5GLOGINNOV

D3.4

Evaluation of social, economic, and environmental impacts

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List of abbreviations and acronyms

Abbreviation	Meaning
3GPP	3rd Generation Partnership Project
4G	Fourth generation of broadband cellular network technology
4K	Video resolution (3840 × 2160)
5G	Fifth generation of broadband cellular network technology
ADAS	Advanced driver-assistance systems
AI	Artificial Intelligence
AMF	Access and Mobility Management Function
API	Application Programming Interface
ATP	Automated Truck Platooning
CAM	Connected and Automated Mobility
CO_2	Carbon dioxide
CN	Core Network
CNF	Containerized Network Function
COTS	Commercial off-the-shelf
C-ITS	Cooperative Intelligent Transportation System
DCET	Dynamic Control Loop for Environment Sensitive Traffic Management Actions
E2E	End to end
EAMS	Enterprise Asset Management System
ECS	Elastic Search
eMBB	Enhanced Mobile Broadband
eNB	Evolved Node B
FAIR	Findability, Accessibility, Interoperability, Reuse
GW	Gateway
HW	Hardware
EPC	Evolved Packet Core
ETSI	European Telecommunications Standards Institute
FDD	Frequency Division Duplex
FTED	Floating Truck Emission Data
GLOSA	Green Light Optimal Speed Advisory
gNB	Next generation NodeB
GNSS	Global Navigation Satellite System

HMI	Human-Machine Interfaces
IaaS	Infrastructure as a Service
IoT	Internet of Things
ITS	Intelligent Transportation System
KNF	Kubernetes network function
KPI	Key performance indicator
LCMM	Low Carbon Mobility Management
LL	Living Lab
LTE	Long Term Evolution (4th generation mobile network technology)
M2M	Machine to machine
MANO	Management and Network Orchestration
MIMO	Multiple Input, Multiple Output
MEC	Multi-access Edge Computing
MME	Mobility Management Entity
mMTC	massive Machine Type Communications
ML	Machine Learning
mMTC	Massive Machine-Type Communications
MNO	Mobile Network Operator
Nb-IoT	Narrow-band Internet of Things
NFV	Network Function Virtualization
NFVI	Network Function Virtual Infrastructure
NR	New Radio
NSA	Non-Stand Alone
NSD	Network service descriptor
OBU	Onboard Unit
OSM	Open Source MANO (Management and Network Orchestration)
OTA	Over the air
PCT	Piraeus container terminal
PER	Packet error rate
PGW	Packet Data Network Gateway
QC	Quay side crane
RAN	Radio Access Network
SA	Stand Alone
SAE	Society of Automotive Engineers

SGW	Serving Gateway
SMF	Session Management Function
SME	Small-medium enterprise
SW	Software
TAVF	Testfeld autonomes- und vernetztes Fahren
TDD	Time Division Duplex
TLF	Traffic Light Forecast
TMS	Traffic Management System
TRL	Technology readiness level
UC	Use Case
UDM	Unified Data Management
UE	User Equipment
UI	User interface
UHD	Ultra-High Definition (video)
UMTS	Universal Mobile Telecommunications Service
UPF	User Plane Function
uRLLC	Ultra-reliable low latency communications
VNF	Virtual Network Function
vTMC	Virtual Traffic Management Center
WiFi	Wireless networks technology based on IEEE 802.11 family standards

EXECUTIVE SUMMARY

The objective of this deliverable is to assess the social, economic, and environmental impacts of the 5G-LOGINNOV.

For this purpose, an update of the evaluation framework is presented, which consists of a methodology to identify and update the micro-criteria of the Use Cases (UCs) and the scores assigned to each impact according to the information included in D1.4 and D4.3. Compared to deliverable D1.4, the updated methodology to perform the quality and quantitative analysis consists of ranking 5G-LOGINNOV UCs according to a set of micro-criteria belonging to one of the considered macro-criteria such as social, economic and environmental, respectively.

D3.4 has included the analysis of existing literature regarding the impact of 5G on the logistics sector to update the micro-criteria previously identified in deliverable D1.4. The merge of the literature review analysis and the D1.4 micro-criteria allowed us to identify eight categories of impacts (micro-criteria) belonging to three macro-criteria. More specifically, the capability of the UC to impact the labour maker, for instance, by automating processes, or to improve the quality of life by simplifying and clarifying the procedures and the possibility to increase safety and security by developing services for automatic control procedures in dangerous areas, are all relevant micro-criteria of the social scenario. Concerning the economic scenario, the capability of a UC to increase the efficiency of operations or to optimise resources or traffic flows are all relevant micro-criteria. Finally, regarding the environmental scenario, the capability of the UC to decrease CO_2 emissions or reduce fuel and energy consumption is the most relevant criterion.

D3.4 has also included an analysis of the stakeholder assessment survey for which it was collected a second round of answers. We illustrate the degree of adoption of 5G technologies has increased by 0.5 points on average on a scale of 5 points at the end of 5G-LOGINNOV demonstrations and that there was no change in the opinion on the relevance of the micro-criteria identified in D1.4, meaning that the respondents considered all the micro-criteria equally relevant for the success of the UCs. Based on this result, we deemed the findings of D1.4 to remain valid and incorporated the results into this deliverable

D3.4 present also the outcomes of the multicriteria analysis, wherein UCs are ranked across various scenarios, encompassing social, economic, and environmental perspectives. We found that UC10 and UC11 of Hamburg and UC4 of Athens generate the highest positive impacts on the labour market, quality of life, safety and security (social scenario). According to D1.4 and D4.3, we found that UC8/9 of Hamburg and UC2 of Athens help to optimise resources, increase the efficiency of operations and improve traffic flow (economic scenario). Finally, UC8/9 generates the highest environmental impacts because it enables the reduction of CO_2 emissions and fuel consumption (environmental scenario).

In the last section of the deliverable, we delve deeper into the analysis of Hamburg LL by incorporating data generated during the platoon demonstration. In our efforts to enhance platoon cohesion and minimize CO2 emissions a methodology was implemented. Initially, it was evaluated the influence of road infrastructure on platoon cohesion. Subsequently, it was implemented a routing algorithm that enhances platoon cohesion by 12% compared to the shortest path and concurrently reduces CO2 emissions by 5%.

1 INTRODUCTION

1.1 Introduction to 5G-LOGINNOV

5G-LOGINNOV aims to strategically impact emerging markets by enhancing 5G-enabled port and freight operations, focusing on logistics hub maintenance. The project anticipates cost reduction opportunities and positive ecosystem impacts. It seeks to establish a leading European industrial supply for 5G technologies in logistics globally, fostering innovation and open collaboration. Through Living Labs, the project has tested and evaluated 5G-enabled services and applications and has involved SMEs and start-ups. The selected start-ups have developed innovative applications. The existing collaboration with 5G-PPP ensures a smooth knowledge transition for start-ups. 5G-LOGINNOV showcases 5G's relevance in logistics, contributing to the future 5G logistics corridor. It develops and deploys 5G devices to optimize port operations, manage vehicles and freight, and address environmental concerns. The project contributes to global standards and spectrum harmonization for 5G frequency bands in the port and logistics hub environment.

Aligned with the European Green Deal's ambitious target to decarbonize the EU by 2050, 5G-LOGINNOV Living Labs aim for significant cost savings and environmental benefits, particularly in CO_2 and NOx mitigation. By reducing freight trips, the project lowers energy needs and total fuel consumption. For instance, in the port of Hamburg, implementing 5G-LOGINNOV resulted in a substantial CO_2 reduction in the road network. Expanding these strategies to multiple logistics corridors and major seaports could lead to remarkable CO_2 savings. Additionally, the project anticipates measurable NOx savings through 5G truck platoons, aligning with the EU Clean Air Policy and addressing urban challenges recognized by the European Court.

1.2 Attainment of the objectives and explanation of deviations

This deliverable aims to assess the social, economic and environmental impacts of innovative services enabled by 5G and demonstrated in 5G-LOGINNOV. We analyse the results of the stakeholders' assessment survey that we executed at the beginning of the project and made another round before the end. We make a comparison and see how answers change after the 5G-LOGINNOV demonstrations. Thanks to this analysis, we intend to evaluate the impacts of 5G-LOGINNOV.

In the second part of the deliverable, we analyse the existing literature to integrate and expand the evaluation framework presented in D1.4 “Initial specifications of evaluation and KPIs”. More specifically, we consider the impacts of 5G on the economy, environment and society, and we look for the criteria that allow us to assess those impacts at the use case level. Finally, we integrate them with the evaluation criteria initially identified in D1.4, and we look for these impacts in D1.4 and D4.3 “Achievements with new actors and opportunities” to perform a multicriteria analysis in which the use cases are the alternatives. In D3.4 three main scenarios (social, economic, and environmental) to assess the impact of each UC have been considered. Table 1 describes the activities performed and presented in the deliverable.

Table 1: Activities and roles for the preparation of the deliverable

Role:	Who:
Analysis of the literature to identify the economic, social and environmental impacts	Piergiuseppe Di Gregorio, Giacomo Cantini
Comparison of the economic, social and environmental impacts identified in the literature with these reported in D1.4 and D4.3	Selini Hadjidimitriou
Multicriteria analysis to rank alternative use cases according to three scenarios (economic, social, and environmental)	Selini Hadjidimitriou

Analysis of the stakeholders' assessment survey results	Selini Hadjidimitriou
Analysis of Hamburg LL	Selini Hadjidimitriou

1.3 Purpose of the deliverable

The main objective of this deliverable is to present a qualitative and quantitative assessment of the economic, social, and environmental impacts of 5G-LOGINNOV implemented services and applications. We evaluate the impacts by relying on the methodology described in D1.4 with some important updates which consist of using the results of other project activities.

While the "D3.3 Evaluation of Operation Optimization" presents a pure quantitative assessment, the "D3.4 Evaluation of social, economic and environmental impacts" mainly focuses on the quality and quantitative analysis which considers the impacts presented in D1.4 "Initial specifications of evaluation and KPIs" and D4.3 "Achievements with new actors and opportunities". The quantitative impact assessment relies on the data collected by the tools developed in the context of the project (T2.2) and provided by each Living Lab on the results of the UCs demonstrations. We must point out that, in D3.4, we use the results reported in D1.4 and D4.3 to establish the evaluation criteria and rank the use cases according to different scenarios such as economic, social and environmental, respectively.

With reference to the 5G Action Plan for Europe (5GAP) Corridors which aims to achieve uninterrupted coverage in all urban areas and along all main transport paths across Europe by 2025, in the analysis of the existing literature, we consider 5G in terms of social, economic and environmental impacts and integrate these impacts in the multicriteria evaluation framework that aims to rank the alternative use cases according to three macro criteria/scenarios (economic, social and environmental). Similarly, we consider the economic impacts of the 5G-LOGINNOV core technologies by inserting the impacts identified in the D4.3 "Achievement of new actors and opportunities" into the multicriteria analysis. Finally, we evaluate the impacts of 5G-LOGINNOV technologies by reiterating the stakeholders' assessment survey at the end of the project and comparing the results. In our opinion, the differences between the average answers at the beginning and end of the project give an idea of the impacts of the 5G-LOGINNOV technologies.

By analysing the impacts produced by the different services or applications, it is possible to understand and point out the strengths of the 5G-LOGINNOV project within each LL. In the last part of the deliverable, we analyse the Hamburg LL by focusing on the platoon demonstration and on the related environmental impact.

1.4 Intended audience

The dissemination level of the deliverable is public and therefore is directed and available to any stakeholder interested in the 5G-LOGINNOV social, economic and environmental impacts' assessment. It is specifically aimed at providing a clear understanding of how the 5G-LOGINNOV impacts' assessment relies on the overall project evaluation framework and the results of the impact analysis on social, economic and environmental aspects.

1.5 Structure of the deliverable

The D3.4 consists of three main chapters in which we show and implement the methodology already presented in D1.4 and updated in this document to adapt to the latest project results:

- Introduce and outline the methodology already presented in D1.4 and the updates introduced to integrate the latest results of the 5G-LOGINNOV project.
- Analyse the existing literature and extract impacts of 5G on the transport and logistic sector.

- Analyse the stakeholders' assessment survey results to understand how the perception of the 5G-LOGINNOV technologies and the importance of the evaluation criteria changed after the demonstration.
- Identify the evaluation criteria and combine them with those reported in D1.4, those included in D4.3, the answers received to the stakeholders' survey, and perform a multicriteria analysis to rank use cases according to different scenarios (economic, social and environmental).

1.6 Relationship with other work packages and deliverables

This deliverable considers the use cases described in D1.1 "5G-enabled logistics use cases" and reconsidered in D3.1 "Trial methodology, planning and coordination". Most importantly, D3.4 updates the evaluation methodology of the 5G-LOGINNOV project presented in D1.4 "Initial specification of evaluation and KPIs". Since D3.4 includes a selection of quantitative KPIs, it deploys the KPIs provided thanks to the tool developed and presented in "D2.2 Tools for evaluation and data collection".

Concerning the social, economic and environmental criteria to evaluate the 5G-LOGINNOV use cases, we refer to the D3.3 "Evaluation of operation optimisation" from which we collect the impacts and transform them into qualitative ones. Regarding the economic analysis, we consider the business models presented in D4.3 "Achievements with new actors and opportunities" and D4.4 "Lessons learned and recommendation for stakeholders' report". Finally, we found many similarities between the Key Exploitable Results (KER) impacts and the social, economic and environmental ones. Therefore, we considered the D5.5 "Exploitation Report" and integrated these impacts into the new evaluation framework. Aiming at considering the general impacts of the project, D6.3 "Innovations' impacts" and D5.7 "Clustering and networking impacts" have been revised and mentioned for the scope of the deliverable.

2 METHODOLOGY

The methodology presented in this deliverable considers the evaluation framework outlined in D1.4: "Initial specification of evaluation and KPIs". Nevertheless, there was a need to update and integrate the evaluation framework presented in D1.4 to consider all the results accomplished by the 5G-LOGINNOV project activities. Therefore, the social, economic, and environmental analysis consists of the further elaboration of other 5G-LOGINNOV deliverables and the results of the survey for the stakeholders' assessment which was repeated in a second round at the end of the project.

