value network model for Use case 1: Virtual validation of vehicle cooperative perception



Value network model for Use case 2: Secure and resilient orchestration of IoT NWs



Value network model for Use case 3: Edge AI assisted monitoring of linear infrastructures using drones in BVLOS operation



Value network model for Use case 4: Smart content & data curation for in-flight entertainment services

Figure 5 Value network models for AI@EDGE use cases

3.1.1.2 Step 2 - Business Case Viability study

3.1.1.2.1 Relevant technoeconomic analyses

In this subsection, we summarize surveys and reports that have as goal related investments, targeting at the technoeconomic aspects of those reports. The common denominator of all the selected reports is the fact that they aim at finding the most cost- and energy-efficient solution which covers all the requirements of the scenarios that they target at.

Techno-Economic Analysis for Programmable Networks (Bouras & Kollia) paper compares a programmable with a traditional technoeconomic model. The programmable network has mainly virtual parts and its architecture is based on SDN (Software-Defined Networking) and NFV (Network Function Virtualization). The traditional model refers to the existing networks which are currently used for mobile communication, and they are based on hardware resources without having any virtualization parts. The comparison between these models is occurred in a technoeconomic way and it has to do with base station (BS) cost, power consumption cost, OPEX, CAPEX and TCO cost. More specifically, the BS costs affects both models, but it is noticed that traditional model has higher BS cost, and especially when the amount of BS is increased. This observation is not the same for the SDN networks while the cost of cells is lower and as result the BS cost is not affected much. Power consumption is so important for environmental reasons as for economical ones. In particular, the traditional network needs four times the cost of the SDN network which means that the second one is more cost efficient. The OPEX costs do not affect the overall pricing model that much, making the SDN option a viable solution for operators and providers. The CAPEX cost is high, which is affected by oVS, OFController and other parameters, and it is the main concern of adopters. The analysis shows that the benefits of this technology, the financial profits and the low OPEX cost will contribute to the adoption and integration.

Small cells for Micro-Operators-Deployment Framework (Smail & Weijia, 2017) paper is about an indoor deployment framework of a uO (micro-operator) in a campus which is incorporating network slicing, network sharing and small cells. Femtocells are low-cost, low-power and plug-and-play devices and they can be deployed with Wi-Fi. They can also replace Wi-Fi access points and use the existing network cabling, local servers, switches, and existing internet backbone. The goal of this paper is to examine different scenarios for a campus network (in-building wireless access), having as criterial not only technical such as performance, coverage and spectrum utilization but economical ones, including the Total Cost of Ownership (TCO), capital expenses (CAPEX) – site acquisition, equipment, planning, commissioning and deployment costs- and operational expenses (OPEX) – annual site lease, power usage, operational costs. The result of this techno economic analysis is the cost of femtocells and Wi-Fi access points are almost comparable. Even though femtocells have higher OPEX (the CAPEX is close to Wi-Fi cost) they present advantages in latency, reliability, performance, and they totally cover the needs of the initial scenario. On the other hand, for the same amount of capacity, it requires less femtocells than Wi-Fi access points which leads to lower TCO. According to the above results, it is proven that small cell network deployment can be cheaper and more beneficial than an exclusive Wi-Fi deployment, even though small cells are more expensive than WiFi access points on a unit basis.

Techno-economic Analysis and Prediction for the Deployment of 5G Mobile Network (Smail & Weijia, 2017) This techno economic analysis for the deployment of 5G technology over the existing 4G mobile network, took place in Shanghai/China with duration of 6 years. The main goal of this analysis is the benefits and the cost effectiveness of adoption 5G technology. In order to be performed this model, several parameters have to be defined, such as the predicted number of users, the churn rate that focuses on its impact on revenue of 5G network, the pricing strategy analysis and the evolution of CAPEX and OPEX for a variety of Base Stations classes and different indoor scenarios. Apart from the price and cost, the coverage and the capacity are under consideration. The outcomes show that a good analysis of Price Elasticity of Volume (PED), which is a measure of sensitivity of realized volume to changes in unit price, provides an important margin of benefit. Also, for the current mobile broadband demand of the different scenarios, microcells are the most cost-efficient solution. The network investment model reveals that the deployment of a large amount of new sites is expensive, but this cost can be decreased by the reuse of existing sites or using the carrier aggregation functionality of LTE-A RAT. Finally, it is ascertained a lack of the capacity limited by the macro sites and in general a limited coverage with small cell solutions such as femtocells, picocells deployed with 5G mmW system and Wi-Fi. To overcome the lack of these, operators should investigate the cooperative layouts of macro sites with femtocells, 5G mmW PBS or Wi-Fi and achieve the trade-offs among capacity, cost, and coverage.

Techno-economic Analysis of 5G Immersive Media Services in Cloud Enabled Small Cell Networks: The Neutral Host Business Model (Paglierani, et al., 2020) Edge computing and 5G can be a beneficial and interesting combination for vertical industries to develop unconventional services. The study in (Paglierani, et al., 2020)aims to examine a cloud-enabled Small Cell network, that belongs to a NH, which is going to support Immersive Media Services in Crowded Events. A potential investment in a 5G infrastructure must be reviewed and a planning model to be created to predict the required compute, storage, and radio resources. Also, some economic indices must be taken into consideration such as net present value, internal rate of return and in general the Price evolution. This techno-economic analysis concentrates on the IT and radio infrastructure, that are deployed by NH, for sport stadiums or concert halls where there are a lot of attendees. Particularly, this study, is based on out-turns from three funded research projects which are the SESAME project for the planning model and the IST-TONIC and CELTIC-ECOSYS for the economic part. A Cloud Enabled Small Cell network which can provide Immersive Video Services can be a profitable and viable solution for the above scenario. More specifically, it needs servers, small cells and GPU that mostly contribute to CAPEX by 45%, 25% and 14% respectively. 58% of OPEX is covered by installation and employee costs. This investment can reach a break point at 6.5 years, and it can be considered fruitful having in the mind that the effective functional period of telecom infrastructures is 15 to 20 years.

3.1.1.3 State of Model inputs and mathematical formulas of TCO for all AI@EDGE use cases

Following the introduction of the cost model and TCO the cost model is based on several assumptions that should be made to have as realistic results as possible:

- We assume a lifetime of 10 years
- Project horizon is 10 years (hence no hardware renewal is anticipated)
- Hardware installation cost is 15% of the hardware costs
- Maintenance cost for infrastructure is assumed to be 10 % of the original hardware and labour costs (CAPEX)
- The overhead cost is around 22% on top of the sum of the CAPEX and OPEX costs
- Yearly costs are also corrected for inflation (time value of money) with 5% as growth rate
- The TCO is the total cost of ownership for the project lifetime (hence, costs are not discounted)

The Total Cost of Ownership (TCO) of the proposed solution is counted as the sum of the CAPEX, the OPEX of T years and the overhead costs of T years (T is the project horizon).

$$TCO = CAPEX + \sum_{t=1}^{T}(OPEX(t) + Ovhd_c(t))$$

Maintenance costs are counted in the OPEX costs.

$$M = 10\% \times CAPEX$$

Specific calculations (plots) will be presented for each use case in D6.3 in parallel with the development and testing of the use cases. We expect that in some use cases the CAPEX costs will be dominant, on the other hand in some others the operational and maintenance costs will be higher.

3.1.1.4 Step 3 - Impact of new technologies on business case

The main goal of AI@EDGE is to build a platform and a set of accompanying tools for enabling secure and automated management, orchestration, and operation of AI-powered services over edge and cloud compute infrastructures, with close to zero-touch of the underlying heterogeneous MEC resources (network, storage, and compute resources). One of the key aspects to achieve this vision, is to develop a set of solutions broadly divided into two distinct areas: (i) solutions for the creation, utilization, and adaptation of secure and privacy-aware AI/ML models; and (ii) solutions managing distributed resources inside the operators' infrastructure.

The following are the main AI@EDGE platform objectives: i) design and validate a connect-compute platform enabling the creation of network slicing, ii) extend ETSI MEC/NFV architectures with applications and models capable of providing the AI@EDGE platform with the context and metadata necessary to take automatically actionable decisions and to realize intelligent data and computation offload control and management of applications and services deployed over the decentralized and distributed AI@EDGE platform, iii) investigate different hardware acceleration solutions (FPGA, GPU, CPU) spanning from the terminals to the cloud for highly decentralized and distributed workload management, iv) analyse and compare dual-connectivity monolithic RANs with cross-layer multi-connectivity disaggregated RANs to see if dynamically adapts the network topology to the network conditions. The new technologies being developed in AI@EDGE project (a connect-compute platform providing solutions based on privacy-aware AI/ML models and managing distributed resources inside the operator's infrastructure) are expected:

(1) to accelerate the business model as part of the strategic plan of each firm and (2) to provide revenues to the supplier of the services in the coming 5 to 10 years.

3.1.1.5 Step 4 - Sensitivity analysis

A comprehensive Sensitivity Analysis is vital for the AI@EDGE project, especially within the techno-economic methodology that considers both the technical and economic aspects of the project. This assessment must be aligned with the previously discussed cost and benefit analyses to provide a holistic view of potential challenges and uncertainties the project might face. The Table below outlines the challenges and mitigation strategies across different risk categories.

Table 2 Sensitivity analysis

Risk Category	Challenge	Mitigation Strategies
Technological Risks		
Rapid Technological Obsolescence	AI and edge computing technologies evolve rapidly, leading to possible quick obsolescence.	Implement a continuous development model with regular updates. Establish partnerships with academic and research institutions.
Performance and Reliability Issues	Edge AI systems may face unexpected performance and reliability issues.	Conduct extensive testing and quality assurance. Develop a robust feedback mechanism from pilot users.
Data Security and Privacy Concerns	Handling sensitive data in edge environments raises data security and privacy concerns.	Implement advanced security protocols and regular audits. Educate users and stakeholders about data privacy.