In D1.4, we identified a set of actions and procedures to assess the impact of the UCs demonstrated in the context of 5G-LOGINNOV with the introduction of the 5G network in the port areas. As mentioned in D1.4, the main issue concerning the set-up of an evaluation framework for the UCs demonstrated in the context of European projects is related to the need to measure the impact of a technology that is not fully operational but is only tested on a limited area and for a limited period. Thus, the real impact of a service or a technology introduced by a research project is difficult to assess on a larger scale and over a longer period. For this reason, the first version of the evaluation framework consists of quantitative and qualitative assessments and three main layers: the first layer aims to define an Action Plan in which we plan the main activities to successfully complete the evaluation and the main workflow is described. The other two layers concern the evaluation methodology itself, which consists of two main approaches: quantitative and qualitative analysis.

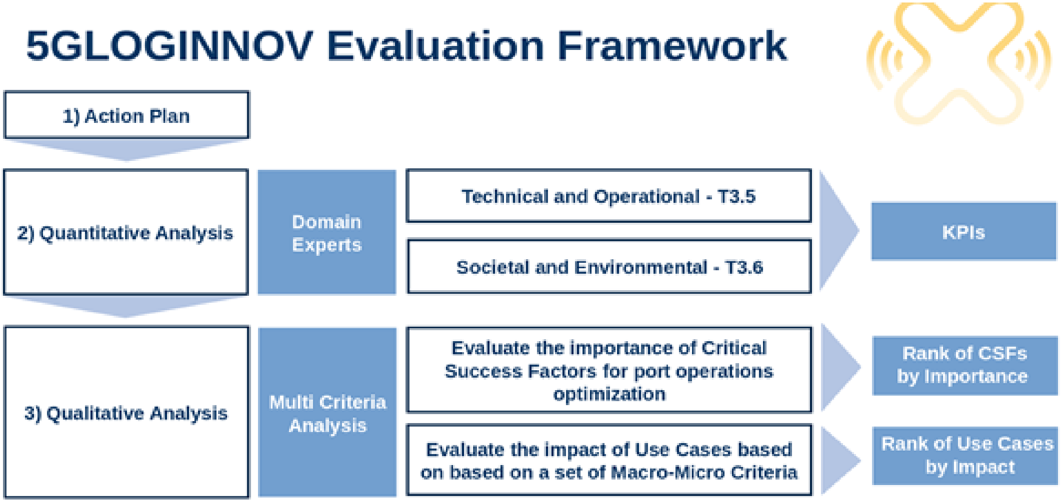


Figure 1: Overall 5G-LOGINNOV evaluation framework outlined in D1.4

As described in D1.4 and D2.2 “Data collection and evaluation procedures”, the quantitative analysis consists of identifying the KPIs and verifying their correspondence with the measurable objectives set up by the 5G-LOGINNOV project. It relies on the measurements performed by the Living Labs using collected data (see D2.2).

While performing 5G-LOGINNOV activities, it became clear that D3.3 "Evaluation of operation optimization" is the technical report in which we present the quantitative KPIs, including the social, environmental and economic ones; while D3.4 "Evaluation of social, economic and environmental impacts" should present the qualitative and quantitative analysis which also considers the main outcomes of other reports. For this reason, we had to update the evaluation framework to clarify our approach.

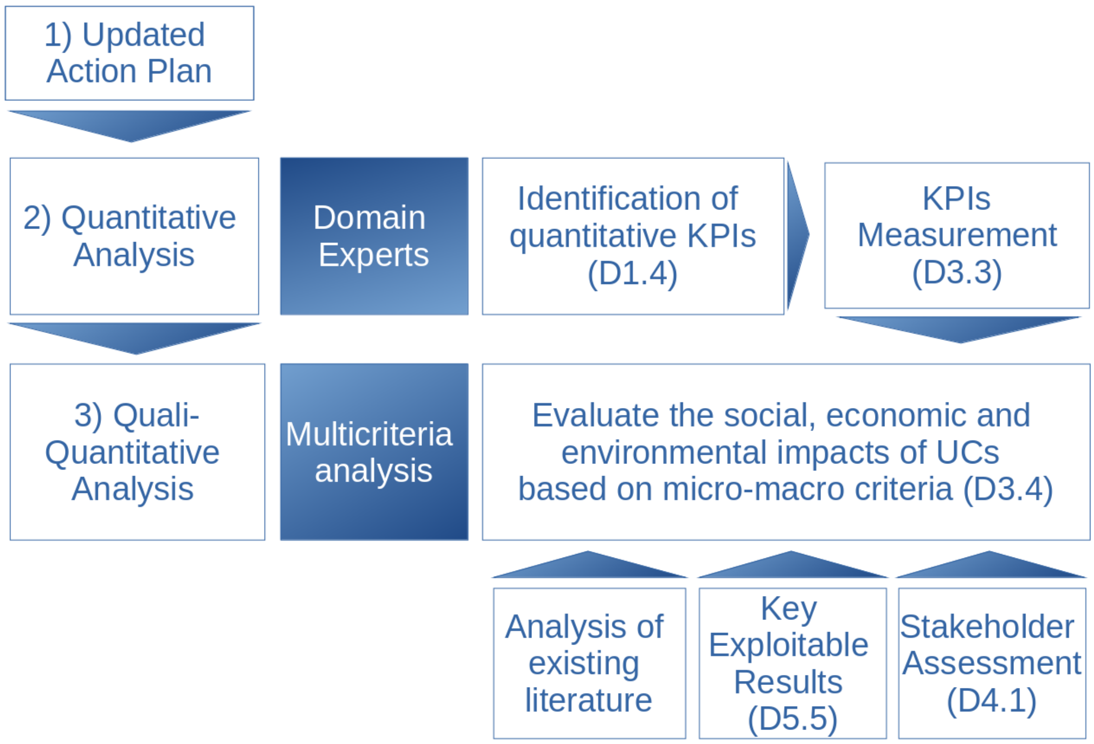


Figure 2: Update of the 5G-LOGINNOV evaluation framework

Figure 2 depicts the updated evaluation framework in which D3.3 consists of the quantitative KPIs identified in D1.4; while D3.4 performs the qualitative and quantitative analysis which exploits the results of the identification of the quantitative KPIs (D1.4), the UCs impacts identified in D4.3 and the literature review analysis including other EU projects' impacts evaluation framework.

We performed the multicriteria evaluation by considering a set of micro criteria identified in different 5G-LOGINNOV documents and survey results, and we assign a score to each UC in correspondence with each criterion. This score is the number of times we found the impact mentioned in each document (D1.4 or D4.3 or both).

The results have been used to identify the evaluation criteria that enables us to assess the UCs. Next, the number of times each impact appears in D1.4 and D4.3 has been considered and each UC impact according to the results of the stakeholders' assessment survey to create an impact matrix based on which we perform the multicriteria analysis.

Finally, the multicriteria analysis encompasses three scenarios: environmental, social, and economic. The final outcomes are reflected in the ranking of UCs, where those occupying the highest positions exert the greatest impact within their respective scenarios.

3 STATE OF THE ART ANALYSIS

3.1 Social, economic, and environmental assessments in the logistics sector

In this chapter, an extended analysis of the literature to identify the main impacts and combine them with these identified in D1.4 is presented.

3.1.1 What is qualitative assessment

Qualitative assessments in socio-economic and environmental domains encompass diverse fieldwork methodologies and multi-dimensional approaches, including techniques such as interviews, workshops, and focus groups. These methods are adaptable to various contexts, allowing researchers to engage with transport decision-makers, other professional stakeholders, the end users and recipients of transport interventions. By employing such interactive and participatory approaches, qualitative research seeks to capture the richness of experiences, perspectives, and interactions within the realm of transportation, shedding light on not only the technical and decision-making aspects but also the human dimensions that change because of transport interventions (Lucas, 2013).

In the framework of qualitative assessments of 5G technologies in the logistics sector, the social, economic and environmental impacts represent a crucial element for the development projects' evaluation. The three domains considered together allow a more holistic understanding of the consequences of a decision or a project, considering not only economic factors but also social and environmental considerations. It is a multidimensional approach that can lead to more informed and balanced decision-making (Alomoto et al., 2022).

In particular, the social assessment examines the effects of an action on the community or society. It could include aspects like cultural impacts, social cohesion, and the well-being of the people involved (Shortall and Mouter, 2021). The environmental assessment focuses on the impact on the environment. It looks at how a project or action might affect ecosystems, air and water quality, biodiversity, and overall environmental sustainability (Montgomery et al., 2015). Finally, the economic assessment involves evaluating the financial implications and economic feasibility of a project or policy. It looks at costs, benefits, potential revenue, job creation, and the overall economic impact.

The qualitative assessment involves non-numeric data, often based on opinions, experiences, and narratives. It provides a deeper understanding of the subjective aspects and can complement quantitative data.

3.1.2 Importance of qualitative assessment in transport and logistics

Assessing the qualitative social, economic and environmental impacts in transport and logistics is crucial for understanding their broader implications.

Qualitative assessments help identify the environmental and social sustainability of transportation systems (Sirkku, 2021). This can include the assessment of how a specific mode of transportation affects air and water quality, biodiversity, and climate change. By assessing these impacts qualitatively, policymakers can make informed decisions about infrastructure investments, alternative fuels, and technologies to minimize harm to the environment.

Moreover, qualitative assessments have a crucial role in policymaking (Macura et al., 2019), since transportation systems have a significant impact on everyday life, affecting the accessibility of jobs, education, healthcare, and other essential services. Qualitative assessments can help identify how different groups; particularly marginalized communities are affected. This information can help policy makers to reduce disparities in transportation and increase accessibility (Lucas et al., 2022). With reference to land use and urban planning, qualitative assessments can help define policies and interventions, improve transportation infrastructures, design urban areas, and promote sustainable and efficient land use patterns (Garau & Pavan, 2018). Qualitative assessments are relevant in long-term planning, providing valuable information regarding the broader societal, economic and environmental impacts of decision-making processes and providing solutions that promote sustainability and resilience in transportation systems.

Qualitative assessments are crucial in the implementation of solutions to optimize logistics processes. The information provided can help to identify potential safety issues, such as accident-prone areas, and create measures to improve safety for all road users. Finally, qualitative assessments help determine the long-term economic viability of a system by considering factors such as accessibility to markets, job creation, and potential for economic development (Xenou & Madas, 2022).

3.1.3 Data collection methodologies adopted in qualitative assessment

Qualitative assessments involve a variety of methodologies and techniques to gather and analyse non-quantitative data. The choice of the most appropriate ones depends on the research question, the nature of the subject, and the resources available. Methodologies used in qualitative assessments include different data collection techniques combined to obtain a more holistic understanding of the subject under study.

Some of these techniques involve an interactive approach i.e., based on verbal interaction between participants and researchers (Arabelen & Kaya, 2021). The most common technique in this sense is the interview. The interview can be structured, thus involving a structured set of questions, or semi-structured when it allows for open-ended questions and exploration of participants' responses. Similarly, focus groups involve the participation of small groups of people who collaborate interactively in the data collection process through guided discussions to generate a range of perspectives and ideas. Other data collection techniques rely on document analysis, historical records, and research to understand the context and history of a given topic.

Finally, an effective method for collecting qualitative data is the administration of questionnaires. They consist of predefined questions, which can be adapted, such as open questions, to allow participants to elaborate their own answers.

These evaluation methodologies allow the integration of quantitative analyses, collecting data that would otherwise not be quantifiable through quantitative analysis.

3.2 Impacts of 5G on the environment, society and economy

In this section, we describe the impact of 5G on the society, economy and environment by analysing the existing literature on the topic. The objective of this section is to analyse and identify the potential impacts of 5G and consider them in the context of the evaluation framework detailed in D1.4. More specifically, we will consider the economic, social and environmental impacts resulting from this analysis and assess their relevance with reference to the 5G-enabled services demonstrated by the 5G-LOGINNOV project.

3.2.1 Impacts of 5G on the economy

The introduction of 5G or 5G-enabled services implies the consideration that algorithms could potentially replace human workers. However, as pointed out by Wilson et al. (2017), this shift may give rise to new job opportunities that involve higher interaction between humans and computers. This consideration highlights the dynamic nature of the evolving job market as automation technologies, such as AI and IoT, reshape traditional roles. The introduction of 5G technologies is poised to have a profound impact on the labour market. This transformation encompasses several fundamental aspects. Firstly, some job roles could undergo significant modifications or even be replaced altogether due to the integration of IoT and AI technologies. These advanced technologies have the capability to efficiently handle routine and repetitive tasks, thereby diminishing the reliance on human labour for these specific functions (Su et al., 2022).

In parallel, as some traditional job functions evolve or disappear, there will be a shift in the roles and responsibilities of employees (Wilson et al., 2017). Instead of performing the tasks that are now automated, the human workforce will assume roles that involve monitoring the performance of these technologies and integrating them into various processes and workflows. This realignment of responsibilities highlights the need for employees to adapt and develop the skills to collaborate with and oversee these advanced technologies. The outcome of these changes in the labour market will be a workforce that is more specialized and highly focused on the proficient management of these technologies (Lehr, 2019). There will likely be a growing preference for individuals with IT skills and expertise, particularly at each level of the production chain. In this evolving landscape, those who can effectively leverage and optimize 5G, IoT, and AI technologies will have a competitive edge in the job market as these skills become increasingly vital for driving efficiency and innovation within industries. In alignment with the evolving labour market, businesses in urban areas are continuously on the lookout for opportunities that stem from enhancing their existing services or introducing novel ones. This entrepreneurial drive not only serves as a magnet for investments but also plays a pivotal role in generating job opportunities for residents. The introduction of 5G technology stands as a crucial catalyst in this ongoing quest for growth and innovation (Rao & Prasad, 2018).

The implementation of 5G technology is expected to have a multifaceted impact on the economic landscape of cities. It is anticipated to foster enhanced productivity across various industries by providing faster and more reliable connectivity (Awoyemi et al., 2020). This, in turn, enables the proliferation of Internet of Things (IoT) applications, which can be instrumental in optimizing processes and services across sectors such as manufacturing, transportation, and healthcare (Rao & Prasad, 2018). The resultant connectivity and data exchange between devices and systems are poised to stimulate innovation, not only in these sectors but also in many others, thus broadening the scope of economic growth.

Furthermore, the influence of 5G extends to the sectors of e-commerce and retail (Kshetri, 2018). The enhanced connectivity and low latency of 5G networks can significantly improve the online shopping experience, making it faster, more interactive, and more responsive, which can boost the growth of e-commerce businesses, as well as transform the retail industry by encouraging the integration of online and offline shopping experiences.

On the other hand, it is relevant to integrate multiple technologies, including Artificial Intelligence (AI), blockchain, and 5G, to usher in the fourth industrial revolution. This integration implies a holistic approach to technological advancements, with potentially profound implications for various industries and the overall economy (French et al., 2020).

Collectively, these advancements are expected to contribute to economic growth by enhancing the overall efficiency and competitiveness of businesses in the city (Rao & Prasad, 2018). This, in turn, creates job opportunities for residents, both directly in the technology sector and indirectly in various supporting industries, thus fostering economic prosperity and job creation in urban areas. In essence, 5G technology serves as a linchpin for a dynamic and innovative urban economy that offers benefits not only to businesses but also to the local workforce and the city.

In addition to the transformative effects of 5G technology on the urban landscape, the adoption of Information and Communication Technology (ICT) technologies in conjunction with 5G further reshapes the dynamics of businesses and organizations. This integration is expected to yield substantial benefits, particularly in terms of cost reduction and operational efficiency. For instance, the enhanced use of video conferencing as a viable alternative to physical attendance at events which enables organizations to engage in remote meetings and collaborations that rival the in-person experience, reducing the need for frequent and costly travel to attend events, conferences, or meetings. As a result, organizations can realize significant savings by minimizing expenses related to travel, accommodation, and logistics, ultimately contributing to cost reduction (Kokez, 2020).

Moreover, 5G technology itself brings advantages that further impact cost reduction. Its superior end-to-end latency, high network availability, capacity to support many devices simultaneously, and enhanced interoperability among various devices and systems offer a fertile ground for cost savings (Shahinzadeh et al., 2020). For example, the low latency ensures that data and commands are transmitted in real time, which is crucial for applications like remote robotic control and augmented reality, reducing the need for on-site presence (Lema et al., 2017). The high network availability ensures uninterrupted connectivity, reducing downtime and improving overall operational efficiency. Additionally, the ability to support a multitude of devices within the Internet of Things (IoT) ecosystem fosters automation and streamlines various processes, reducing the need for manual intervention. Furthermore, the interoperability aspect of 5G facilitates seamless communication and data exchange between devices and systems, which can lead to more efficient workflows and streamlined operations. As organizations increasingly leverage 5G's capabilities for machine-to-machine communication and data sharing, they can transition from traditional, paper-based communication methods, such as sending physical posts, to more efficient and cost-effective telecommunications.

The convergence of 5G technology, network slicing, edge computing, and Artificial Intelligence (AI) serves as a pivotal driving force behind the realization of Industry 4.0, underpinning the wireless connectivity of an extensive array of devices (French et al., 2021). This dynamic network is anticipated to assume a central role in manufacturing and related services, harnessing the power of cutting-edge technologies, including robotics, AI, the Internet of Things (IoT), 3-D printing, Augmented Reality (AR)/Virtual Reality (VR), and cloud computing (Rao & Prasad, 2018). The deployment of 5G technology is particularly instrumental in facilitating machine-to-machine communication, creating an environment that is agile, responsive, and adaptable.

In this context, the 5G-enabled environment is expected to foster a highly flexible and responsive manufacturing landscape. It will empower businesses to enhance their production capabilities, enabling them to meet dynamic market demands and customization requirements with efficiency and precision (Shim et al., 2022). The increased connectivity and data exchange capabilities of 5G will enable real-time adjustments and optimizations in manufacturing processes, ensuring that products can be tailored to specific customer needs and market trends.

Moreover, the virtualization of 5G network functions presents substantial business opportunities for Mobile Network Operators (MNOs) (Marquez-Barja et al., 2021). This virtualization allows MNOs to monetize their infrastructure by offering services like Security as a Service (SaaS) and Network as a Service (NaaS). This diversification of services not only contributes to the economic growth of MNOs but also aids in the optimization of network resources and management (Shim et al., 2022).

Artificial Intelligence, empowered by the capabilities of 5G, is expected to catalyse the proliferation of intelligent robots that can operate within a broader "smart" environment. These robots are anticipated to be instrumental in various industries, including manufacturing, healthcare, and logistics, as they can perform complex tasks efficiently and autonomously (Pisarov & Mester, 2020).

Table 2: Summary of 5G impacts on the economy

Impact	description
Labor market	5G technologies will transform the labour market by automating routine tasks through IoT and AI, making the workforce more specialized, while in urban business, the adoption of 5G drives

	productivity, innovation, and job opportunities, bolstering economic growth.
Cost reduction	The integration of ICT technologies and 5G enables cost savings through increased video conferencing use over physical events and leverages 5G's benefits in terms of reduced latency, enhanced network availability, greater device support, and interoperability, making telecommunications more cost-effective than traditional mail services.
Industry 4.0	The integration of 5G, network slicing, edge computing, and AI forms the foundation of Industry 4.0, revolutionizing manufacturing with robotics, AI, IoT, 3-D printing, and more, creating a flexible, responsive environment to meet market demands; this technology also provides business opportunities for Mobile Network Operators.

In conclusion, the integration of 5G technology with other cutting-edge elements, such as network slicing, edge computing, and AI, serves as a transformative force propelling the transition to Industry 4.0. This interconnected ecosystem promises to create a highly adaptable and responsive manufacturing environment, benefiting various industries and sectors, while offering new business opportunities for Mobile Network Operators.

3.2.2 Impacts of 5G on the environment

The integration of 5G technology is revolutionizing urban development by promoting sustainability, incorporating renewable energy, curbing emissions, and cultivating eco-conscious behaviours, resulting in a cleaner, more sustainable urban environment.

The shift toward a digital culture, driven by the expanded data capacity of 5G networks, promises to reshape the way we interact with services and information in profound ways. With the ability to access a wide range of services through digital communication devices, the requirement for physical presence at service locations diminishes. This transformative transition holds the potential to significantly impact fuel consumption and paper usage, offering a more sustainable and eco-conscious way of conducting business and daily life.

One of the most notable outcomes of this shift is the reduction in the need for physical travel. Traditionally, individuals and professionals have had to commute to offices, service centres, and meeting locations (Williams et al., 2022). These commutes often involve long journeys, traffic congestion, and substantial fuel consumption. However, 5G technology enables remote access to services, promoting telecommuting and remote work arrangements. This shift not only results in less demand for transportation but also reduces greenhouse gas emissions, alleviates traffic congestion, and contributes to cleaner air. The environmental benefits of reducing the reliance on personal vehicles and long commutes align with global efforts to mitigate climate change and foster sustainability (Liu et al., 2017).

In addition to the environmental advantages, 5G fosters the development of digital communication and services which can decrease the use of printed materials. Many conventional business transactions and communications rely heavily on paper documents, such as brochures, reports, invoices, and postal services. By transitioning to digital communication and documentation, there is a profound reduction in the need for paper production and usage. This shift has a dual impact: it minimizes the environmental footprint of paper production, which often entails resource-intensive processes, and it offers cost savings for businesses, as digital documentation often provides more efficient storage and archiving options (Kokez, 2020). Furthermore, it decreases waste generated from obsolete or discarded printed materials, contributing to a more sustainable waste management system.

The overall implications of this shift are multifaceted and resonate with a broader eco-friendly approach to business and daily life. As organizations and individuals reduce their carbon footprint by cutting down on fuel consumption and paper usage, they not only reduce operational costs but also adhere to more sustainable and environmentally responsible practices (West, 2016). These environmentally conscious practices create a positive impact on the environment, fostering cleaner air and more sustainable resource management. In turn, this contributes to a higher quality of life for individuals and communities by promoting a healthier and more harmonious living environment.

The advent of 5G technology plays a crucial role in reshaping not only the way we access services and information but also in fostering innovative urban models with a strong focus on sustainability and eco-friendliness. This transformative technology is a driving force behind the emergence of forward-thinking urban paradigms that promote a surge in environmentally responsible policies and practices (Pisarov & Mester, 2020).

One of the cornerstones of this shift is the adoption of renewable energy sources. In the quest for a greener and more sustainable urban environment, cities are increasingly turning to renewable energy solutions such as solar and wind power. 5G technology plays a pivotal role in enabling the efficient management and integration of these renewable energy sources into the urban grid (Israr et al., 2021). This not only reduces reliance on fossil fuels but also leads to lower greenhouse gas emissions, contributing to a cleaner and more sustainable urban landscape.

In addition to renewable energy, eco-friendly policies also focus on curbing greenhouse gas emissions (West, 2016). The efficient deployment of 5G networks allows cities to implement smart transportation solutions, reducing traffic congestion and emissions through real-time traffic management, intelligent routing, and the promotion of eco-friendly modes of transportation. Furthermore, the Internet of Things (IoT) sensors and devices supported by 5G contribute to monitoring and reducing emissions in various sectors, from energy consumption to waste management.

Another critical aspect of these innovative urban models is the cultivation of eco-conscious behaviours among residents. With 5G technology enabling better connectivity and communication, cities can engage with their residents to raise awareness and promote sustainable practices (Rao, Prasad, 2018). This includes initiatives like community recycling programs, energy conservation campaigns, and public transportation incentives. The seamless communication and data exchange facilitated by 5G technology empower cities to interact with their residents in real-time, fostering a sense of collective responsibility for the environment.

The combined efforts toward adopting renewable energy sources, curbing emissions, and cultivating eco-conscious behaviours among residents lead to a transformation in urban development that prioritizes sustainability. These eco-friendly policies and practices enhance the overall well-being of urban residents, providing them with a cleaner and healthier living environment. Furthermore, they promote a sense of responsibility and collective action, fostering a community-driven approach to environmental sustainability.

Table 3: Summary of 5G impacts on the environment

Impact	description
Carbon footprint	5G facilitates the rise of digital culture and minimises physical travel and paper usage, effectively lowering the carbon footprint, reducing emissions, and promoting eco-friendly business practices with cost-saving benefits.
Sustainability	5G technology will fuel the development of sustainable urban models, fostering eco-friendly policies and practices, including renewable energy adoption, emissions reduction, and eco-conscious behaviours, thereby promoting environmentally responsible urban growth for enhanced resident well-being and sustainability.

In conclusion, the integration of 5G technology into urban development plays a fundamental role in driving innovative urban models that prioritize eco-friendly policies and practices. This encompasses the adoption of renewable energy sources, efforts to curb greenhouse gas emissions, and the cultivation of eco-conscious behaviours among residents. The outcome is an environmentally responsible urban environment that not only benefits the planet but also enhances the well-being and sustainability of urban residents, ultimately fostering a more harmonious and sustainable way of life.

3.2.3 Impacts of 5G on society

The advent of 5G technology heralds a digital revolution, reshaping how society interacts and communicates, enhancing urban infrastructure, empowering self-driving cars, and offering an array of benefits, from streamlined public services to efficient transportation and economic transformation.

Digital culture is poised to reshape the way people engage with society, giving rise to new and evolving needs. Central to this transformation is the unparalleled communication prowess offered by the 5G network. With its rapid data transfer capabilities, 5G will serve as a catalyst for the effective utilization of remote communication devices, not only in professional settings but also in personal relationships. This technology is set to redefine the dynamics of the modern world, enabling seamless and efficient connections across diverse domains of life (French et al., 2021; Kokez, 2018).

In particular, the 5G network will underpin the burgeoning data traffic generated by the ever-expanding digital culture. As people increasingly rely on digital tools for work, education, entertainment, and social interactions, 5G's high-speed connectivity will be indispensable. It will empower individuals and businesses to harness the full potential of remote communication devices, facilitating instant and reliable connections, thereby cementing its pivotal role in the ongoing evolution of the digital era.

The pivotal role of 5G extends beyond personal communication, as it emerges as a linchpin on the Internet of Things (IoT) with transformative potential for urban infrastructure (Rao, Prasad, 2018). Its capacity to connect myriad devices, from connected cars and smart meters to diverse sectors like manufacturing, utilities, and raw material production, has unlocked an array of innovative Smart City applications. These applications encompass intelligent solutions that cut across various aspects of urban life, including advanced infrastructure, sustainability, efficient public transportation, responsible urban planning, effective governance, innovative energy utilities, machine learning integration, telemedicine, and robust data privacy protection (Pisarov & Mester, 2020).

The result is an evolving urban landscape, where the fusion of 5G and IoT is reshaping the everyday lives of city dwellers. Personal assistants, powered by this synergy, enhance the quality of life, while smart cities become more efficient, sustainable, and responsive. Through the deployment of advanced technology and interconnected systems, the vision of a smarter, more connected urban environment comes to fruition, heralding a new era of progress, convenience, and data-driven decision-making for communities around the world.

In 5G-connected urban areas, residents experience a myriad of advantages that significantly elevate their quality of life. Thanks to faster internet speeds, seamless streaming, quick downloads, and reduced latency, everyday tasks become more efficient and enjoyable. The enhanced connectivity provided by 5G is particularly vital for smart homes and the Internet of Things (IoT), enabling the seamless operation of numerous interconnected devices, from smart appliances to security systems (Attaran, 2023).

Furthermore, 5G's impact extends to critical public services, revolutionizing safety and efficiency in various ways. It enhances real-time video surveillance, strengthening security measures and deterring criminal activity. Swift data transmission benefits traffic management, resulting in reduced congestion and improved transportation systems. In emergency situations, 5G enables rapid responses, empowering authorities to react swiftly and potentially save lives. Particularly noteworthy is its transformative role in healthcare, with telemedicine services harnessing 5G's low latency and high data speeds to provide remote medical consultations, chronic condition monitoring, and swift health crisis responses. This not only enhances healthcare access but also has the potential to save lives and improve the well-being of city residents. As the integration of 5G technology and urban life continues to evolve, the opportunities for innovation and enhancement are limitless.