Economic and Financial Risks		
Budget Overruns	Complexity of the project could lead to exceeding budget, especially in R&D and infrastructure setup.	Adopt rigorous budget management. Consider phased implementation.
Uncertain ROI	ROI may be uncertain or delayed, especially if market adoption is slow.	Develop a flexible business model. Diversify revenue streams.
Funding and Resource Allocation Risks	Securing consistent funding and optimizing resource allocation can be challenging.	Explore various funding sources. Implement efficient resource management systems.
Market and Adoption Risks		
Market Competition	Highly competitive market with the risk of competitors developing similar or superior technologies.	Build unique value propositions. Maintain technological leadership. Monitor market trends.
Adoption and Integration Challenges	Resistance or challenges in adopting new technologies, especially in slower industries.	Engage with potential users early. Provide comprehensive training and support.
Regulatory and Compliance Risks	Rapidly evolving regulations around AI and data privacy pose compliance risks.	Establish a dedicated regulatory compliance team. Regularly update policies.
Project-Specific Risks		
Collaboration and Partnership Risks	Dependencies on collaborations and partnerships can lead to risks like goal misalignment.	Clearly define roles and responsibilities. Establish transparent communication channels.
Scalability and Deployment Risks	Scaling from a prototype to a market-ready solution can face obstacles.	Plan for scalability from early stages. Conduct pilot tests to validate scalability.
External Risks		
Economic Fluctuations	Economic downturns can affect funding and market opportunities.	Develop a resilient financial plan. Diversify the economic base.
Technological Dependencies	Success may depend on other technologies like 5G networks, which have their own risks.	Monitor the development of dependent technologies. Develop contingency plans.

In the context of techno-economic analysis, the Risk Assessment for AI@EDGE highlights a range of potential challenges spanning technological, economic, market, and external factors. Addressing these risks requires a proactive approach, including contingency planning, continuous market and technology trend monitoring, and flexible project management strategies. Identifying and mitigating these risks is crucial for aligning the project's execution with its envisioned benefits and cost projections, ensuring its long-term success and sustainability.

3.2 Techno-Economic Impact and Link with SDGs and Exploitation Plans

AI@EDGE project involves understanding how the project's technological and economic aspects influence its exploitation strategy. This analysis essentially bridges the gap between the project's technical development and its market application, focusing on how the project can be leveraged for commercial or societal benefit.

The AI@EDGE project involves a comprehensive techno-economic analysis that aims to bridge the gap between its technological developments and market application. This analysis focuses on leveraging the project for commercial and societal benefits. Additionally, the concept of Sustainable Development Goals (SDGs) is integrated into this analysis, which will be elaborated in the subsequent section on socio-economic analysis.

3.2.1.1 Techno-Economic Impact

- **Technology Assessment**: This step evaluates the technical advancements achieved by AI@EDGE, such as enhancements in AI algorithms for edge computing, and their practical implications. The focus here is on how these advancements contribute to increased efficiency, improved performance, and new capabilities.
- **Economic Analysis**: This involves examining the project from a cost-benefit perspective. It includes analysing financial feasibility, cost structures (CAPEX and OPEX), potential revenue streams, and overall return on investment. The goal is to quantify economic benefits, like cost savings for users or revenue generation from new products or services.
- **Market Readiness**: This step assesses the readiness of the developed technology for market entry. It involves evaluating the technology's maturity, compliance with industry standards, and alignment with current market needs and trends.

3.2.1.2 Link with the Sustainable Development Goals (SDGs)

In evaluating the impact of the techno-economic analysis, it is crucial to consider the alignment with Sustainable Development Goals (SDGs). The project’s contribution to SDGs will be detailed in the socio-economic analysis section.

Apart from the socio-economic analysis, the techno-economic analysis of AI@EDGE also incorporates an assessment of how the project aligns with and impacts various SDGs. This involves establishing specific criteria to measure the project's contribution to achieving these global goals, considering both technological advancements and economic factors.

To quantify the impact of AI@EDGE on SDGs in the context of techno-economic analysis, we introduce an index, formulated as:

$$\text{SDG Impact Index} = \frac{\text{Number of Correlated SDGs}}{\text{Total Number of SDGs}}$$

SDG Impact Index=Number of Correlated SDGsTotal Number of SDGsSDG Impact Index=Total Nu mber of SDGsNumber of Correlated SDGs

This equation will provide a clear metric to evaluate the extent to which the AI@EDGE project aligns with the SDGs, factoring in both technological innovation and economic viability. By integrating this index, the techno-economic analysis not only reflects the project's commercial potential but also its commitment to contributing to sustainable development.

3.2.1.3 Link with Exploitation Plans (D2.5)

Commercialization Strategy: This is about planning how to bring the AI@EDGE technologies to the market. It involves identifying potential customers or industries that could benefit from these technologies, developing pricing strategies, and establishing sales and distribution channels.

Partnerships and Collaborations: Exploitation plans may involve forming partnerships with other companies, research institutions, or industry groups. Such collaborations can be crucial for technology validation, gaining market access, and enhancing product development.

Intellectual Property Management: This includes strategies for protecting the intellectual property (IP) developed during the project, such as patents or trademarks. Effective IP management is key to creating value and is a critical aspect of the exploitation plan.

Socio-Economic Benefits: Beyond commercialization, exploitation plans should consider the broader societal impact. This includes assessing how the project can contribute to societal goals like digital inclusion, sustainability, or improved public services.

Risk Management: Identifying potential risks that could impact the exploitation plans, such as technological obsolescence, market competition, and regulatory changes. Developing mitigation strategies for these risks is an essential part of the planning process.

This analysis helps to ensure that the project not only achieves technological success but also translates this success into marketable products or services that offer real economic value. It requires a careful balance of technology assessment, economic viability, market strategy, and risk management, all while considering the broader societal impact of the project.

3.3 Business Model Evolution

AI@EDGE project involves examining how the integration of AI/ML technologies and the adoption of new technologies like network slicing and hardware acceleration will reshape the project's business approach. This analysis is crucial for understanding how technological advancements will influence the project's economic viability and market strategy.

AI/ML Integration

- **Business Approach:**
  - The integration of AI and ML models is expected to significantly enhance the efficiency of operations and processes within the AI@EDGE project. This improvement could lead to reduced operational costs and faster time-to-market for new applications and services.
  - AI/ML technologies can enable more sophisticated data analysis, predictive maintenance, and automation capabilities. These enhancements can lead to improved customer experiences and potentially higher customer satisfaction.
- **New Revenue Streams:**
  - The introduction of AI and ML models opens up opportunities for new revenue streams. This could include offering AI-as-a-Service, where AI capabilities are provided to clients on a subscription basis.
  - Another potential revenue stream could come from the sale of insights derived from AI-driven data analytics to interested parties in related industries.
- **Implications for the Business Model:**

  - A shift towards a more service-oriented or data-driven business model could be beneficial. This might involve transitioning from a product-centric model to one that emphasizes ongoing customer engagement and service provision.
  - The project must consider how to monetize these AI/ML capabilities effectively, which may involve rethinking pricing strategies, sales models, and customer relationship management.
  - Technology Adaptation
- **Impact of Network Slicing and Hardware Acceleration:**
  - The adoption of technologies like network slicing can significantly improve network efficiency and performance. It allows for the creation of multiple virtual networks on a single physical network infrastructure, which can be tailored to specific needs of different applications.
  - Hardware acceleration, such as the use of specialized processors for specific tasks, can enhance performance and efficiency, particularly for compute-intensive AI/ML tasks.
- **Influence on Business Case:**
  - These technological advancements can make the AI@EDGE project more competitive by enhancing its capability to handle a wider range of applications more efficiently.
  - The project's business case needs to account for the costs associated with implementing these technologies versus the potential benefits they bring. This includes not just direct financial benefits but also improvements in customer satisfaction, market positioning, and long-term scalability.
- **Strategic Considerations for Adoption:**
  - The project should strategically evaluate which technologies to adopt and how to integrate them into the existing framework to maximize benefit.
  - Consideration should be given to the skillsets required to implement and manage these technologies and whether additional training or hiring is needed.

In summary the integration of AI/ML technologies and the adoption of advanced technological solutions like network slicing and hardware acceleration are poised to significantly influence the project's business approach. These technological integrations are expected to enhance operational efficiency, create new revenue streams, and require adaptations to the existing business model. The project's success in leveraging these technologies will depend on careful economic analysis, strategic implementation, and an understanding of how these changes align with overall market and business objectives.

4. Socioeconomic Impact

The Socioeconomic Impact of the AI@EDGE project presents a vital perspective on how cutting-edge technologies like AI and 5G can positively influence society and the economy. This introduction sets the scene for a detailed examination of the project’s broader impacts, moving beyond the technical details to explore its real-world significance.

In this analysis, we aim to uncover how the AI@EDGE project aligns with global goals for sustainable development and contributes to important societal and economic objectives. The focus here is on understanding how the integration of AI and 5G technologies within the project can lead to significant advancements in various sectors, benefiting both individuals and communities at large. We will explore the various ways in which AI@EDGE impacts society and the economy, considering aspects like improved connectivity, economic growth, and environmental sustainability. This approach provides a comprehensive understanding of the project's value, highlighting its role in driving technological progress that benefits everyone.

In the following sections, we will detail the methodology used to assess these impacts, offering insights into the tangible benefits and challenges of implementing AI and 5G technologies on a large scale. This analysis aims to provide clarity on the project's potential and guide stakeholders in making informed decisions about future technological initiatives.

4.1 Methodology

The methodology for assessing the Socioeconomic Impact of the AI@EDGE project involves a structured approach, focusing on its influence on society, economy, and the environment. Key to this methodology is the project's alignment with Sustainable Development Goals (SDGs), akin to the approach in the techno-economic analysis but with a broader societal focus.

Methodology Breakdown

1. Project Impact Measurement

- AI Impact on SDGs:
    - Data Collection: Gathering data on AI@EDGE's impact, such as efficiency, automation, and decision-making enhancements.
    - Alignment with SDGs: Mapping these impacts to relevant SDGs like Quality Education, Industry, Innovation and Infrastructure, and Sustainable Cities.
    - Analysis: Using both quantitative and qualitative methods to assess AI's contribution to these SDGs.
- 5G Impact on SDGs:
    - Role of 5G: Analysing how 5G integration influences SDGs through improved connectivity and reliability.
    - Outcomes: Identifying benefits like better access to information, communication in remote areas, and advanced healthcare services.