The implementation of 5G networks in rural regions holds significant promise in terms of cost-effectiveness, primarily owing to the advantageous propagation properties within higher frequency bands, enabling the deployment of compact base stations (Jain et al., 2018). This technological advancement has the potential to substantially elevate the quality of life in rural areas, as it will grant local communities enhanced access to digital services. By embracing 5G, rural regions stand to bridge the digital divide, unlocking opportunities for improved connectivity and digital inclusion, ultimately contributing to the overall development and well-being of these underserved areas.

City governance is actively striving to enrich residents' quality of life by streamlining utility delivery, optimizing operations, and upgrading infrastructure, all of which can lead to heightened revenues and resident productivity (Campbell et al., 2017). In this endeavour, 5G technology assumes a pivotal role in underpinning smart city infrastructure, harnessing real-time data for decision-making, fortifying security measures, and fostering citizen engagement through online platforms. Successful advancement in the 5G economy hinges on robust policy frameworks that champion innovation, risk-taking, and investment, as well as safeguarding intellectual property rights in standardized technology. The evolution of novel business models and the transformation of traditional service delivery within the 5G economy will necessitate policy modernization in various domains, including public safety, cybersecurity, privacy, healthcare, and education, ensuring that regulations keep pace with the rapid technological developments of this digital era.

Table 4: Summary of 5G impacts on the society

Impact	Description
Digital culture	The expansion of digital culture, coupled with the enhanced communication capabilities of the 5G network, will drive the emergence of new societal needs, revolutionizing both work and social interactions by facilitating the effective use of remote communication devices and supporting increased data traffic.
Smart Cities	5G's integration with the Internet of Things transforms urban infrastructure, enabling smart cities to advance in numerous aspects, such as advanced infrastructure, sustainability, efficient transportation, responsible planning, effective governance, innovative energy solutions and data privacy protection, ultimately enhancing overall quality of life and urban functionality.
Enhanced connectivity	In 5G-connected areas, residents enjoy faster internet speeds, seamless streaming, and quick downloads, while improved connectivity supports smart homes and IoT applications. Additionally, public services benefit from real-time video surveillance, enhanced traffic management, and rapid emergency response.
Rural areas	The introduction of 5G networks in rural areas, enabled by favourable propagation in higher frequencies, allows for smaller base stations. This advancement promises to boost development and quality of life in rural communities by providing improved access to digital services.
Governance	5G enables Smart City infrastructure, real-time data utilization, enhanced security, and online citizen engagement. Policy frameworks supporting innovation, risk-taking, and intellectual property protections are crucial for advancing the 5G economy, necessitating regulatory modernization in areas like public safety, cybersecurity, privacy, healthcare, and education to accommodate new business models and the transformation of service delivery.
Urban mobility	The incorporation of 5G technology into self-driving cars holds the potential to enhance their speed, intelligence, and safety by enabling real-time data processing and communication, addressing parking challenges, and improving traffic safety, with significant economic implications for industry transformation, cost reduction, and traffic optimization.

The seamless integration of 5G technology into self-driving cars holds the potential to revolutionize transportation, making these vehicles faster, smarter, and safer through real-time data processing and communication with other vehicles and infrastructure. The implications of these autonomous vehicles extend beyond just improved transportation; they have the capacity to tackle urban challenges such as parking congestion and traffic safety, ultimately contributing to more efficient and controlled urban mobility. Moreover, the ripple effects of these advancements reach into the economic realm, potentially reshaping industries, reducing costs associated with accidents, and optimizing traffic flow, thereby positioning the 5G-powered self-driving car as a key player in the transformation of the modern urban landscape (Pisarov & Mester, 2020; Attaran, 2023).

3.2.4 Related projects and their evaluation process

In this section, we present an overview of selected projects and their approach to the evaluation. More specifically, we focus on the evaluation methodology and how they measured the social, environmental and economic impacts.

The Architecture for EurOpean Logistics Information eXchange (**AEOLIX**) project aimed to increase visibility along the supply chain with the creation of a cloud ecosystem that integrates the existing ICT services. In the context of the impacts assessment carried out at the end of the project, the "D6.2 AEOLIX Living Labs Operational Impacts Assessment" concentrated on socio-economic aspects, such as including jobs creation, Small and Medium Enterprises (SMEs) empowerment and quality of life; business aspects such as the reduction of operational costs and environmental issues like CO_2 emissions and noise reduction. The methodology mainly focuses on the presentation of KPIs, data collection and analysis. With reference to qualitative KPIs such as AEOLIX's usefulness or willingness to use, the authors performed a survey with the LL participants and compared the results with the target. In the present deliverable, we will not focus uniquely on the quantitative KPIs as they are all presented in D3.3. We will mainly assess the 5G-LOGINNOV use cases according to different scenarios and the results of two project deliverables (D3.3 and D5.5).

The 5G for cooperative & connected automated MOBIlity on X-border corridors (**5G-MOBIX**) project aimed at testing CCAM at border and EU corridors. The 5G-MOBIX deliverable D5.1 "Evaluation methodology and plan" presents the evaluation methodology which adapts the FESTA methodology. The approach consists of quantitative KPIs related to 5G and autonomous driving (i.e., precise positioning, latency) and qualitative indicators such as quality-of-life, acceptance and business indicators. The data collection for the qualitative analysis consists of interviews and surveys. The 5G-MOBIX deliverable D5.3 "Report on impact assessment and cost-benefit analysis" presents the evaluation results although, at the time of writing this deliverable, the approval of the European Commission was still pending. The deliverable considers the externalities reported in the Handbook on the External Costs of Transport, Version 2019 – 1.1: climate change costs, delay, fatalities, serious injuries, and slight injuries. According to D5.3, the quality-of-life benefits are specifically related to the use case impacts and the evaluation considers different scenarios consisting of percentage reduction or increase of costs.

The AUTOmated driving Progressed by Internet Of Things (**AUTPILOT**) aims to bring IoT into the automotive sector to enable fully automated mobility. The AUTOPILOT deliverable D1.4 "Methodology for Evaluation" considers FESTA and four areas of evaluation (technology, business, quality of life and user acceptance). The AUTOPILOT deliverable D4.3 "Final Technical Evaluation" presents the evaluation results with the research questions and the quantitative and qualitative KPIs.

The Piloting Automated Driving on European Roads (**L3Pilot**) aims to test and explore the introduction of automated driving on public roads. The L3Pilot deliverable D7.3 "Pilot evaluation results" presents the technical results related to vehicle behaviour on the road and its interaction with other road users, the impact of automated driving on safety, efficiency and mobility and the costs and benefits of automated driving on society.

Overall, we can conclude that most European projects on 5G or related topics base their approach on the FESTA methodology, which also includes the identification of quantitative KPIs. In 5G-LOGINNOV, we identify quantitative KPIs and present them in D3.3 and deploy the results presented in other deliverables (D3.3, D5.5 and literature review analysis) to create a multicriteria analysis framework that enables us to rank the UCs according to social, economic and environmental scenarios.

3.2.5 KPIs to assess the impact of EU projects on transport and logistic

In this section, we proceed with the existing literature analysis by considering KPIs deployed to measure the effectiveness of European projects in the field of logistics in terms of economic, social and environmental impacts. These KPIs can be quantitative or qualitative and compare the pre-and post-intervention situation. We present here below a summary of these KPIs.

1. **Carbon Emissions Reduction**: Measure the reduction in carbon emissions achieved by logistics projects compared to baseline data. KPIs could include percentage reductions in CO_2 emissions, energy efficiency improvements, or the adoption of alternative fuels.

2. **Supply Chain Efficiency**: Evaluate how logistics projects improve the efficiency of supply chains. KPIs could include reduced lead times, lower inventory levels, and increased on-time deliveries.

3. **Sustainability Goals Alignment**: Assess the alignment of logistics projects with the sustainability goals of Horizon Europe, such as those related to the European Green Deal. KPIs might involve tracking progress toward specific sustainability targets.

4. **Innovation Adoption**: Measure the rate at which logistics projects adopt innovative technologies and practices, such as IoT, blockchain, or autonomous vehicles. KPIs could include the number of pilot projects implemented or the adoption rate of new technologies.

5. **Cross-Border Collaboration**: Evaluate the level of international collaboration in logistics projects. KPIs might include the number of countries involved, the number of cross-border pilot projects, or the percentage of project partners from different EU member states.

6. **Economic Impact**: Assess the economic impact of logistics projects. KPIs could include the creation of new jobs, the growth of logistics-related industries, or the increase in revenue for participating companies.

7. **Inclusivity and Equity**: Measure the extent to which logistics projects promote inclusivity and equity. KPIs might include tracking the participation of underrepresented groups, ensuring equal access to project benefits, or conducting surveys to assess the satisfaction of various stakeholders.

8. **Data Security and Privacy Compliance**: Evaluate the adherence of logistics projects to data security and privacy regulations. KPIs could include the number of data breaches, the level of compliance with GDPR, or the implementation of data protection best practices.

9. **Stakeholder Engagement**: Measure the effectiveness of stakeholder engagement. KPIs might include the frequency of stakeholder meetings, the number of feedback sessions, or the level of satisfaction reported by stakeholders.

10. **Project Dissemination**: Assess how well logistics projects disseminate knowledge and findings. KPIs could include the number of publications, the reach of public awareness campaigns, or the level of open access to project data and results.

11. **Risk Mitigation**: Track the identification and mitigation of risks associated with logistics projects. KPIs might include the number of identified risks, the successful mitigation of critical risks, or the percentage of project objectives achieved despite unforeseen challenges.

12. **Resilience**: Assess the resilience of logistics systems in times of crisis or disruption. KPIs could include the time required for recovery, the percentage of disrupted services restored, or the number of crisis response plans tested.

4 STAKEHOLDERS' ASSESSMENT RESULTS

In this chapter, we analyse the results of the stakeholder's assessment survey and make a comparison between the first and second round. Compared to the first round in which we had 40 respondents, in the second round, we obtained only 20 answers. Table 5 shows the number of answers for each UC.

Table 5: Number of answers collected by UC, authors' elaboration

UC	Number of answers
1	4
2	3
3	1
4	3
5	7
6	7
7	2
8	8
9	7
10	6
11	5

Figure 3 depicts the expected impacts (micro-criteria) that the respondent considers relevant for the success of the use case. The impacts of the second round (After) refer to three UCs (UC1, UC5, UC6), while the impacts of the first round (Before) refer to the seven UCs (UC1, UC4, UC5, UC6, UC8/9, UC10, UC11).

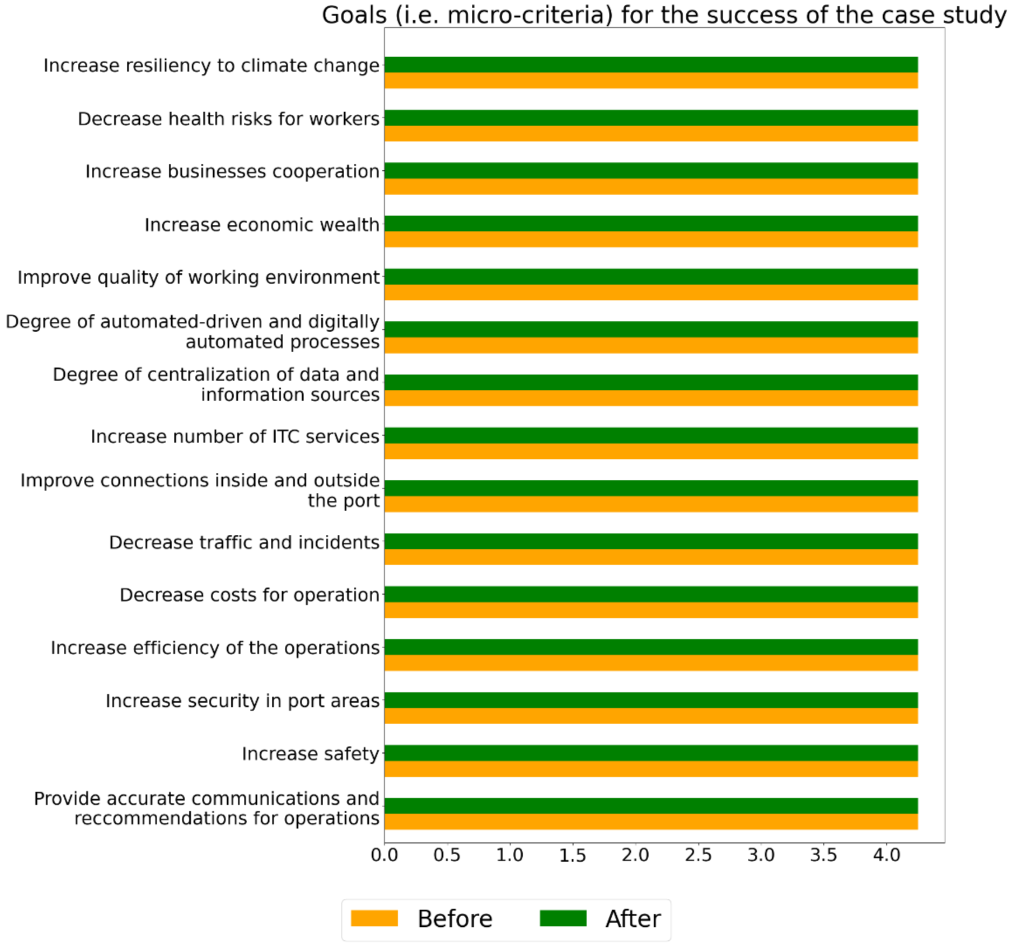


Figure 3: Expected impacts, authors' elaboration

Figure 3 shows that all impacts are equally relevant to the success of the UCs, and this opinion has not changed after the 5G-LOGINNOV demonstrations.

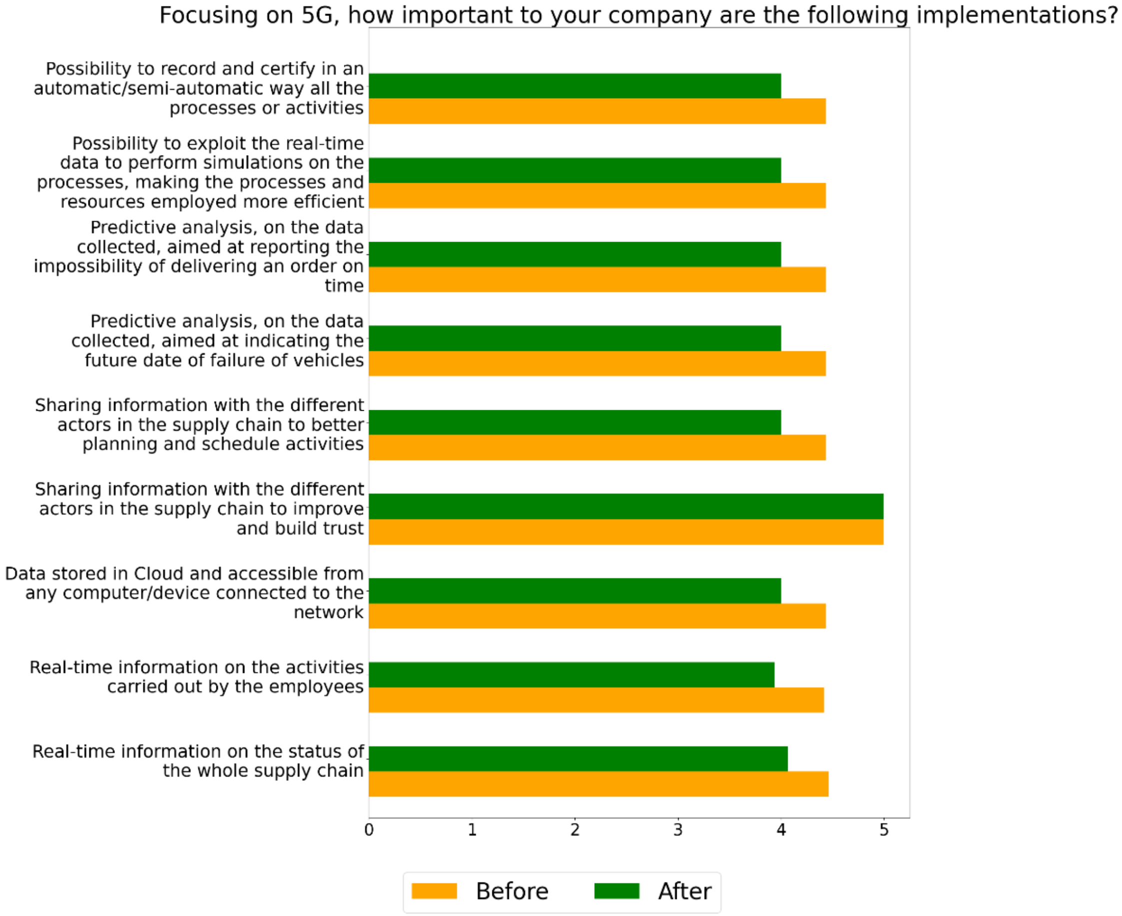


Figure 4: Importance of 5G implementations

Concerning the relevance of 5G implementations shown in Figure 4, the possibility to share information with different actors in the supply chain to improve and build trust has confirmed its relevance, and it is considered the most relevant 5G implementation for the respondents. All the other considered 5G implementations are somehow less relevant after the 5G-LOGINNOV demonstrations. It is possible to explain this result because the project has helped implement some 5G applications and services that are no longer a priority for the company.

Figure 5 presents the level of companies' implementation of a set of technologies. Compared to the first round, all technologies reached a higher implementation level, which is evidence of the 5G-LOGINNOV project impact.

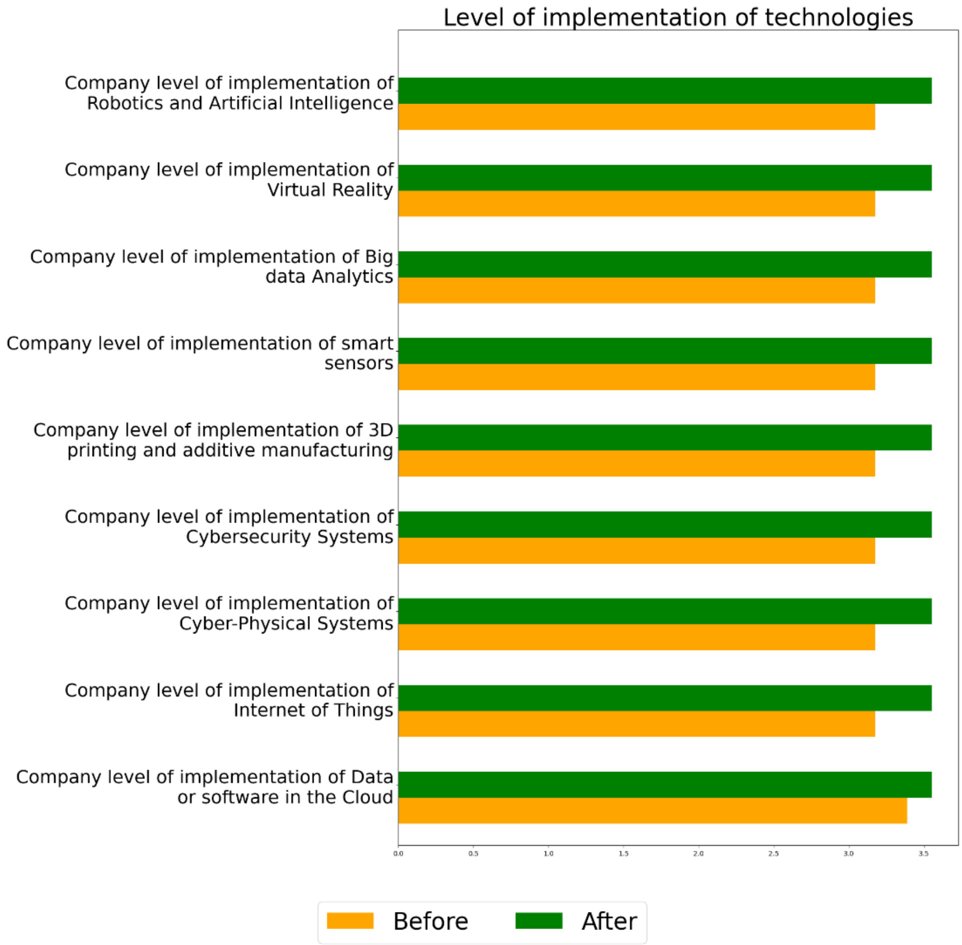


Figure 5: Level of implementation of technologies

Overall, we can conclude that there is evidence that 5G-LOGINNOV has created a positive impact in terms of technology implementations. Although, this impact could be the results of a wider 5G implementation.

5 QUALI-QUANTITATIVE ASSESSMENT OF SOCIAL, ECONOMIC AND ENVIRONMENTAL IMPACTS

The qualitative and quantitative analysis aims to assess the impacts of 5G-LOGINNOV that we cannot measure using quantitative KPIs. More specifically, we evaluate the Use Cases according to different areas of impact or evaluation criteria. We consider the methodology presented in Task 1.4, in which we deploy the multi-criteria approach. The approach consists of measuring indicators related to three different scenarios (social, economic and environmental) and ranking the Use Cases accordingly. The UC in the rank which occupies the first position has the highest impact.

Compared to the analysis performed in D1.4, in which we assessed the importance of Critical Success Factors for port operations optimization, in this deliverable, we evaluate the UCs' impact according to the three scenarios (economic, environmental and social). Furthermore, we consider the evaluation criteria identified in D1.4 and we integrate them based on the analysis of the existing literature presented in Chapter 2. The chapter starts with a brief description of the Living Labs (LL) impacts.

5.1 Overview of the 5G-LOGINNOV results

5G-LOGINNOV aims to strategically impact emerging markets by enhancing 5G-enabled port and freight operations, focusing on logistics hub maintenance. The project anticipates cost reduction opportunities and positive ecosystem impacts. It seeks to establish a leading European industrial supply for 5G technologies in logistics globally, fostering innovation and open collaboration. Through Living Labs, the project has tested and evaluated 5G services, involving SMEs and start-ups. A dedicated network of start-ups has been supported, and selected ones have been integrated into the project for innovative application development. The existing collaboration with 5G-PPP ensures a smooth knowledge transition for start-ups. 5G-LOGINNOV showcases 5G's relevance in logistics, contributing to the future 5G logistics corridor. It develops and deploys 5G devices to optimize port operations, manage vehicles and freight, and address environmental concerns. The project actively contributes to global standards and spectrum harmonization for 5G frequency bands in the port and logistics hub environment.

Aligned with the European Green Deal's ambitious target to decarbonize the EU by 2050, 5G-LOGINNOV Living Labs aim for significant cost savings and environmental benefits, particularly in CO_2 and NOx mitigation. By reducing freight trips, the project lowers energy needs and total fuel consumption. For instance, in the port of Hamburg, 5G-LOGINNOV demonstrations will result in a substantial CO_2 reduction in the road network. Expanding these strategies to multiple logistics corridors and major seaports could lead to remarkable CO_2 savings. Additionally, the project anticipates measurable NOx savings through 5G truck platoons, aligning with the EU Clean Air Policy and addressing urban challenges recognized by the European Court.

Relying on the Living Labs at the ports of Athens, Hamburg and Luka Koper, the present analysis focuses on the social, economic and environmental impacts and analyses them in relation to the 5G-LOGINNOV project objectives.

- **O1:** Develop and Deploy the Next Generation ports and logistics hubs, the operation system architecture, and integrate them into 5G networks at three main ports in Europe: Athens (GR), Hamburg (DE) and Koper (SL), utilising new types of 5G IoT sensors and devices.
- **O2:** Optimise ports & logistics hubs' operation and maintenance to reduce operational costs with innovative concepts and use cases.
- **O3:** Significantly reduce ports & logistics hub operation emissions (CO_2/NOX) and regulate the freight traffic on the future 5G logistics corridor in the EU, including CAM truck platooning management.
- **O4:** Regulate the freight traffic generated by ports & logistics hubs on the future 5G logistics corridors in the EU and integration of future Connected and Automated truck platoons.

The first objective regards the family of UCs 1 to 4. Objective 2 concerns the family of UCs from 5 to 7, relying on technical indicators evaluated in D3.3. The focus of the present analysis is to combine a qualitative impact assessment with the technical and logistic KPIs already discussed in D3.3. The third objective concerns UC 8-9, while the fourth relates to UCs 10 and 11.

The 5G-LOGINNOV project tackles the impacts related to the other project objectives in D4.3 "Achievements with new actors and opportunities", D5.5 "Transferability assessment and exploitation report" (Objectives 5 and 6), and D5.7 "Clustering and networking impacts" (Objective 7).

D4.3 describes the engagement process of start-ups in the project, the value propositions for each UC and the related business models. Business opportunities were identified by involving new entrants (winning start-ups) and initial project partners (SMEs) in the business modelling process. Deepening on the commercial impacts of the project, D5.5 presents the main Key Exploitable Results (KERs) for each LL and the related exploitation strategies. It provides strategic recommendations and identifies potential stakeholders, benefits, and strategies for new actors. Furthermore, D5.5 outlines the main challenges and mitigation actions beyond the 5G-LOGINNOV project.

On the other hand, D5.7 focuses on the clustering and networking impacts of the project, leveraging on the networking with European-wide organizations and trans-national initiatives such as 5G PPP; ALICE (Alliance for Logistics Innovation through Coordination in Europe) and European Technology Platform (ETP); Digital Transport and Logistics Forum (DTLF)– sub-group 2: Corridor Information System; European Commission – DG CONNECT Strategic Deployment Agenda (SDA) for preparing 5G corridor Digital CEF; European Commission CCAM (Cooperative, Connected and Automated Mobility) platform.

Table 6: Comparison between the innovations and the social, economic and environmental impacts

INNOVATIONS areas of impact (D6.3)	SOCIAL, ECONOMIC AND ENVIRONMENTAL IMPACTS (D3.4)
Efficiency and Capacity Enhancement	Resource optimisation Efficiency of operations Labour market
Safety and Security	Safety and Security
Environmental Sustainability	Carbon emissions Fuel and energy consumption
Digitalization	-
Transportation Optimization	Efficiency of operations Efficiency of traffic flow
-	Labour market
-	Quality of life

Finally, to conclude this brief overview of other projects' results and where they have been evaluated and presented, D6.3 "Innovations management report" identifies five main areas of impacts partially overlapping or related with the impact areas identified for the scope of the present deliverable.

5.1.1 Athens LL

In Athens LL, a collaborative effort involving various partners has successfully implemented 5G technology with a specific focus on port operations, both within and outside the port premises. The implementation aims to bring considerable improvements in operational efficiency, safety, and overall logistics based on 5G-enabled capabilities.

- **Real-Time Tracking and Visibility for Yard Trucks:** the implementation of 5G technology has enabled real-time tracking and enhanced visibility of yard trucks within the port premises. This real-time tracking facilitates service optimization, efficient job allocation, and predictive maintenance services for yard trucks.

- **5G-Enabled Video Analytics for Safety and Logistics:** the partners have orchestrated 5G-enabled video analytics as Network Function Virtualization (NFV) and Management and Orchestration (MANO) services. These services target both safety and security aspects, as well as logistics applications. The video analytics contribute to a safer working environment and improved logistics operations.
- **Integration with 5G-IoT Nodes:** the implementation involves the integration of 5G technology with Internet of Things (IoT) nodes. This integration enhances the connectivity and capabilities of the 5G network, particularly in relation to port operations. It likely supports various IoT devices and sensors for data collection and communication.
- **Real-Time Monitoring of Logistics Supply Chain:** the 5G implementation includes real-time monitoring of the logistics supply chain. This involves live tracking of 5G-connected external trucks inbound to Piraeus port. Real-time monitoring enhances the visibility and management of logistics activities, potentially leading to improved efficiency and responsiveness.