2. Scientific Evidence Components
    - Case Studies and Pilots: Conducting empirical studies in diverse settings.
    - User Feedback: Gathering real-world impact insights from users.
    - Academic Collaborations: Partnering with institutions for comprehensive studies and publication.
3. AI + 5G Overall Impact
    - Connectivity and Accessibility: Examining how AI and 5G enhance digital access and societal inclusivity.
    - Public Sector Impact: Assessing improvements in services like healthcare and transportation.
    - Market and Jobs: Estimating the influence on market growth, business opportunities, and job creation.
    - Cost-Benefit Analysis: Quantifying the economic returns from AI and 5G investments.
4. Environmental Impact

- Resource Efficiency: Evaluating how AI and 5G contribute to SDG 12 (Responsible Consumption and Production).
- Carbon Footprint: Assessing the project's overall impact on emissions.

SDG Impact Index Application

Similar to the techno-economic analysis, the socio-economic evaluation also employs the SDG Impact Index, defined as the ratio of the number of correlated SDGs to the total number of SDGs. This index quantifies AI@EDGE's contribution to SDGs from a socio-economic standpoint, differentiating it from the purely techno-economic perspective. This dual-index approach ensures a holistic assessment of the project's alignment with sustainable development goals, highlighting its societal, economic, and environmental.

4.2 United Nations Sustainable Development Goals

The United Nations Sustainable Development Goals are the basis that AI@EDGE considered for analysing the socioeconomic impact of the project.

Figure 6 SDGs (source: https://sustainabledevelopment.un.org/topics/sustainabledevelopmentgoals)

The United Nations Sustainable Development Goals (SDGs) are a comprehensive collection of 17 interrelated global goals created by the United Nations to address the most important issues facing the planet today. These objectives, accepted by all UN member states in 2015, and including a wide range of issues facing humanity (ending poverty and hunger, advancing gender equality, clean water and sanitation, affordable and clean energy, reduced inequalities, sustainable cities and communities, life below water, life on land, and strong institutions), has subsequently been expanded to include issues like economic inequality, innovation, sustainable consumption, peace, and justice, as well as climate change.

The Sustainable Development Goals (SDGs) offer a framework for worldwide action that promotes cooperation, creativity, and inclusive strategies to guarantee a more prosperous, just, and sustainable future for everybody that governments, corporations, civil society organizations, and individuals everywhere must work together to achieve.

4.3 Correlations between SDGs and the AI@EDGE project

The consortium of AI@EDGE was formed around the vision that edge computing could be an important enabler of a greater world. Edge computing is in its nature a distributed technology and will, or at least can, reside in every base station and this reach every user and application that has mobile coverage. Becoming connected to the Internet and digital services is a must today to take part in the value creation of the modern digitized economy. For instance, if we are to eradicate poverty, everybody must become connected. We believe that it will become equally important to get access to edge computing in the future as it is to become connected today. We also see that the same argument applies equally strongly for access to AI-based services. The introduction of AI into the digitized economy will create enormous value in virtually every field of economic activity and we must strive to make this universally available. The AI@EDGE project is set out to make both edge computing and AI-based services ubiquitous, affordable, practical, resilient and secure. The unrest that has stricken the world since the project was formed has increased the importance of the latter two. The impact ambitions of AI@EDGE can be illustrated using the seventeen Sustainable Development Goals (SDGs) as presented above.

We view the impact of AI@EDGE on the SDGs as presented in the table below.

Table 3 SDGs & AI@EDGE project

SDG number	SDG name	AI@EDGE's Contribution
SDG 1	No Poverty	To rise out of poverty today it is essential to have Internet access to be able to become part of the digitized economy. In the same way, we believe it will become crucial to get access to edge computing and AI-based services once their value creation permeates the economy. AI@EDGE strives to make both edge computing and AI-services affordable, practical, flexible and scalable.
SDG 2	Zero hunger	AI-based services will have an increasing importance for food production. AI@EDGE is striving to make AI-based services available everywhere, not the least in rural areas, and will assist large-scale farming in their increasingly difficult task to overcome climate change. As low-cost AI-based services develop, we will also be able to make a difference for small-scale farming, helping newly digitized farmers to attain increasing yields in a sustainable way.
SDG 3	Good health	An important application for AI@EDGE has always been the demographic challenge. The only thing that scales with the increasing number of elderly is precisely the increasing number of elderly. This suggests that selfcare is the only scalable solution to the demographic challenge. This should be data-driven, technology-supported self-care. Data-driven means personalized, adapted to everyone; and technology-supported means that there are connected sensors providing the measurement data each individual needs to stay healthy, often determined by the set of chronic diseases one is afflicted by. This data should stay close to the end user for integrity reasons, and there are also sometimes legal frameworks that mandates that such data stays within national borders. If so, edge computing is a practical solution since AI-services are suitable for the data-driven personalized selfcare where inference is done locally, but learning can be global, simultaneously meeting both efficiency and integrity. Although the demographic challenge is a very important application for AI@EDGE, we chose to avoid it as a use case for the project. It is more complicated (especially legally) than our use-cases and not better suited to demonstrate the technology.

SDG 7	Affordable and clean energy	The AI@EDGE project has two main impact strategies to help bring the energy sector forward. As already mentioned in the project proposal, we can send calculations that are not latency sensitive from areas where the electricity is either expensive or not green to an edge computing site where the electricity is both cheap and green. Electricity prices (disregarding transport fees) are increasingly negative when production from solar and wind power exceeds local demand. A solution for large installations is local production of hydrogen gas, a necessity for a sustainable European industry, but there are no viable small-scale solutions. Instead of moving the electricity around, we move the consumption of electricity. In addition, if requirements to be fossil-free would be put on cloud computing, this could become a crucial competitive advantage for European edge computing over US-based cloud computing, enhancing Europe's strategic autonomy in the digital field. In fact, we see base stations with edge computing as components in the European energy system. Many base stations will be equipped with local power generation, in particular solar panels, and battery packs, and can be used to stabilize the grid and profit from variations in the electricity price. This could become an important side business for telecom operators and help pay for the investments in edge infrastructure. The second line of impact is providing distributed intelligence for the energy system and electricity grid. The electricity grid is evolving from a set of simple star-shaped networks to a complex and distributed grid where electricity is generated in numerous places and with a complicated and intelligent behaviour. This provides both more sustainability and increased resilience, if managed properly. The troubling scenario is if failure of a few components can bring down large parts of the network. If the intelligence of the network is distributed throughout a compute-connect continuum, like the AI@EDGE edge computing network, this would be avoided. The AI@EDGE technology is specifically designed so that no matter how a national computing network is being hit, every piece that remains and have power will provide edge computing and AI-services as best it can. No attack or failure can bring it all down if any pieces remain.
SDG 8	Economic growth	Edge computing as a technology will bring with it considerable economic growth and enable new applications and services. Cloud-based AI-services are already having a tremendous impact on economic growth and will likely be seen as an industrial revolution. Once local AI becomes practical, partly through edge computing, the value created by AI will reach new levels. The distribution and de-centralization of AI-services will also be critical to increased resilience and important for European geopolitical safety.
SDG 9	Industry, innovation and infrastructure	AI@EDGE aims at enabling new services and value creation in European industry and society. Let us take our Use Case 1 as an example. With cloud-based AI-services we can achieve collision avoidance in roundabouts. If we would send all the camera streams and other data, the total bandwidth from all roundabouts would completely swamp the Internet's transport network, not the least the Atlantic cables. If we use edge computing for the AI-functionality, we do not only get collision-avoidance but also traffic capacity

		optimization, increased comfort, and could half the fuel consumption (as shown in UC1). The video streams are jointly analysed locally, and optimized action can be taken locally. The same basic reasoning applies to many other applications too. Locally computed AI-services can access and use much richer datasets than cloud-based AI, simply because it is impossible to transport such large amounts of raw data. Local AI will thus outperform cloud-AI in many applications and often do things that otherwise would be impossible.
SDG 11	Sustainable cities and communities	The same reasoning that applies to SDG9 also applies here. The cheapest way for our cities to become more sustainable is that they become smarter. By analysing vast amounts of local data, we can run our cities in a more efficient way and simultaneously achieve a higher quality of life. We can achieve a broader social acceptance for a sustainable transformation as we can combine selfish value gains with broad sustainability.
SDG 13	Climate action	We can and will contribute to SDG13 and all other SDGs not mentioned above by providing more local intelligence. Our processes, be it driven by societal goals or financial gain, can become smarter and more sustainable by becoming smarter and better optimized using more data. AI, and in particular local AI, can make a big difference in this direction.

4.4 Key Value Indicators

The AI@EDGE project emerges at the intersection of technological innovation and global sustainability, where the transformative power of AI and edge computing is harnessed to propel progress across multiple sectors. In this context, central to evaluating this progress are Key Value Indicators (KVIs), which offer measurable metrics directly linking the project's ambitions to concrete outcomes. These KVIs are particularly vital in assessing alignment with the Sustainable Development Goals (SDGs).

Beyond the basic SDG correlation index introduced in the techno-economic and socio-economic analyses, there is an identified need for more sophisticated indices in the project's long-term vision. These advanced indices will provide a deeper, more nuanced understanding of the project's impact on SDGs, offering a comprehensive picture of its contributions not only in technological advancements but also in promoting sustainable development globally.

The development of these advanced KVIs will involve a blend of quantitative measures and qualitative assessments, ensuring that both the direct and indirect influences of AI@EDGE on global sustainability are captured. This approach will enable a holistic evaluation of the project's success in meeting its sustainable development objectives and will be instrumental in guiding future strategies and initiatives.

Establishing KVIs

KVIs are designed to translate the broad objectives of the AI@EDGE project into specific, measurable targets. These indicators not only capture the direct impacts, such as technological advancements and economic gains but also encompass the indirect benefits that ripple through society and the environment.