5G-LOGINNOV at Athens LL has demonstrated a diverse set of use cases, including (i) the optimal assignment of container jobs based on localisation (and other sensor) data of yard trucks; (ii) coordination with external truck operations; (iii) improvement of personnel safety; (iv) automation for ports: port control, logistics and remote automation through analytics of 4K video streams (enabled as a far-edge computing services based on computer vision and machine learning techniques); and (v) predictive maintenance service in port assets (i.e., yard trucks).

Table 7: Summary of Athens LL

ATHENS LIVING LAB	
LOCATION	Port of Piraeus
PARTNERS INVOLVED	PCT, ICCS and Vodafone
OBJECTIVE	Implementation of novel 5G technologies (MANO-based services and orchestration, pioneering far-edge computing as a service, computer vision, AI/ML video analytics) and cutting-edge prototypes into an operational port environment.
IMPACTS AREAS	Safety and Security Workforce Productivity Efficiency of traffic flow Resource optimization Efficiency of port operations Green Supply Chain Practices
INNOVATION	INNO3- 5G and IoT Platform in Port Operations. INNO4- 5G&AI enabled container seal detection for supporting logistics process. INNO5- 5G&AI enabled human presence detection to support safety/security operations. INNO11- 5G and IoT technologies for supporting security and logistics process in port environment. INNO13 - SeaFront - Synthetic Dataset for Visual Container Inspection.
USE CASES	UC2, UC3, UC4, UC5, UC7
KPIs SELECTED	CO_2 emissions (A-KPI7) Fuel consumption (A-KPI8) Assets idling (A-KPI18) Percent of empty containers runs (A-KPI4) Mean time of container job (A-KPI5) Human resource optimization (A-KPI9) Vessel operation completion time (A-KPI10) Parts in stock (A-KPI13) Vehicle breakdown (A-KPI14) Vehicle under maintenance (A-KPI15) Vehicles unexpected breakdown (A-KPI16) Maintenance costs of vehicle (A-KPI17)

5.1.2 Koper LL

Koper Living Lab focuses on the MANO architecture (Management and Network Orchestration) and its cloud extensions, which supports the automated deployment and life cycle management of Industrial IoT applications related to port control, remote automation and security. Such applications include advanced video analytics for identification of container markers and detection of structural damage, port equipment monitoring and remote telemetry of operating machines (e.g. terminal tractors) and mission-critical communications (namely real-time video surveillance using body-worn cameras, video surveillance cameras with night vision capabilities for security monitoring, automated drone-based and automated detection of objects, vehicles and personnel movement in a specific port area).

Table 8: Summary of Koper LL

KOPER LIVING LAB	
LOCATION	Port of Koper
PARTNERS INVOLVED	LUKA KOPER, INTERNET INSTITUTE, TELEKOM SLOVENIJE, VICOMTECH and CONTINENTAL
OBJECTIVE	Development and demonstration of novel 5G technologies targeting future European ports (e.g., cloud-native and MEC driven infrastructures, MANO-based services and network orchestration, Industrial IoT, vehicle telemetry, AI/ML based video analytics, drone-based security monitoring etc.) and cutting-edge prototypes tailored to the needs of port environment.
IMPACT AREAS	Safety and Security Workforce Productivity Resource optimization Efficiency of port operations Green Supply Chain Practices
INNOVATION	INNO1- Improved Industrial IoT System for specific needs of the ports and logistics domain. INNO2- Improved private 5G mobile system for use cases in port and logistics domain. INNO3- 5G and IoT Platform in Port Operations. INNO11- INNO11- 5G and IoT technologies for supporting security and logistics process in port environment.
USE CASES	UC1, UC5, UC6
KPIs SELECTED	Time Trucks Parked in the Area (K-KPI25) Truck speed (K-KPI26) Truck Acceleration (K-KPI27) Truck Stand Still Time (K-KPI28) Fuel Consumption (K-KPI29)

5.1.3 Hamburg LL

Hamburg Living Lab focuses on 5G to enhance traffic management applications, with reference to freight road traffic in the port hinterland area. The LL has developed an innovative methodology to capture the effect of the traffic infrastructure on pollutant emissions and is part of an agenda for the development of Intelligent Transportation Systems (ITS) in the area of Hamburg City (ITS Policy Strategy 2030), also featuring advanced cooperative services (C-ITS) like GLOSA (Green Light Optimisation Speed Advice) and ATP (Advanced Truck Platooning).

Table 9: Summary of the Hamburg LL

HAMBURG LIVING LAB	
LOCATION	Port of Hamburg and hinterland
PARTNERS INVOLVED	SWARCO, tec4U, Continental and T-Systems

OBJECTIVE	Demonstrate the potential of leveraging positive environmental impact by applying the functionalities of 5G at V2X communication and traffic management, outside the port and the hinterland.
IMPACT AREAS	Safety and security Human resources optimization Driver Behaviour Efficiency of traffic flow Resource optimization Efficiency of port operations CO_2/NOx emissions' reduction Fuel and Energy Consumption Noise Reduction Green Supply Chain Practices
INNOVATION	INNO7- 5G enabled Floating Truck Emission Data (FTED). INNO8- 5G enabled GLOSA for Intelligent Transport Systems (I.T.S.). INNO9- 5G enabled Collision Warning. INNO10- 5G enabled Carbon Emission Trading. INNO 12-Mechanism to enable cities' traffic management to work with emission data originating from vehicles.
USE CASES	UC8-9, UC10, UC11
KPIs SELECTED	Avg. truck speed single mode (H-KPI1) Avg. acceleration activities single mode (H-KPI2) Avg. stillstand time single mode (H-KPI3) Truck speed profile by platoon mode (H-KPI4) Acceleration profile by platoon mode (H-KPI5) Stillstand time profile by platoon mode (H-KPI6) Fuel consumption single mode (H-KPI7) CO_2 emissions single mode (H-KPI8) Fuel consumption platoon mode (H-KPI9) CO_2 emissions platoon mode (H-KPI10) Energy performance index value EPI (H-KPI11)

5.1.4 Identification of the micro-criteria

We compared the results of the analysis of the existing literature with the D1.4 micro-criteria and selected the social, economic and environmental micro-criteria of the 5G-LOGINNOV project.

Table 10: Evaluation criteria

Macro Criteria	D3.4 Micro criteria	D1.4 Micro criteria	SOA impacts
ECONOMIC	Efficiency of operations	Increase communications accuracy	
		Increase operations efficiency	Improve efficiency of the supply chain
		Improve connections inside and outside the port	
		Increase number of ITC services	
		Degree of centralization of data and information sources	
		Degree of data-driven and digitally automated processes	
		Increase businesses cooperation	Increase stakeholders' engagement
	Resource optimization	Decrease costs for operation Increase economic wealth	Save costs with videoconferencing Increase revenues
SOCIAL	Safety and security	Increase security in port areas Decrease traffic and incidents	Enable real-time surveillance
		Increase safety within port Decrease health risks for workers	Improve traffic safety
	Quality of life	Improve quality of working environment	
	Labour market		Improve remote communication
			Automate routine tasks through IoT and AI
			Create new jobs
			Make the workforce more specialized
			Increase inclusivity and equity
ENVIRONMENTAL	Carbon emissions'	Increase resilience to climate change	Minimize physical travels and paper usage
	Fuel/energy consumption		
	Eco-consciousness behaviour		Increase eco-conscious behaviours
	Noise		

Table 10 compares the micro criteria identified in the literature review and those identified in D1.4. The first column of the table shows the macro-criteria, and the second column presents the selected micro-criteria to evaluate the UCs. We chose the micro-criteria based on the cross-analysis. We did not include eco-consciousness criteria and noise because there was only one UC referring to them. Therefore, we thought they were not relevant to compare the UCs.

Table 11: Description of the micro-criteria

Macro-criteria	Micro- criteria	Description of the micro-criteria
Economy	Efficiency of traffic flow and logistics chain	Impact of the UC on improving traffic flow.
	Efficiency of operations	Impact of the UC on the efficiency of logistics operations or along the logistics chain.
	Resource optimization	Impact of the UC on the ability to use more efficiently the existing resources or to make more efficient the logistics process.
Social	Labour Market	Impact of the UC on increasing employee productivity and satisfaction within the logistics sector, as well as human resources optimization and working conditions improvement.
	Safety and Security	Impact of the UC on safety and security improvement for workers, vehicles, and goods.
	Quality of Life	Impact of the UC on the workers' quality of life, on creating new jobs or automating the existing ones.
Environment	CO_2 emissions	Impact of the UC on the greenhouse gas emissions reduction as a result of optimized route planning and the other 5G-enabled technologies.
	Fuel and Energy Consumption	Impact of the UC on the reduction of fuel and energy consumption because of traffic decrease, more conscious environmentally friendly practices, or more efficient loading/unloading operations.

Table 11 summarises and describes the micro-criteria considered in the multicriteria analysis. In the next section, we outline how we assigned the scores to each UC about each micro-criterion.

5.1.5 The impact matrix

For each UC, we analyse the information reported in D1.4 and D4.3 to assess for each UC the impacts measured according to the micro-criteria. For instance, if D1.4 mentions that UC4 allows increased safety, the impact matrix will report 1 in correspondence to the micro-criteria “safety and security”. If also D4.3 does the same, there will be a 2 in the impact matrix. We considered D1.4 because it reports the main expected impacts of each UC. Furthermore, we created the impact matrix using the information included in D4.3 because the deliverable presents the main achievements of 5G-LOGINNOV activities.

Table 12: Description of the impacts reported in D1.4 and utilised in the impact matrix

LL	UC	1.4 impacts
Athens	2	Optimize port operations Reduce percentage of empty container runs Traffic redistribution in port operations based on real-time truck localization data Reduced time for a device to connect to the network Extrapolation of the potential CO_2/NO_X savings based on the real traffic volume to the port terminals Reduce emissions produced by trucks delivering/picking up containers
	3	Optimise port operations
	4	Optimise port operations Optimise the use of human resources in yard equipment port operations

	5	Reduce vessel operation completion times Optimise the use of human resources in yard equipment port operations
	7	Improve utilisation of the port warehouses and storage spaces Reduce total cost of spare parts and tyres annually Minimise percentage of yard equipment assets idling for more than one shift
	1	Enhancing 5G IoT backend system elements with new functionalities and MANO orchestration support Dedicated private mobile system that will be built as standalone and self-operated 5G network and services platform infrastructure Provision of private 5G-based mobile services tailored to the needs of port operation
Koper	5	Dedicated private mobile system that will be built as standalone and self-operated 5G network and services platform infrastructure Provision of private 5G-based mobile services tailored to the needs of port operation Enhance functionalities of the 5G IoT GW to support 5G Non-Standalone and Standalone capabilities Develop proprietary computer vision SDK, multiplatform, to rapid prototyping in a large variety of sectors, including Advanced Driver Assistance System (ADAS), security, inspection and HMI Annotation model to describe content of image sequences, in the form of spatiotemporal entities Enhance equipment monitoring through the collection of telemetry data from vehicles involved in port operations Enhance functionalities of the 5G IoT GW to support 5G Non-Standalone and Standalone capabilities
	6	Enhance functionalities of the 5G IoT GW to support 5G Non-Standalone and Standalone capabilities Proprietary computer vision SDK, multiplatform, to rapid prototyping in a large variety of sectors, including Advanced Driver Assistance System (ADAS), security, inspection and HMI Enhance functionalities of the 5G IoT GW to support 5G Non-Standalone and Standalone capabilities Develop novel surveillance technologies and mechanisms
	8/9	Calculate the optimum speed for the automated truck platoon in the logistics corridor avoiding stop & go incident of the truck platoon Facilitate the quantification of CO_2 emissions
Hamburg	10	Calculate the optimum speed for the automated truck platoon in the logistics corridor avoiding stop & go incident of the truck platoon Facilitate the quantification of CO_2 emissions
	11	Calculate the optimum speed for the automated truck platoon in the logistics corridor avoiding stop & go incident of the truck platoon Facilitate the quantification of CO_2 emissions

Table 13: Summary of the impacts reported in D1.4 in relation to the micro-criteria

LL	UC	Labour market	Quality of life	Safety and security	Efficiency of traffic flow	Efficiency of operations	Resource optimization	Carbon emissions	Fuel/energy consumption
Athens	2				Traffic redistribution	Optimize port operations	Reduce empty containers	Extrapolate emissions	Reduce emissions
	3					Optimize port operations			
	4	Optimize human resources				Optimize port operations	Optimize human resources		
	5	Optimize human resources				Reduce vessels completion time	Optimize the use of human resources		
	7					Reduce costs	Improve the utilization of port warehouses		
Koper	1					Provision of 5G for the needs of port operations			
	5					Enhance equipment monitoring			
	6			Develop surveillance technologies					
Hamburg	8/9			Avoid stop & go incidents	Calculate optimum speed			Quantify CO_2 emissions	
	10			Avoid stop & go incidents	Calculate optimum speed			Quantify CO_2 emissions	
	11			Avoid stop & go incidents	Calculate optimum speed			Quantify CO_2 emissions	

Table 14: Description of the impacts reported in D4.2 and utilised in the impact matrix

LL	UC	4.3 impacts
Athens	2	Improved information and reduction of work stress for truck drivers Increased safety for port personnel within the port area Improved safety and working conditions inside the port with a reduction of the costs for potential incidents
	3	Increased safety for yard personnel with reduction of potential injuries and working stress Optimization of operations and risk management
	4	Increased safety of workers within the port area Increased security due to real-time monitoring Improvement of working conditions and real-time monitoring of potential risks for yard personnel
	5	Optimization of port procedure Improve effectiveness in monitoring

	7	Increased efficiency of the fleet of machineries Better and easier planning of yard activities Increased monitoring of the status of the yard fleet Increased effectiveness of the maintenance actions Increased service life of yard machineries with the reduction of costs for their maintenance More effective handling service for external transport and logistics companies Better working and safety conditions
Koper	1	Optimization of port operations Optimization of resource usage
	5	Operational optimization Higher security
	6	Reduction of downtimes Improvement working conditions
Hamburg	8/9	Reduce consumption and emissions Increase service lifetime of vehicles Optimize scheduling of the operational workforce Optimization of the infrastructure planning Increased capacity management Improved international cooperation Optimization of costs and time management Optimization of yard personnel and improvement of working conditions Improved quality of life in the urban
	10	Increase user satisfaction Optimization of infrastructure planning Compliance with net-zero carbon policies Optimization of traffic truck platooning Optimization of workflow Reduction of work stress and potential injuries Improvement of safety on the road network
	11	Reduction of costs for vehicles' usage Reduction of incidents Improved working conditions for personnel Improved planning of activities Optimization of traffic flow Increased quality of life for citizens and workers Compliance with sustainability policies

Table 15: Summary of the impacts reported in D4.3 and utilised in the impact matrix

LL	UC	Labour market	Quality of life	Safety and security	Efficiency of traffic flow	Efficiency of operations	Resource optimization	Carbon emissions	Fuel/energy consumption
Athens	2	Improvement of working conditions	Reduction of work stress	Increased safety					
	3			Increased safety		Optimize operations			
	4	Improvement of working conditions	Increased safety for workers	Increased safety and security					
	5					Optimization of port procedures			
	7	Better working conditions	Better working conditions	Better safety conditions		Increased Efficiency of the fleet			
Koper	1					Optimization of port operations	Optimization of resource usage		
	5			Higher security		Operational optimization			

	6	Improvement of working conditions	Improvement of working conditions						
Hamburg	8/9	Optimize scheduling and working conditions	Improvement of quality of life			Optimization of costs	Increase service lifetime	Reduce emissions	Reduce consumption
	10	Optimization of workflow	Increased user satisfaction	Improve safety	Optimization of traffic	Optimize infrastructure planning		Compliancy with zero-carbon policies	
	11	Improvement of working conditions	Improvement of quality of life	Reduction of incidents		Reduction of costs		Compliance with sustainability policies	

Table 16 shows the impact matrix in which we express the impact of each UC in relation to each criterion based on the D3.3 and D5.5 assessment.

Table 16: Impact matrix

	social			economy			environment	
UC	Labour market	Quality of life	Safety and security	Efficiency of traffic flow	Efficiency of operations	Resource optimization	Carbon emissions	Fuel/energy consumption
UC1K	0	0	0	0	2	1	0	0
UC2A	1	1	1	1	1	1	1	1
UC3A	0	0	1	0	2	0	0	0
UC4A	2	1	1	0	1	1	0	0
UC5A	1	0	0	0	2	1	0	0
UC5K	0	0	1	0	2	0	0	0

UC6K	1	1	1	0	0	0	0	0
UC7A	1	1	1	0	2	1	0	0
UC8/9H	1	1	1	1	1	1	2	1
UC10H	1	1	2	2	1	0	2	0
UC11H	1	1	2	1	1	0	2	

Regarding UC1, in Koper, the implementation of the system yields a positive impact on port operations, which results in the reduction of downtimes, contributing to a more streamlined and efficient workflow. Additionally, the system facilitates the optimization of resource usage within the port environment. By minimizing downtimes and maximizing resource efficiency, UC1 plays a pivotal role in enhancing overall operational effectiveness, ensuring a smoother and more productive functioning of the port.

In Athens, the primary aim of UC2 is to enhance the safety of port personnel while effectively monitoring traffic within the port, thus bringing tangible benefits for truck drivers and alleviating their stress by providing a more controlled and secure traffic environment. Simultaneously, port personnel experience increased safety, fostering improved working conditions overall. By addressing stressors and increasing safety, UC2 creates a more secure and conducive work environment for those involved in port operations.

In Athens, the UC3 focuses on elevating safety standards for yard personnel, with a dual emphasis on reducing potential injuries and alleviating working stress, extending its positive impact even to truck drivers. The optimization of operations and risk management contributes not only to enhanced safety but also to improved working conditions for all involved. This multifaceted approach underscores UC3 as a comprehensive system dedicated to the well-being of personnel and the efficient management of risks.

In Athens, the objective of UC4 is the improvement of working conditions through real-time detection of potential sources of risk events. By providing a proactive system for identifying and addressing risks, UC4 creates a safer and more secure work environment. The real-time nature of risk detection ensures timely intervention, minimizing the impact of potential threats on the well-being of port personnel and their working conditions.

In Athens, UC5 is geared towards optimizing port operations, directly impacting working conditions by reducing downtimes and streamlining container handling processes. The enhanced operational efficiency translates into a smoother workflow, contributing to a more conducive and stress-free work environment for the personnel involved in port operations. In Koper, UC5 introduces direct benefits that are twofold. Firstly, it contributes to operational optimization by addressing and mitigating downtimes, which ensures a more seamless and uninterrupted container handling process, ultimately leading to increased efficiency in port operations. Secondly, UC5 bolsters security measures through an improved detection system for damages. This enhancement in security protocols not only safeguards assets but also adds a layer of protection against potential risks, reinforcing the overall resilience of port operations.

In Koper, UC6 stands out as a comprehensive system designed to optimize port operations while enhancing safety and security within the port area. The primary benefits are the optimization and automation of security operations and procedures. The system introduces sophisticated processes that not only streamline security protocols but also automate certain aspects, reducing manual intervention and potential errors, which not only fortifies the security framework but also leads to greater operational efficiency. Moreover, the implementation of UC6 translates into improved working conditions for personnel. By automating routine security tasks and procedures, the system mitigates the need for manual, repetitive efforts, which results in a more favourable work environment for personnel, minimizing stress and potential risks associated with security-related tasks. The combined effects of operational optimization and improved working conditions underline UC6 as a pivotal contributor to the holistic betterment of port operations and safety standards.

UC7 focuses on increasing the efficiency of the fleet of machinery by mitigating negative externalities such as breakdowns and downtimes. This improvement allows for better planning of yard activities, contributing to cost reduction for maintenance operations. The increased monitoring of vehicle status not only enhances efficiency but also promotes better working and safety conditions by minimizing the effects of stressful situations commonly associated with unexpected machinery issues. UC7, therefore, emerges as a fundamental component in ensuring a more efficient and safer working environment within the port.

The implementation of UC8-9 in Hamburg, yields a multifaceted array of positive impacts. Firstly, it brings increased user' satisfaction by optimising infrastructure planning and enhancing capacity management, thereby fostering an environment conducive to improved international cooperation.

Moreover, the system increases operational efficiency, leading to the optimisation of cost and time management, which triggers a ripple effect through the optimisation of workflow, better alignment with internal and external operators and shippers, and an overall improvement in working conditions. The net result is a reduction in work stress and potential injuries. Furthermore, UC8-9 contributes to an elevated quality of life and work in urban areas, aligning seamlessly with sustainability goals.

Regarding UC10, in Hamburg, the primary anticipated impacts consist of emissions and vehicle consumption reduction. Real-time data collection from vehicles not only enhances the synchronisation of port operations but also positively impacts the working conditions for personnel.

In Hamburg, the main impacts of UC11 regard the optimisation of resources and processes within the port area, manifesting in cost reduction for vehicle usage and incidents, contributing to improved working conditions for personnel. Extending its influence beyond the port, UC11 actively seeks the optimisation of traffic flows within urban areas. The overarching goal is to enhance the quality of life for citizens and workers by reducing congestion and pollution, all while ensuring compliance with sustainability policies and requirements.

5.1.6 Results of the multicriteria analysis

In this section, we describe the results of the multicriteria analysis. Based on the results discussed in D1.4, we decided to implement the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) methodology. TOPSIS is a popular approach which consists of evaluating the distance with ideal solutions (Garg et al., 2023). We implemented the multicriteria evaluation using the impact matrix defined in the previous chapter and the Python library pymcdm proposed by Kizielewicz et al., 2023.

Table 17: Equal weights scenario

UC	ranking	pref
8/9H	1.0	0.690983
2A	2.0	0.648371
10H	3.0	0.572949
11H	4.0	0.538692
4A	5.5	0.500000

7A	5.5	0.500000
5A	7.0	0.395644
1K	8.0	0.366025
6K	9.0	0.343070
3A	10.5	0.309017
5K	10.5	0.309017

The analysis is performed with an equal consideration of weights for all micro criteria. Table 16 shows that UC8/9 of Hamburg has the highest social, economic, and environmental impacts, followed by UC2 of Athens and UC10 of Hamburg, which means that the considered documents (D1.4 or D4.3) mentioned the social, economic, and environmental micro-criteria. The highest rank of UC8/9 of Hamburg is because the reduction of CO_2 emissions, a micro-criterion of the environmental macro-area, is mentioned in D1.4 and D4.3. The UCs of Koper are in the lowest positions of the ranking, thus having a low impact for most of the micro-criteria. The UCs demonstrated in Koper allow for increased efficiency and optimise resources but have no social and environmental impacts reported in D1.4 or D4.3. Their focus on 5G suggests the need for measuring their impact on society, the economy, and the environment in a longer time horizon.

Table 18: Weights of each scenario

Micro-criteria	Weights of Social scenario	Weights of Economic scenario	Weights of Environmental scenario
Labour market	0.25	0.05	0.04
Quality of life	0.25	0.05	0.04
Safety and security	0.25	0.05	0.04
Efficiency of traffic flow	0.05	0.25	0.04
Efficiency of operations	0.05	0.25	0.04
Resource optimization	0.05	0.25	0.04
Carbon emissions	0.05	0.05	0.38
Fuel/energy consumption	0.05	0.05	0.38

The multicriteria analysis was implemented by assigning different weights to the micro-criteria. The sum of all weights is always 1. In each scenario, the weights reflect the relevance of the micro-criteria. For instance, in the social scenario, the sum of the micro-criteria labour market, quality of life and safety and security is 0.75. In the environmental scenario, the weights' sum of carbon emissions and fuel/energy consumption micro-criteria is 0.76. Table 18 presents an overview of the weights assigned in each scenario.

Table 19 shows the ranking results of the social scenario in which the labour market, quality of life and safety and security micro-criteria have higher weights. In this case, the UC10 and UC11 of Hamburg are in the first and second position of the ranking because they positively impact the labour market and increase quality of life and D1.4 and D4.3 both describe their impact on safety and security. UC4 of Athens is in the third position because it impacts the labour market, quality of life and, to a lesser extent, Safety and security. The UCs demonstrated in Koper are again at the bottom but in a different order. Although UC6 in Koper impacts the labour market, quality of life and safety and security, it does not generate benefits to the economy and environment.

Table 19: Social scenario

UC	Ranking	pref
10H	1.0	0.724018
11H	2.0	0.719813

4A	3.0	0.711000
8/9H	4.0	0.639757
2A	5.0	0.635424
7A	6.0	0.614846
6K	7.0	0.594131
5A	8.0	0.271747
3A	9.5	0.257548
5K	9.5	0.257548
1K	11.0	0.138026

Table 20 shows the ranking of the economic scenario in which UC8/9 has the highest impact because it allows to optimise resources, increase efficiency of operations and reduce traffic flow. Overall, according to D1.4 and D4.3, UC8/9 generates positive impacts on all micro-criteria. The next UCs in the ranking are the three in Athens UCs (UC2, UC7 and UC5). UC2 impacts all micro-criteria and, for this reason, has a similar preference value as the one of UC8/9 (0.63). In the lowest positions of the ranking are the two UCs demonstrated in Koper LL (UC5 and UC6), among which only UC5 allows for increased efficiency of operations. Surprisingly, the Hamburg UC11 is second last in the raking because, according to D1.4 and D4.3, it enables traffic flow and operations' efficiency but does not allow to optimise resources.

Table 20: Economic scenario

UC	ranking	pref
8/9H	1.0	0.639757
2A	2.0	0.635424
7A	3.0	0.577788
5A	4.0	0.567232
1K	5.0	0.563508
10H	6.0	0.507464
4A	7.0	0.500000
3A	8.5	0.405551
5K	8.5	0.405551
11H	10.0	0.389326
6K	11.0	0.122131

Table 21 shows the ranking of the environmental scenario in which UC8/9 has the highest impact with an increased value of the preference function from 63-72 of the social and economic scenarios to 0.93, thus demonstrating a strong preference of this UC in terms of CO_2 reduction, compared to the other UCs. It follows UC2 in Athens, which also enables fuel consumption reduction. In the lowest positions of the ranking, the UCs demonstrated in the port of Koper. For these UCs, D1.4 and D4.3 do not report any impact on the environment or on fuel consumption.

Table 21: Environmental scenario

UC	Ranking	pref
8/9H	1.0	0.931254
2A	2.0	0.689152
10H	3.0	0.502695
11H	4.0	0.501351

4A	5.5	0.121786
7A	5.5	0.121786
5A	7.0	0.099632
1K	8.0	0.094298
6K	9.0	0.082812
3K	10.5	0.076003
5K	10.5	0.076003

Overall, it is possible to conclude that the UCs demonstrated in the 5G-LOGINNOV have different potential impacts depending on the macro-criteria. The H8/9 of Hamburg LL and UC2 of Athens enable the highest economic and environmental impact. The UC10 and UC11 of Hamburg have the highest economic impact while the UCs demonstrated in Koper, have the lowest.

6 EVALUATION OF THE HAMBURG LL

In this chapter, we evaluate Hamburg LLs which deal with emissions monitoring and vehicles' platoons. Vehicles on the road can cooperatively form a platoon-based driving pattern, in which a vehicle follows another vehicle and maintains a small and nearly constant distance from the preceding vehicle (Jia et al., 2016). In the literature, Hall and Chin (2005), Jia et al. (2016), Piacentini, et al. (2021), van Arem & Visser (2006) show that platoons can bring several benefits. First, the platoon pattern can considerably reduce exhaust (GHG) emissions because streamlining vehicles in a platoon can minimize air drag. The results of field experiments indicate following trucks in a platoon may obtain a fuel-saving rate between 5% and 20% (Al Alam et al., 2010, Bonnet & Fritz, 2000, Browand et al., 2004, Han et al., 2022), Robinson et al., 2010). In addition, since vehicles in the platoon are much closer to each other, the road capacity increases, while the traffic congestion decreases accordingly. Moreover, with the help of advanced technologies, driving in a platoon can be safer and more comfortable. Finally, platoons can facilitate cooperative communication applications due to the relatively fixed vehicles' mutual positions, which may improve networking performance.