Correlation with SDGs

Each KVI is mapped against relevant SDGs, forming a framework that illustrates the project's multifaceted contributions:

- SDG 1 – No Poverty: KVIs here may include metrics such as the number of individuals in low-income regions gaining access to AI@EDGE services, or the percentage reduction in costs due to more efficient edge computing solutions.
- SDG 2 – Zero Hunger: Indicators might measure the increase in agricultural yields or the efficiency of resource use in farming, enabled by AI analytics and decision-making.
- SDG 3 – Good Health: Potential KVIs include the deployment rate of AI@EDGE in healthcare services or the improvement in patient outcomes due to enhanced data-driven care.
- SDG 7 – Affordable and Clean Energy: Here, KVIs could quantify the energy savings achieved through optimized network operations or the reduction in carbon footprint due to intelligent energy management systems powered by AI@EDGE.
- SDG 8 – Economic Growth: Economic KVIs might capture the number of new jobs created through AI@EDGE-enabled industries or the contribution to GDP from new services and applications.
- SDG 9 – Industry, Innovation, and Infrastructure: Indicators here could reflect the rate of innovation within industrial sectors or the scalability of infrastructure improvements due to AI@EDGE technologies.
- SDG 11 – Sustainable Cities and Communities: Urban KVIs may encompass the extent of smart city implementations and the resultant improvements in urban efficiency and quality of life.

Measuring Impact

The KVIs for AI@EDGE are not static; they are dynamic and evolve as the project progresses and as its technologies become more deeply integrated into various ecosystems. The measurement of these indicators involves:

- Data Collection: Systematic gathering of quantitative and qualitative data that reflects the project's performance against each KVI.
- Analysis and Reporting: Regular analysis of collected data to evaluate progress, which is then reported to stakeholders to demonstrate the project's impact.
- Feedback and Adaptation: Using the insights gained from KVI analysis to refine project strategies and adapt to emerging challenges and opportunities.

Currently, the Key Value Indicators (KVIs) for the AI@EDGE project cannot be quantified as the project has just reached its conclusion. The primary purpose of establishing these KVIs at this stage is to set clear, tangible benchmarks for future evaluation. This foresighted approach allows us to develop a structured framework for assessing the project's impact once it is complete. By pre-defining these indicators, we aim to ensure a robust and measurable analysis of our project's effectiveness in terms of technological advancement, societal benefit, and environmental sustainability. The establishment of these KVIs now is a strategic step towards ensuring that, upon completion, we can accurately measure and articulate the project's contributions to the Sustainable Development Goals.

5. Extended Impact

This chapter provides a detailed look into how we measured and calculated Key Performance Indicators (KPIs) for each use case in the AI@EDGE project. Understanding these KPIs is essential, as they serve as vital indicators of our project's performance and success. We explore the components of the AI@EDGE platform and detail how they have significantly influenced these KPIs. This exploration is crucial for understanding the relationship between the platform's features and the overall impact of the project.

Additionally, achieving these KPIs has led to new advancements within each use case, reflecting on the technological progress and procedural improvements made. This discussion demonstrates how the KPIs have not only served as benchmarks but also as catalysts for innovation and growth within the project. Finally, we tie these insights back to the broader context of the AI@EDGE project. We connect our findings to the techno-economic and socio-economic impacts, as discussed in previous sections. This comprehensive approach provides a full picture of each use case, showcasing not only their technical effectiveness but also their relevance and impact in a wider economic and societal context.

5.1 Extended impact Use Case 1: Virtual validation of vehicle cooperative perception

5.1.1 Description of Use Case

Use Case 1 aims to explore the integration of AI-enabled platforms in digital infrastructures dedicated to Cooperative, Connected and Automated Mobility (CCAM). This platform will be used to implement an innovative communication protocol called Vehicle-to-Network-Network-to-Vehicle (V2NN2V). In this protocol, all vehicles are connected to the edge via a 5G connection. A Multi-access Edge Computing (MEC) server, located near the roundabout and also connected to the network, collects all the information provided by vehicles and runs the DRL policy responsible for all Automated Vehicles in the traffic scenario. This communication protocol combines Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) protocols, optimizing both and reducing the associated operation and maintenance costs for both the vehicle and the infrastructure.

A virtual simulation environment has been developed, both in terms of digital infrastructure and vehicle replication. It is employed to test the DRL policy that optimizes traffic flow within roundabouts while safely navigating CCAVs in a mixed traffic situation with humans in the loop. The reference scenario for the simulations is a four-leg, single-lane mini-roundabout, which is based on an actual roundabout located in Milan. This specific type of intersection is selected as it is known to be a bottleneck for automated driving. A Microscopic traffic simulator (MTS) is employed to analyse the network and traffic conditions. However, due to the complexity of the human being, driver models roughly approximate human behaviour. Therefore, computer experiments with SUMO had to be substantiated with a human-in-the-loop. To this end, SUMO (Simulator of Urban Mobility) is coupled with the dynamic driving simulator at the DriSMi Laboratory of Politecnico di Milano and the VI-WorldSim graphical environment. This architecture allows for very accurate replication of the real scenario, thus being able to create an effective Digital Twin. Three types of vehicles are present in the simulation:

- CCAVs driven by the DRL policy hosted in the Artificial Intelligence Framework (AIF). They communicate with the infrastructure, giving and asking for information (e.g. position and speed) about them and all other vehicles.
- Simulated human-driven vehicles, controlled by a car-following model, specifically an Intelligent Driver Model (IDM), only sending their data.
- The ego-vehicle driven by the real human driver in the dynamic driving simulator. The cockpit is equipped with a telematic box that reads data from the ego-vehicle and transmits it to a 5G radio platform connected to the infrastructure, with the actual communication delay.

Two specific market penetration rates for CCAVs are considered. Specifically, 20% and 80%.

5.1.2 *Specific KPIs for Use Case*

KPIs for this Use Case consider both macroscopic and microscopic traffic characteristics. Specifically, they assess the scenario, considering the vehicle as a part of a complex traffic scenario and considering performance indicators of the whole network, such as traffic flow improvement and fuel consumption reduction. Furthermore, the vehicle is also considered as a single entity of which real latency must be ensured. The following Table 4 presents the KPIs for this use case.

Table 4 KPIs Use Case 1

Group [ID]	KPI Description	Achieved Value	Comments
Networking [N]	Vehicle Density	1200 vehicle/km2	
Computing [C]	Latency V2N	36.253 ms	
	Communication Reliability	99.9999%	
AIF [A]	Traffic Flow	12,88%	Defined as the improvement with respect to the same network without CCAVs. Look at Table 5.
	Fuel consumption	24,6% for CCAVs 33,8% for HVs	Defined as the reduction of fuel consumption for CCAVs and Human Vehicles (HVs). For CCAVs the reference scenario is the one with 20% of CCAVs. For HVs the reference scenario is the one with 0% of CCAVs. Both scenarios are compared with the case in which 80% of CCAVs are present. Look at Table 6.
	Driver comfort	Lateral acceleration < 0.5 g Lateral Jerk < 1.18 m/s^3 Longitudinal Jerk < 2.9 m/s^3	These values are necessary to obtain a CCAV able to provide a good level of comfort to the vehicle passengers. Look at Figure 7.

Table 5 and Table 6 present the quantitative analysis of the final policy, considering fuel consumption and traffic smoothness. With regards to fuel consumption, the worst-performing and best-performing vehicles are used as normalising factors, generating a score between 0, lower fuel consumption and 1, worst performance, for each vehicle. The traffic smoothness is represented by the crossing time and number of vehicles that completed their path. Both quantities are computed as function of the percentage of CCAVs. Crossing time is defined as the time interval between departure and arrival for every vehicle.

Table 5 Normalized consumption and emission scores given a penetration rate of CCAVs, considering a simulation of 3600 seconds. The worst-performing and best-performing vehicles are used as normalising factors, generating a score between 0, lower fuel consumption and 1, worst performance, for each vehicle.

% CCAVs	CCAVs		Human driven vehicles (HD)			
	Consumption	Emission	Consumption	Emission	#CCAVs	#HD

0	-	-	0.74	0.69	0	1540
20	0.61	0.56	0.64	0.58	308	1232
80	0.46	0.38	0.49	0.44	1232	308
100	0.43	0.36	-	-	1540	0

Table 6 Crossing time, defined as the time interval between departure and arrival for every vehicle, and the number of vehicles that completed their path as a function of the percentage of CCAVs, considering a simulation of 100 seconds.

	0% CCAVs	20% CCAVs	80% CCAVs
Average crossing time [s]	56.26	54.49	49.01
Maximum crossing time [s]	87.53	83.32	79.66
N. vehicles [-]	35	39	41
Reduction of crossing time	Ref.	3.15%	12.88%

The policy has been trained to limit accelerations and jerks below limit values obtained from experimental tests, corresponding to a lateral acceleration below 0.43 g, a lateral jerk below 1.18 m/s^3, and a longitudinal jerk below 2.9 m/s^3. In this case, the vehicle reaches lower values of lateral acceleration, remaining below 0.5 g, and satisfies the limits on jerks. This solution has been tested with real human drivers. Passengers' feedback reported as satisfactory the perceived comfort provided by the policy. Referring to the time required to navigate the roundabout, the limits on the lateral acceleration reduce the performance of the vehicle, and an increment of about 3 seconds in terms of crossing time can be observed with respect to a policy not considering them. Figure 7 shows the results in terms of longitudinal and lateral accelerations for the old and the new policy.

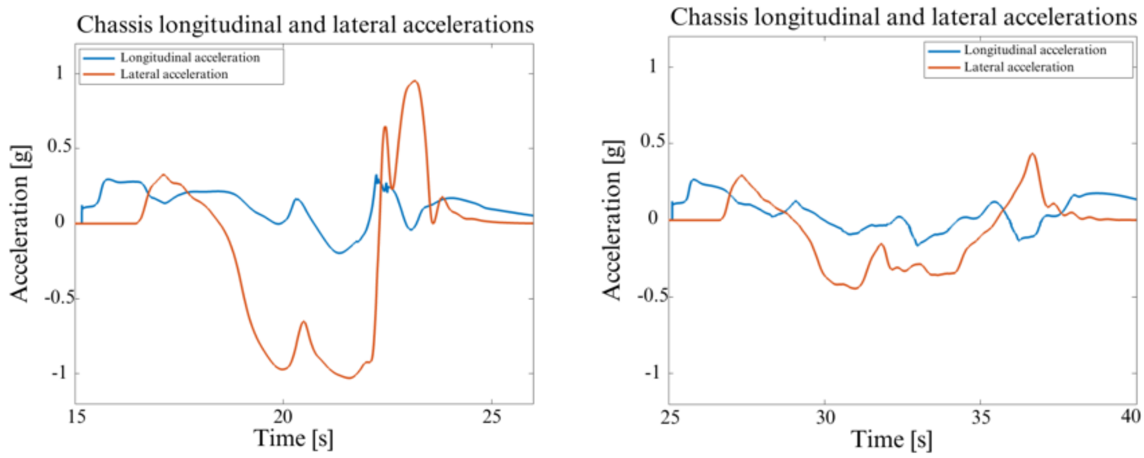


Figure 7 Lateral and longitudinal accelerations during the roundabout crossing of a CCAV. On the left, limits on accelerations and jerks are not considered. On the right, limits on accelerations and jerks are considered.

5.1.3 Platform Impact

A relevant Component that directly impacted the performance of KPIs AI@EDGE platform is the telematic box module that is a modem which is equipped with the ITS network system and has C-V2X capabilities. This modem is equipped with the Quectecl AG55xQ series (5G NR + C-V2X/DSDA Module) that serves as the foundation for this device, which can operate in either the NSA or SA modes of 5G NR. This telematic box has the bare-bones version of the features, making it possible to perform fundamental networking-related tests like device registration, mobility from LTE to NR and back again in both NSA and SA modes, carrier aggregation, and MIMO antenna-based connection. The telematic box module offers additional options, such as C-V2X PC5 direct communications.

5.1.4 Innovation Through KPI Achievement

AI@EDGE would mark a significant advance in the deployment of technological enablers for automated and connected vehicles by validating the vehicle's cooperative perception. With its dynamic resource allocation and autonomous connect-compute container deployment method, AI@EDGE will specifically make it possible for a variety of cooperative perception services to effectively manage several vehicles in urban traffic situations where the communication latency should be lower, and the network robustness and reliability are KPI's for enabling connected services and features. This will be made possible by i) utilizing knowledge of network systems to implement local learning models; (ii) adapting the network to meet the needs of the service; iii) MEC/NFV-based data-driven service management strategies for AIFs; (iv) Allocating resources and deploying distributed AI/ML services while maintaining privacy and security. Additionally, this study's overall impact would be on the success of connected and autonomous vehicles because cooperative perception is the primary enabler for a variety of safe driving services like vision transparency, a forward collision warning, collision detection at an intersection, and an automated system for avoiding hidden obstacles.

5.1.5 Quantified Techno-Economic Impact

From a technological perspective, the integration of 5G communication and the V2N-N2V architecture represents a significant advancement in transportation infrastructure. These technologies enable seamless communication between vehicles and the surrounding infrastructure, leading to optimized traffic flow and enhanced safety. Moreover, the implementation of advanced sensors and algorithms in CCAVs can significantly reduce accidents caused by human error. From an economic perspective, the implementation of Automated Vehicles can have several positive impacts. Firstly, the reduction in fuel consumption can lead to significant cost savings for both individuals and businesses. Secondly, the optimization of traffic flow can reduce congestion and travel time, leading to increased productivity and reduced transportation costs. In general, Cooperative, Connected and Automated Mobility (CCAM) can reduce the cost related to private and public transportation, making it more accessible. Thirdly, the policy responsible for driving Automated Vehicles has been instructed to also consider the driver's comfort. This is crucial to obtain a technological advancement applicable in future mobility. To this extend, and considering a fast advancement in this field too, Dynamic Driving Simulators, like the one of Politecnico di Milano used in this Use Case, are a fundamental resource. The study proposed has been able to perfectly replicate a real scenario and deeply investigate it.

The AI@EDGE platform can create a new value in a scenario that connects several key points in the (Urban) Mobility. The ones who might be able to capture this value are:

- Drivers will have vehicles and systems that support them in managing road hazards
- Citizens will then be protected thanks to such "digital transformation" and so they will be able to move around cities more safely
- Municipalities and Road Operators will be able to increase the control of road safety, to improve the viability
- Vehicle OEMs will source new parts and products to assembly new connected vehicles and can also contract with Communication Service Provides directly or with Telematics Service Providers for the necessary connectivity solution that enables all cellular communications of the vehicle
- Mobile Network Operators or specialized MVNOs (Telematics Service Providers) that offer connectivity and other communication services to Car OEMs for use by both the vehicles and their drivers (i.e., 5G and C-V2X connectivity)
- Information and Communication Technologies (ICT) Solution Providers/Communication Service Providers will provide ICT infrastructure and services (typically cloud/MEC services)

SDGs impacted for the technoeconomic aspect from the AI@EDGE project
N = 2 := 9, 11
Percentagewise Impact = $\frac{\boldsymbol{N}}{\boldsymbol{Total\ number\ of SDGs}} = \frac{\mathbf{2}}{\mathbf{17}}$ = 11.76%

5.1.6 Quantified Socioeconomic Impact

The implementation of Cooperative, Connected, and Automated Vehicles (CCAVs) in a roundabout has the potential to revolutionize transportation by introducing advanced technologies that can significantly reduce fuel consumption, optimize traffic flow, enhance safety. One of the primary advantages of CCAVs is their potential to reduce fuel consumption. By utilizing advanced technologies and algorithms, these vehicles can optimize their routes, acceleration, and deceleration patterns, leading to more efficient fuel usage. This reduction in fuel consumption contributes to a decrease in greenhouse gas emissions, aligning with SDG number 13, which focuses on climate action. Moreover, the optimization of traffic flow is another significant advantage. The implementation of 5G communication and the V2N-N2V architecture proposed by Use Case 1 enables seamless communication between vehicles and the surrounding infrastructure. By obtaining comprehensive information about the intersection environment, CCAVs can make informed decisions to minimize congestion and improve traffic flow, much more than considering simple V2V or V2I communication architectures. This optimization aligns with SDG number 11, which aims to make cities and human settlements inclusive, safe, resilient, and sustainable. Another critical advantage of CCAVs is their enhanced safety features. Automated vehicles are equipped with advanced sensors and algorithms that can detect potential hazards and react faster than human drivers. This increased safety can save lives and reduce the burden on healthcare systems, aligning with SDG number 3, which focuses on ensuring healthy lives and promoting well-being for all ages. Lastly, the implementation of CCAVs also aligns with SDG number 9, which aims to build resilient infrastructure, promote inclusive and sustainable industrialization, and foster innovation. The use of the AI@EDGE connect and compute platform represents a significant advancement in transportation infrastructure. This project fosters innovation by integrating cutting-edge technology into the existing transportation system, paving the way for future developments in smart cities and intelligent transportation systems. Overall, the implementation of CCAVs in a roundabout has far-reaching socio-economic impacts that contribute to several SDGs. By reducing fuel consumption, optimizing traffic flow, enhancing safety, and promoting sustainable and resilient infrastructure, this project represents a significant step towards a future of intelligent transportation systems and smart cities.

SDGs impacted for the socioeconomic aspect from the AI@EDGE project
N = 4 := 3, 9, 11, 13
Percentagewise Impact = $\frac{\boldsymbol{N}}{\boldsymbol{Total\ number\ of SDGs}} = \frac{\mathbf{4}}{\mathbf{17}}$ = 23.53%

5.2 Extended impact Use Case 2: Secure and resilient orchestration of large (I)IoT networks

5.2.1 Description of Use Case

In use case 2 the security functionalities of AI@EDGE are showcased in an Industrial Internet of things (IIoT) scenario. The scenario consists of a 5G network and multiple stakeholders sharing the network. Therefore, the data privacy must be ensured. The motivation of this use case is the increasing demand for the protection of industrial IoT devices from attacks on availability and confidentiality. The availability of a MEC system for the project AIF supports low-latency model retraining and inference for anomaly detection AIF, in the order of the ms. Low-latency retraining can increase model accuracy, and adaptive reorchestration of the UC2 platform stack to mitigate attacks and anomalies. Moreover, given the short-range network between UE and application server in UC2 environment, with only few hops and few meters path, the deployment of Smart-NICs at MEC servers allows the integration of AI and monitoring acceleration functions in the embedded NetFPGA system.

5.2.2 Specific KPIs for Use Case

For the beginning of the Document, the following KPIs have been identified to be addressed:

- Known-attack detection: the targeted attack detection accuracy was defined as 97% against known attacks.
- Zero-day detection: the targeted attack detection accuracy was defined as 97% against known attacks.
- False Alarm Rate: to keep the risk of alarm fatigue low, it is not only vital to detect as many anomalies as possible, but also to keep incorrectly detected anomalies as low as possible to prevent alarm fatigue. Following the state of the art, the false alarm rate should be below 0.1%.
- Adversarial federated learning attack detection: lower than the federated learning epoch duration, that will be determined during Task 3.3 and WP5 activities.

Nonetheless, as the test cases for UC2 have been specified, additional evaluation metrics were defined and described in the deliverables 5.2 and 5.3.

5.2.3 *Quantified Techno-Economic Impact*

In order to quantify the techno-economic impact of UC2, first the business models and value network has to be identified, as described in sections 3,4. As this use case represents a smart manufacturing setting, the target business model is a vendor creating security and networking solutions for the manufacturing industry, with a focus on potential customers planning to employ highly connect sensors and actuators, which are connected over 5G campus networks.

From here the emerging business models can be derived. Especially with the support of ORAN, a new market emerges for third party services in the realm of mobile networks. The AI functionality and security solutions could be employed in a service-based subscription (Security as a Service, AI as a service). Use case two demonstrates, next to the AI@EDGE platform, AI based security solutions for intrusion detection and anomaly detection. Such models can be progressively improved and maintained, so a subscription-based service is reasonable for such a product. The FPGA acceleration and federated learning, integrated for anomaly and intrusion detection as shown in UC2, are heavily relying on a network architecture supporting such AI features. This market is only enabled through the AI@EDGE platform and would not be feasible without its support. The fast-evolving 5G and beyond 5G market environment allows for more competition and more market participants, but simultaneously heavily increases the attack surface, therefore security solutions are needed.

Please note that this use case was pursued by mainly academic partners, and therefore the quantified techno-economic impact is estimated from an academic perspective.

5.2.4 *Quantified Socioeconomic Impact*

As this UC2 mainly addresses the interconnection of IoT devices in the smart manufacturing context and proposes solution for the cyber security threats introduced, the socio-economic impact will be seen in the areas of work and manufacturing (SDG 8 and 9), but also affect disaster risk reduction in the context of sustainable cities (SDG 11), and the combat of crime and terrorism in the cyber realm by protecting critical infrastructure from cyber threats (SDG 16).

SDGs impacted for the socioeconomic aspect from the AI@EDGE project
N = 4 := 8,9,11,16

$$Percentagewise\ Impact\ = \frac{N}{Total\, number\, of\, SDGs} = \frac{4}{17} = 23{,}52\%$$

5.3 *Extended impact Use Case 3: Edge AI assisted monitoring of linear infrastructures using drones in BVLOS operation*

5.3.1 *Description of Use Case*

The primary purpose of UC3 is to monitor extensive road networks using drones in BVLOS (Beyond Visual Line of Sight) mode, enhanced by the 5G network. In this scenario, reliability and seamless data traffic are required to transmit telemetry, images, and videos with minimal delay to the operator and central office for decision-making process.

The monitoring application entails the use of advanced functionalities such as scanning, 3D modelling of infrastructures of interest, incident identification, and notifying the drone operator. Due to the inherent constraints of drone performance, including weight, energy consumption, and other factors, it becomes imperative to minimize onboard systems. Thus, it becomes necessary to offload as many processes as possible from the drone.

By leveraging UC3's operations on the AI@EDGE platform and its MEC systems based on AI and Edge Computing supported by 5G networks, the optimal monitoring support is achieved, accelerating computational and modelling processes, improving reliability, and extending the operational range.

5.3.2 Specific KPIs for Use Case

As for an improved operation of the Use Case, four specific KPIs have been defined and validated as described in D5.3.

For the operation of drone:

- **Range:** geographical reach of at least 20 km to validate the BVLOS scenario.
- **Latency:** measured at 5G network environment in separated components to address control of drone operation and to reach an adequate performance of the AIFs.
- Control Signal latency: lower than 50 ms for safe remote control of the drone.
- Video Signal latency: both for FPV imagery used for drone operation and for the Payload (stereoscopic cameras) imagery sent to the AIFs, to keep below 100 ms.
- **Reliability:** measured in terms of control signal packet loss throughout the 5G network lower than 1%.

For the operation of the AIFs:

- ***Precision:*** *defined as* Mean Average Precision (mAP), with an Intersection over Union (IoU) equal to 0.5, to be higher than 0,6 (mAP@.5 >= 0.6), which provides an assessment of the capability of the Incident Detection AI Function to detect the defined classes “persons” or “vehicles” with precision.

Command & Control Communication – C2 Latency KPI < 50 ms

To conduct performance measurement tests of the C2 signal between the drone and the operator, the drone is connected to the 5G network of 5TONIC, and signal control points are established between the devices indicated in the following Figure 8.

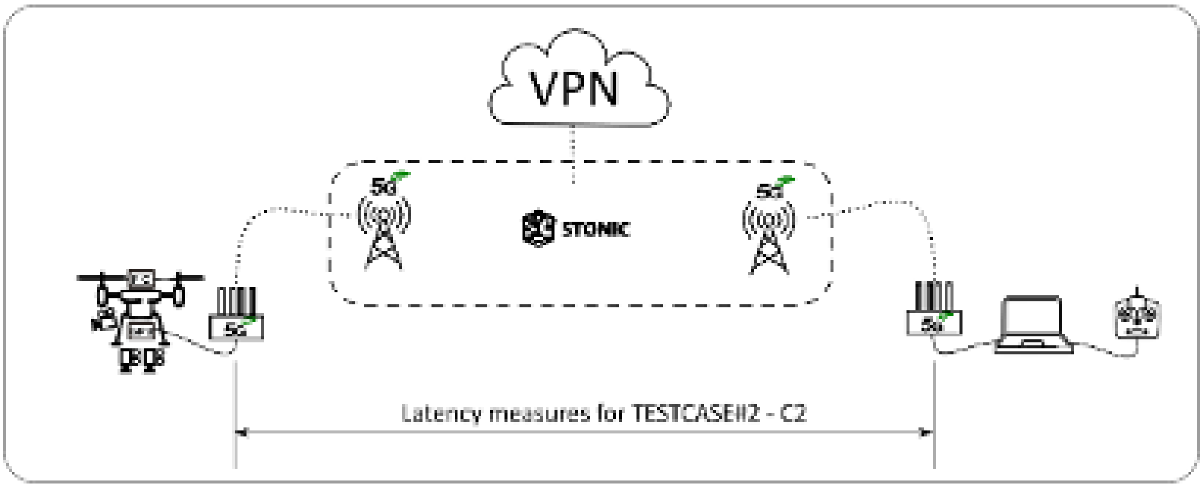


Figure 8 Use Case 3 Latency measurements for Control and Command

At 5TONIC, Ericsson has developed a Key Performance Indicator (KPI) framework designed to efficiently gather and visualize metrics related to the utilization of the 5G System. This framework relies on a sophisticated software, named “probe”, a component adept at extracting metrics from end-user traffic with flow granularity for IP traffic. A flow is uniquely identified by a tuple consisting of the origin IP address, destination IP address, origin port, destination port, and type of protocol. This meticulous approach enables the extraction of KPIs specifically tied to application flows, providing valuable insights into the performance of individual applications within the 5G System.

The software probe is installed in the Raspberry Pi onboard the drone, specifically configured to capture application traffic generated during drone operations on the 5G system network interface. This software probe can generate key metrics, including 'TCP Round-Trip and Throughput,' for both uplink and downlink. Additionally, metrics such as Jitter can be derived from the real-time database, housed in the 5TONIC Data Center, which is populated with data exposed by the software probe. The visualization of this data is facilitated through the Grafana application, an open-source solution designed for network monitoring, providing graphical representations of the stored metrics.

The methodology for C2 Latency measurement revolves around the Round-Trip Time (RTT) of a PING, involving the sending of a PING from one end of the network and recording the complete duration for the request to traverse the network and the corresponding response to return. In this instance, a PING is initiated from the Raspberry Pi device integrated into the drone, with the opposite end situated at the PC of the drone operator.

RTT is recorded at varying intervals, ranging from 1 second to broader periods, to compile a comprehensive database of measurements, serving as evidential data. Grafana facilitates a graphical representation of the performance, illustrated in the following Figure 9, showcasing the RTT measurements at the Raspberry Pi. Additionally, the Jitter factor, a parameter reflective of deviation from the RTT value, is included to depict the stability of this metric.

Video Communication – Video Latency KPI < 100 ms

To monitor the system's video performance, a similar procedure is followed as explained in the previous paragraph regarding C2 communication.

UC3 Reliability KPI < 1%

The system's performance in “packet loss” is documented throughout the trials conducted at 5TONIC, as depicted in the following Figure 9.

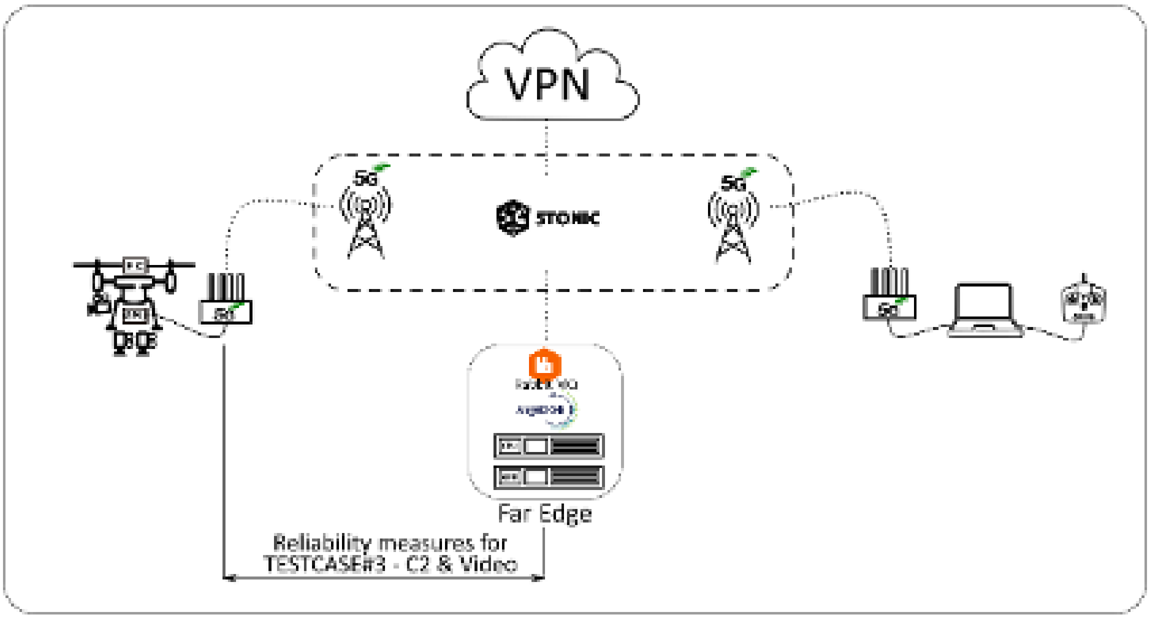


Figure 9 Use Case 3 - Packet Loss

To assess the system's performance regarding data packet loss, the software Iperf is employed to conduct tests simulating the required data flow for the AIFs Video signal (20 Mbps). The tests involve sending a data flow from the Raspberry Pi for 60 seconds and monitoring the reception of packets at the other end in the RabbitMQ server, where the video is managed. The following Figure 10 depicts the process of sending information and the results after monitoring, with the relevant information highlighted at each end.

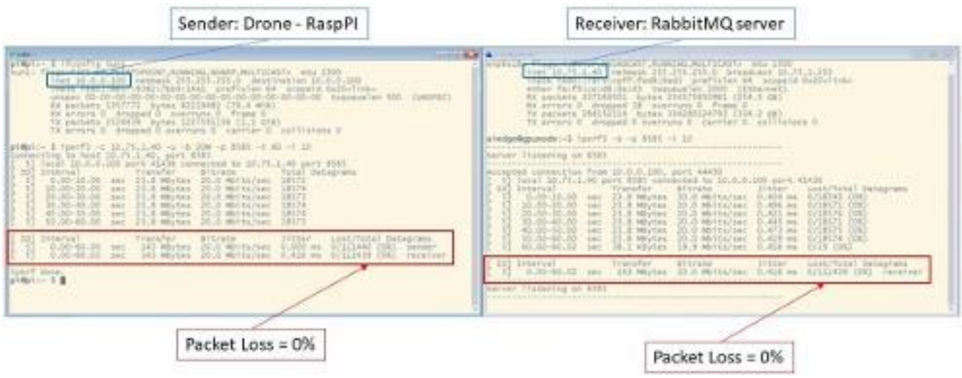


Figure 10 Use Case 3-Sending information and monitoring results

In the conducted tests, it was observed that reliability remains uncompromised when utilizing a 5G connection. Even in simulated scenarios intentionally introducing latency, connections remain stable with no dropped connections and no lost packets. In the absence of packet loss, it becomes the responsibility of the applications to uphold open sessions for each communication. The packet loss tests performed for the project were also replicated with scenarios simulating very high latencies, consistently yielding a 0% packet loss rate.

UC3 Range KPI > 20 km

A critical factor for the BVLOS mode is the distance at which the drone can be controlled by the operator. In the project, a significant distance of 20 km was established as KPI, a parameter that can introduce latency or other performance-degrading factors into the system. The tests conducted to showcase the requisite performance were tailored to the deployment of the 5G network and resources at 5TONIC.

UC3 AIF KPI – AIF KPI mAP@0.5 > 0.6

The performance of the Anomaly Detection AIF (AD AIF) is assessed in the test case 5 through an analysis of its capabilities in the domain of object detection. Our evaluation is based on an aerial dataset specifically generated within the testbed scenario and for relevant use-case situations.

To create this dataset, several dedicated flying sessions have been conducted for aerial surveillance above nearby roadway featuring vehicular traffic and occasional pedestrian activity, capturing on-board video footage. Subsequently, a process to select randomly up to 170 frames from the video is performed, and the frames are manually annotated according to the "car" and "person" categories.

5.3.3 *Quantified Techno-Economic Impact*

To quantify the expected impact of the Use Case 3 in the Techno-Economic side, the methodology stated in sections 3,4 has been followed for this specific case.

The Business Model is proposed from the position of Drone Operator providing services to industry verticals, where AEROTOOLS is currently positioned and has gained experience, know-how and customers, with a track record of innovative services throughout the last 10 years.

The techno-economic analysis of Use Case 3 has been revised to more effectively align with the model described in D2.3 and D2.4, particularly regarding the Value Network model and Cost Classification.

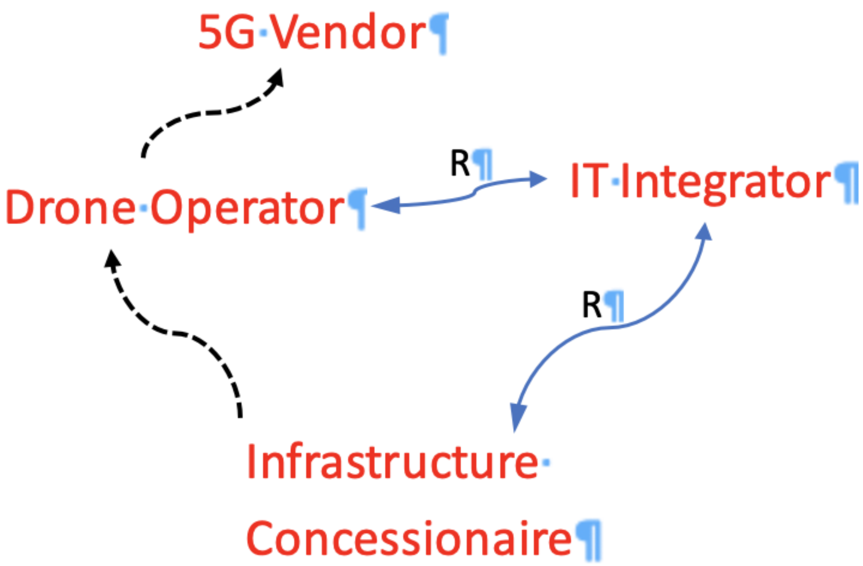


Figure 11 Value network model for Use Case 3

The cost classification has been devised targeting the type of service which is operated by AEROTOOLS and based on the concepts stated in D2.3:

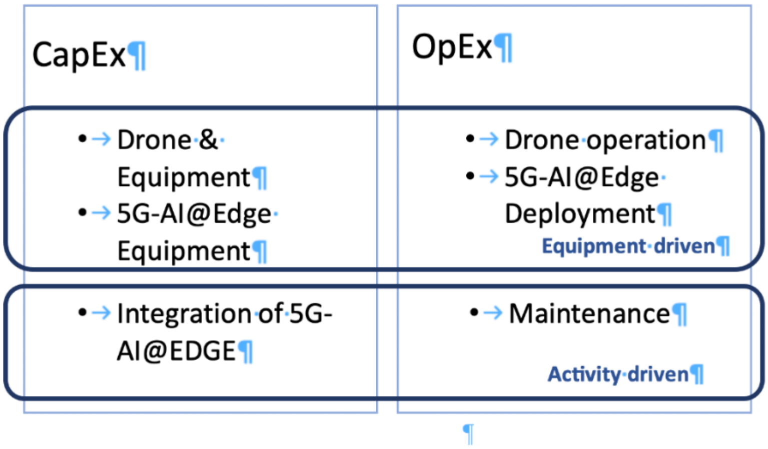


Figure 12 Reviewed Cost classification for UC3

And, finally, the Total Cost of Ownership (TCO) for this specific approach to the operation for the Use Case 3, has been obtained with the following assumptions:

- Lifetime of 5 years
- If project horizon is 10 years, so the total calculated TCO should be multiplied by 2, as renewal of hardware is required attending the features of the drone´s technology.
- The rest of assumptions as stated in D2.3 document (Section 5.3.3.2)

The calculated TCO for a 5-years project providing the service developed by UC3 in ONE CONCESSION (a specific area covered by 4 units) of a customer (Infrastructure Concessionaire), is shown in the following Table 7:

Table 7 Use case 3 - TCO for 5-years

ITEM	COMM	€/Unit	Units	€/CONCESSION
CAPEX				
Drone		25.000,00 €	4	100.000,00 €
Equipment	30% drone	7.500,00 €	4	30.000,00 €
5G-AI@EDGE Equipment	15% drone	3.750,00 €	4	15.000,00 €
		36.250,00 €	4	145.000,00 €
OPEX				
Operation	20% drone	5.000,00 €	4	20.000,00 €
Maintenance	10% drone	2.500,00 €	4	10.000,00 €
		7.500,00 €	4	30.000,00 €
OVERHEAD				
Fixed costs	22% CAPEX	7.975,00 €	4	31.900,00 €
TOTAL	**1 YEAR**	**51.725,00 €**	**4**	**206.900,00 €**
5 YEARS				
Inflation rate	5% yearly rate			
	5%			
	5			
CAPEX		36.250,00 €		
OPEX		63.449,89 €		
OVERHEAD		67.468,45 €		
TCO		**167.168,33 €**	**4**	**668.673,34 €**

With these results, it would be possible to define a service for the Infrastructure Concessionaire that adds value to their operations and with sufficient margin to be profitable.

5.3.4 *Quantified Socioeconomic Impact*

The main socio-economic impact of UC3 focuses on improving energy and industrial efficiency, contributing to sustainable growth, fostering innovation, industrialization, and sustainable cities.

How many SDG's are impacted for the technoeconomic aspect from the AI@EDGE project (E.g. 8,9,11) = 4 (SDG´s 7,8,9,11)

$$Percentagewise\ Impact\ = \frac{N}{Total\ number\ of\ SDGs} = \frac{4}{17} = 23{,}52\%$$

5.4 Extended impact Use Case 4

5.4.1 *Description of Use Case*

The UC4 of AI@EDGE project focuses on the development of a test bed and presents initial experimental results aimed at providing broadband connectivity to the passengers' on-board aircraft, as a step towards achieving ubiquitous access.

SPI provides a detailed account of its research and experimentation conducted within the framework of the AI@EDGE research project, which encompasses a 5G network and an edge-cloud infrastructure built using both avionic-certified and off-the-shelf hardware. The edge-cloud serves as a platform for developing and testing MEC applications and AIFs, which represent the next generation of services offered to airlines and their passengers, relying on machine learning capabilities.

Moreover, the 5G network is seamlessly integrated into the SPI test-bed environment and connected to a ground-based 5G core network via a Low Earth Orbit (LEO) satellite backhaul, such as Starlink.

Specific KPIs for Use Case

Domain [ID]	Group [ID]	KPI Description [ID]	Use Case Nr / All / Generic	Threshold (Number / Qualitative Description)	Achieved Value	Where to Measure	Components Involved	Project enhancement	Comments
Technical [T]	Networking [N] & Computing [C]	Data Rate/Client for Streaming [TN4]	4	> 15 Mbps	>60Mbps	5GUEs connected to in-flight network	Edge Platform, 5G Networks	Providing high-end in-flight Connectivity (IFC)	SISO – 40Mhz BW
		Latency 5GUE-LDN	4	-	<30ms	5GUEs connected to in-flight network	Edge Platform, 5G UE, LDN	Providing high-end in-flight entertainment and connectivity (IFEC)	N/A
		Latency 5GUE-5G core (Control Plane)	4	≤ 500ms	<250ms	5GUEs connected to 5G core over LEO satellite and point-to-point VPN	5G UE, LEO Satellite (Starlink), ZiroTier VPN, 5G core	Broadband access for passengers onboard	N/A
		Latency 5GUE-Internet (Control Plane)	4	≤ 500ms	<120ms	5GUEs connected to Internet over LEO satellite	5G UE, LEO Satellite (Starlink), 5G core	Broadband access for passengers onboard	N/A
		Data rate/client for content loading	4	≥ 200 Mbps	>250 Mbps	RDU	RDU, SuperMicro	Providing high-end in-flight Connectivity (IFC)	Aggregate data rate using MPTCP (WiFi/LiFi)
		Model Accuracy	4	≥ 80 %	F1 Score: 0.878 (87.8%)	Dell PowerEdge server	Dell PowerEdge server	Providing high-end in-flight entertainment (IFE)	Tests for Seatback screen predictive failure AIF

	AIF [A]	Content Curation Precision of Recommendation [TR4]	4	≥ 80 %	0.79	SPI testrack	RDUs, SCU, and SuperMicro	Providing high-end in-flight entertainment (IFE)	N/A
		Service Deployment Time [TR4]	4	≤ 180 s	<15s	SPI testrack	RDUs and SCU	Providing high-end in-flight entertainment (IFE)	Tests for Seatback screen predictive failure AIF
	Reliability [R]	Service Recovery Time [TR4]	4	≤ 180 s	~140s	SPI testrack	RDU	Providing high-end in-flight entertainment (IFE)	Tests for Seatback screen predictive failure GUI
		Service Recovery Time [TR4]	4	≤ 180 s	~1s (when the image is already deployed)	UEs connected to in-flight network	SuperMicro	Providing high-end in-flight entertainment (IFE)	Tests for Seatback screen predictive failure AIF
		Curated Content Delivery Time [TR4]	4	≤ 180 s	<2s	SPI testrack	RDUs, SCU	Providing high-end in-flight entertainment (IFE)	Tests for recommendation engine AIF
		Service Recovery Time [TR4]	4	≤ 180 s	~140s	SPI testrack	RDU	Providing high-end in-flight entertainment (IFE	Tests for recommendation engine GUI
		Service Recovery Time [TR4]	4	≤ 180 s	~1s (when the image is already deployed)	SCU	SCU	Providing high-end in-flight entertainment (IFE	Tests for recommendation engine AIF
		Number Of Served Passengers [TR4]	4	12 for demonstration	6 (passenger GUI) 3 (Crew member) 4 (predictive failure)	Plane Cabin (experimental setup)	RDUs, SCU, and SuperMicro	Providing high-end in-flight entertainment and Connectivity (IFEC)	3 More RDUs are assigned for monitoring. (overall, 16 RDUs are in use)

Detailed information about the UC4 key performance indicators (KPIs) are discussed in Deliverable D5.3.

1. **Data Rate/Client for Streaming:**
   - Measurement Method: Monitored on the N3 interface during live streaming on the internet.
   - Additional Details: Also allows measurement of data rate for accessing the local data network to watch a local movie through the 5G network.
2. **Latencies:**
   - Measurement Method: Achieved through ping tests.
   - Scope: It's important to understand the specific types of latencies being measured, such as network latency or application response latency.
3. **Data Rate/Client for Content Loading:**
   - Measurement Method: Set up an MTCP connection between clients and servers using WiFi and LiFi.
   - Technology: Evaluating data rate for content loading using both WiFi and LiFi suggests a multi-faceted approach to connectivity.
4. **Model Accuracy for Predictive Failure AIF:**
   - Algorithm and Platform: Relied on the H2O Code-based platform with the DRF algorithm for accurate predictions.
   - Service Deployment Time: The time taken for the model to output predictions.
5. **Curated Content Delivery Time:**
   - Definition: The time needed to push the first list of curated content to the passengers' panel.
   - Significance: This metric is crucial for user experience, as it directly impacts the time it takes for users to access relevant content.
6. **Service Recovery Times:**
   - Method: Achieved by restarting the AIFs and their corresponding Graphical User Interfaces (GUIs).
   - Separate Reporting: Recovery times reported separately indicate a focus on understanding and improving the system's ability to recover from failures.

5.4.2 Relevant Components

The pertinent elements for the integration of AI@EDGE with UC4 include MEC Orchestration (MEO) from the AI@EDGE Connect Compute Platform (CCP), multi connectivity and disaggregated radio access, the establishment of 5G core in FBK, edge UPF, and the deployment of 5GRAN.

5.4.3 Project Enhancement

Key achievements include seamless 5G integration adhering to 3GPP 5GNTN specifications, connecting to a ground-based 5G core network through a LEO satellite backhaul like SpaceX Starlink, and deploying an edge user plane function (UPF) of 5G core.

Moreover, the implementation of a cluster, facilitated by Virtualized Infrastructure Manager (VIM) and MEC Orchestrator (MEO) through the AI@EDGE connect compute platform (CCP), provided control over on-board AI-based MEC applications (AIFs), setting the stage for the next Safran Passenger Innovations (SPI) IFEC generation.

Incorporating multi-link aggregation with Multi-path TCP (MPTCP) showcased simultaneous use of wireless links (e.g., WiFi and LiFi), enhancing overall communication robustness.

5.4.4 *Quantified Techno-Economic Impact*

The techno-economic impact of UC4 is multifaceted. Firstly, it involves integrating 5G communication with on-board infrastructure and connecting to ground-based 5Gcore, following the 3GPP 5GNTN specifications. Additionally, incorporating edge UPF on an aircraft facilitates the introduction of edge computing within the 5G and B5G network framework in the aviation industry. Utilizing real LEO satellites, such as SpaceX Starlink, enables detailed measurements on various parameters, paving the way for the next generation of airplane connectivity systems. Secondly, the implementation of a cluster and the utilization of Virtualized Infrastructure Manager (VIM) and MEC Orchestrator (MEO) through the AI@EDGE platform provide complete control over on-board AI-based applications known as Artificial Intelligent Functions (AIFs). This development sets the stage for the next generation of InFlight Entertainment (IFE).

Thirdly, the incorporation of multi-link aggregation, achieved by enabling Multi-path TCP (MPTCP), demonstrates the simultaneous use of two wireless links (specifically WiFi and LiFi) for on-board communication, resulting in more robust and higher capacity communication.

The integration of these three main concepts within the AI@EDGE platform in UC4 contributes to the SPI main product, InFlight Entertainment and Connectivity (IFEC) systems.

SDGs impacted for the technoeconomic aspect from the UC4 of AI@EDGE project
N = 3 (8, 9, 11)
Percentagewise Impact = $\frac{\boldsymbol{N}}{\boldsymbol{Total\ number\ of SDGs}} = \frac{\mathbf{3}}{\mathbf{17}}$ = 17.64%

5.4.5 *Quantified Socioeconomic Impact*

The primary socio-economic impact of UC4 revolves around the substantial enhancement of both in-flight and flight connectivity, significantly improving passenger experiences, even in areas with traditionally underserved connectivity. This technological advancement not only enriches the overall travel experience but also holds the potential to stimulate the emergence of new businesses. By promoting the growth of the aviation sector, UC4 contributes to broader socio-economic benefits, creating opportunities for economic development and innovation within the industry.

SDGs impacted for the Sociooeconomic aspect from the UC4 of AI@EDGE project

N = 4 (3, 8, 9, 11)

Percentagewise Impact = $\frac{\boldsymbol{N}}{\boldsymbol{Total\ number\ of SDGs}} = \frac{\mathbf{4}}{\mathbf{17}}$ = 23.52%

6. Conclusion

In summarizing Deliverable D2.4 of the AI@EDGE project, we have presented a synthesis of the project's achievements and challenges. The deliverable, through its structured chapters, has successfully navigated the complex interplay of technical innovation, economic viability, and socio-environmental responsibility, offering valuable insights and concrete steps forward.

The report's initial focus on the methodology for defining and connecting Key Performance Indicators (KPIs) is pivotal. This methodology represents an approach to ensuring that the project's technical advancements are quantifiable, relevant, and aligned with its overarching goals. The techno-economic analysis, a critical component of the deliverable, offers a view of the project's economic and technological aspects. It goes beyond traditional analyses by incorporating a comprehensive evaluation of business models, value networks, and the potential impacts of new technologies on business cases. This section is particularly enlightening as it provides a roadmap for assessing the viability and sustainability of technological investments in the domain of edge computing and AI. It includes a step-by-step methodology, encompassing everything from the initial identification of business models and value networks to detailed sensitivity analyses. This approach provides an assessment, crucial for stakeholders and decision-makers in the field.

In addressing the socio-economic impact, the deliverable aligns the AI@EDGE project with the broader objectives of societal well-being and environmental sustainability. The deliberate correlation with the United Nations Sustainable Development Goals (SDGs) is a significant aspect of this analysis. It signifies the project's commitment to ensuring that its technological advancements are not only innovative but also contribute to global sustainability efforts. This part of the deliverable is crucial in today's context, where the success of technological projects is measured by their societal and environmental footprint.

The detailed exploration of various use cases in the latter part of the deliverable demonstrates the project's practical applications and real-world impact. Each use case serves as an analysis of the project's broader objectives, showcasing its adaptability and relevance across different sectors and scenarios. These case studies provide tangible examples of how the project's technologies can be applied, offering valuable insights and potential benchmarks for similar future initiatives.

In conclusion, Deliverable D2.4 of the AI@EDGE project stands as a document that not only highlights the project's technical prowess but also underscores its commitment to economic viability, societal relevance, and environmental responsibility. The insights and methodologies presented in this deliverable offer constructive guidelines for future projects aiming to balance technical innovation with practical and societal considerations.

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