Several recent works on intelligent transportation systems and connected vehicles look at platoons as an effective mechanism to reduce the impact of transport on the environment and to improve safety see Hall & Chin (2005), Jia et al. (2016), Piacentini et al. (2021), van Arem et al. (2006). In Pi et al. (2023), the authors review the energy-saving methods for platoons and distinguish between those based on the characteristics and aerodynamics of the vehicle and those methods based on acceleration and deceleration patters of vehicles. Several works focus on platoons driving on highways separated by a few meters' distance. These works estimate a fuel-saving rate included between 5% and 20% thanks to the reduced aerodynamic drag. In the context of the European project PROMOTE-CHAUFFEUR, see Bonnet & Fritz (2000), the authors showed that two trucks driving at 80 Km/h at 10 meters' distance consume 21% less fuel compared to trucks driving isolated. Similarly, the PATH program (Partners for Advanced Transit and Highways) project showed that two trucks driving at 3/4 meters' distance reduces about 11% of fuel consumption (Browand et al., 2004). In similar research Al Alam et al. (2010) show a reduction of 4.7-7.7% of fuel consumption when two trucks travel in a platoon at 70 Km/h. The SARTRE European project demonstrated that vehicles driving in platoons save up to 20% of fuel (Robinson et al., 2010). Such reported variability is the result of many factors affecting platoons' performance. The work of Knoop & Van der Meer (2019) analyses platoon formation over 500 Km road demonstration (mainly on highways). This work analyses multiple metrics (e.g., vehicles' speed, number of vehicles, distance, traffic) and their impact on the platoon.

Given the potentiality of platoons to reduce fuel consumption and GHG emissions, several works propose mechanisms to support platoons' formation. From an algorithmic perspective, the work of Sokolov & Karbowski (2017) proposes a coordination approach of platoons to optimise departure times and routes. Similarly, De Rango & Fazio (2019) present coordination and communication protocols supporting optimal platoon formation. In Lesch & Krupitzer (2021), the authors present an overview of platoons' management and formation approaches: the creation of platoons, inter-platoon interaction and interaction between the traffic and the platoon. Such coordination mechanisms are at the basis of the

Grand Cooperative Driving Challenges (Englund & Didoff, 2016), which comprises vehicles' platoon formation and merge and vehicle coordination at intersections and in (e.g., emergency) situations.

From a technological perspective, several research projects deal with communication infrastructures enabling vehicle coordination to support platoon formation. The COMPANION EU project (Eilersand et al., 2015), Energy ITS (Tsugawa, 2013), KONVOI (Kessler et al., 2006), PATH (Shladover, 2007), CHAUFFEUR (Gehring & Fritz, 1997) are all projects dealing with the development of such infrastructures.

Most of the works in the literature analyse platoons' behaviour on highways or simulations and demonstrate different strategies to optimize platoons' distance, speed, or dynamics, especially at intersections. Very few studies show the behaviour of a platoon in urban traffic. One of the main issues related to platoons in urban traffic is maintaining a constant distance between vehicles, especially at traffic lights or intersections.

When the platoon needs to reassemble, vehicles need to accelerate to reach the other platoon members, thus increasing consumption, CO_2 emissions and reducing safety. Nevertheless, platoons in urban traffic can be very valuable as the benefits of platoon patterns are exacerbated in urban areas (e.g., local impact of GHG emissions, traffic congestion, and safety).

One of the most relevant topics in urban settings is platoon management and formation. The creation process of platoons in urban areas can be complex because of speed limits, traffic lights, intersections, etc. In Hardes & Sommer (2019), the authors present a strategy for dynamic platoon formation at traffic light intersections and claim that being in a platoon allows saving 15% of fuel and 14% of travel time. In this context, one of the most investigated issues is the impact of traffic lights on platoons. Specifically, some works develop coordination mechanisms to allow the platoon to find the green light at intersections so that the platoon is not disconnected. In this regard, Faraj et al. (2017) proposes an optimisation scheme that allows minimizing the stop-and-go at intersections and determining whether it is efficient to be in a platoon. In this chapter, we analyse this problem from a data-science perspective. We create a model to evaluate the impact of different road features (e.g., traffic lights, intersections, turns) on the platoon behaviour and efficiency (especially in terms of platoon's cohesion - measured by inter-vehicle distances, and CO_2 emissions). In this context, our results could provide further motivations and scenarios for the coordination mechanisms presented in the literature.

Another important area of work is platoon routing. In the literature, this problem often refers to the combinatorial optimisation problem to coordinate a fleet of vehicles, each with its own origin and destination schedule, to reach all the intended destinations while minimizing costs (Kammer, 2013). We address platoon routing from a different perspective. We consider a single origin-destination journey and develop a mechanism to optimize the route to avoid those road features and manoeuvres (e.g., traffic lights and right turns at intersections) that can disperse the platoon (as measured by the model we developed). Therefore, our approach can serve as a micro-routing strategy to enrich the coordination and optimisation algorithms.

Overall, we propose and evaluate a methodology to analyse the behaviour of a platoon in urban traffic, focusing on platoon cohesion, fuel consumption and CO_2 emissions. The analysis deploys data collected during tests performed in Hamburg LL.

6.1 Data and methods

We collected data about vehicles' platoons driving in the city of Hamburg. Test drives involved platoons of 3 and 6 vehicles driving in a close circuit across the city. For each test drive, collected data consists of telemetry information of each vehicle, sampled every second, i.e., at 1 Hz, and comprise: Timestamp, Latitude, Longitude, Speed (m/s), Acceleration (m/s2), CO_2 (kg) and Fuel consumption (l). In addition, we extracted road features encountered during the path: four-ways intersections - FW, curves - C, road immissions - RI, traffic lights - TL, and left and right turns - LT, RT.

On the basis of this information, we created a dataset as in Figure 6.

TIME	VEHICLES	DIST (m)	PREV_DIST (m)	CO2 (Kg/s)	FW	C	RI	TL	LT	RT
13/9/2022 9:00	V1-V2	10	12	1.5	0	0	1	0	0	0
13/9/2022 9:01	V1-V2	9.9	10	1.5	0	0	1	0	0	0
...	...	...	...	...	...	...	...	...		

Figure 6: Structure of the data to analyse the impact of road features on the platoon.

For each couple of vehicles in the platoon, we compute inter-vehicle distance at current and previous time stamps (DIST and PREV_DIST, respectively). The current CO_2 emission for the trailing vehicle (CO_2), and Boolean variables stating if the couples have a given road feature in the proximity (at less than 50 meters). These variables generally represent the platoon cohesion (DIST), the CO_2 emissions and the road features being encountered.

6.2 Experimental Setup

The experiment was implemented along the Test Field for Automated and Connected Driving (TAVF) which is located in the northern section of Hamburg. The TAVF is funded by the Federal Ministry of Transport and Digital Infrastructure and consists of 37 traffic lights and a bridge with V2X technology. The test track has several types of intersections and underpasses that could be a challenge for radio communication. The TAVF test drive connects many points of interest such as the Hamburg exhibition hall to the long-distance railway station. Furthermore, the urban area has heavy freight traffic created by the 9 million TEU per year inner-city port. The goal of TAVF is to test and demonstrate Intelligent Transport Systems (ITS) technologies in real traffic conditions.

The test drives were carried out in March 2021 and September 2022 in heavy traffic periods and featured platoons of 3 and 6 vehicles. The test path is about 7.7Km across urban areas featuring traffic lights, intersections, curves, turns, road immissions and the general urban traffic. Compared to highways demonstration, in urban area, the lead vehicle had to follow all traffic rules, while the other vehicles in the middle had to follow the preceding platoon member. In some cases, platoon's members had to react faster to reach the other vehicle, or the platoon was disassembled because of traffic light or congestion. The vehicles tried to keep a distance of about one meter, but that distance was difficult to keep, especially when there were curves.

Test vehicles were equipped with an ISO-23795 compatible smartphone app called Low Carbon Mobility Management (LCMM) developed by T-Systems. The application measures fuel consumption and CO_2 emissions. The measurement is performed by considering several forces of the vehicle such as acceleration, breaking, aerodynamics, rolling function and gradient. Furthermore, the speed and height are measured thanks to GPS data. Finally, the standard configuration parameters of the vehicle are considered. Based on the tests performed by T-System, the LCMM is able to provide the correct measurement of the fuel consumption in 90\% of the times, compared to the one provided by the Controller Area Network CAN bus of the vehicle.

The team of drivers was connected to each other via conference call, thus being able to exchange information along the trip.

6.3 Dataset

The final dataset consists of telemetry information of each vehicle collected with 1 Hz resolution. The 3-6 vehicles were named by the initials of their drivers (PS, JC, RW, DW, AA, AK). PS being the leading vehicle, AK the trailing one). For each vehicle the data consists of: Timestamp, Latitude, Longitude, Speed (m/s), Acceleration (m/s2), CO_2 (kg) and Fuel consumption (l) plus a number of other features about forces sensed by the car that were not analysed. We enriched the dataset by computing a derived feature representing the inter-vehicle distance in the platoon. Since the objective of the platoon's members is to keep a fixed short distance between each other, measuring the distance between vehicles allows to evaluate where and how much the platoon needs to disassemble because of traffic lights or intersections. The procedure to measure the distance between a couple of platoon's members consists of initially considering the position of the platoon leader at time P_{1t}. Then, the *n* nearest neighbour observations of the first follower vehicle, P_2 are considered such that the timestamp is greater than the time stamp of P_1 ($P_{2t+1,t+2,...t+n} > P_t$). Next all the distances between P_1 and the *n* nearest observations of P_2 are measured and the closest observation of P_2 is selected. This procedure is repeated between the nearest P_2 > (nearest to P_1) and P_3 until all vehicles are considered. The output is a list of arrays of distances of the platoon in different times and location of the test drive.

Overall, this dataset is the starting point of the reported analysis. Figure 7, Figure 8, and Figure 9 describe the data as the basis of this work. Figure 7 shows the CO_2 instantaneous emissions together with road features over a test drive for an exemplary vehicle (JC). It is possible to observe that CO_2 emissions have an extremely non-linear behaviour. Spikes in the CO_2 emissions are often associated with encountering road features that force manoeuvres on the car. Figure 7 (right) zooms on the above time series focusing on a specific episode: the car crosses a 4-way intersection with a traffic light, and later, a curve leads to another 4-way intersection. In both cases, the car has to steer and accelerate to maintain the platoon increasing CO_2 emissions.

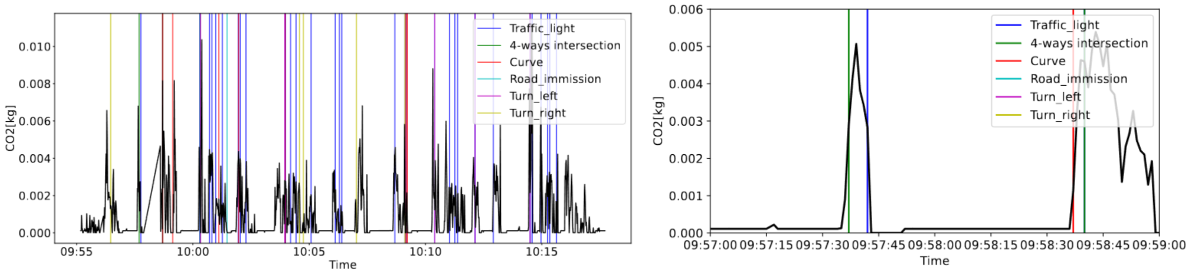


Figure 7: Analysis of CO2 instantaneous emissions together with road features for a vehicle.

Figure 8 shows the cumulative CO_2 emissions for all the vehicles. Overall, each vehicle emits about 1 Kg of CO_2 while driving. However, the time series has nonlinearities, and different vehicles have different emissions. Figure 9 shows the almost perfect correlation ($R2 \approx 1$) between CO_2 emissions and fuel consumption. Therefore, optimizing for one equal optimizing for the other.

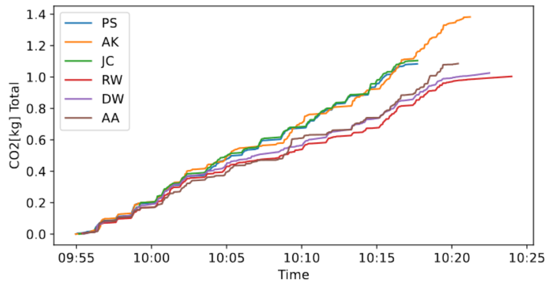


Figure 8: Cumulative CO2 emissions for all the vehicles during a test drive.

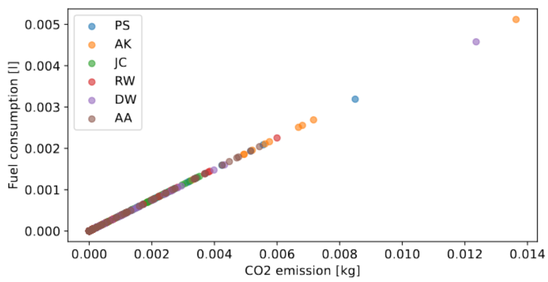


Figure 9: Correlation between CO2 emissions and fuel consumption

Figure 10 (A) shows inter-vehicle distances for all the following couples in the platoon (PS-JC, JC-RW, RW-DW, DW-AA, AA-AK). At about 10:05 AM, the platoon splits into two vehicles so that PS and JC get separated from the rest (PS and JC move forward, while RW, DW, AA, AK remain behind). Figure on the right zooms on the episode: a left turn and a traffic light seem to cause vehicles' separation. Figure 10(B-C) shows inter-vehicle distances for the two split groups (PS and JC) and (RW, DW, AA and AK). The right part of the figure zooms on a specific episode of the time series.

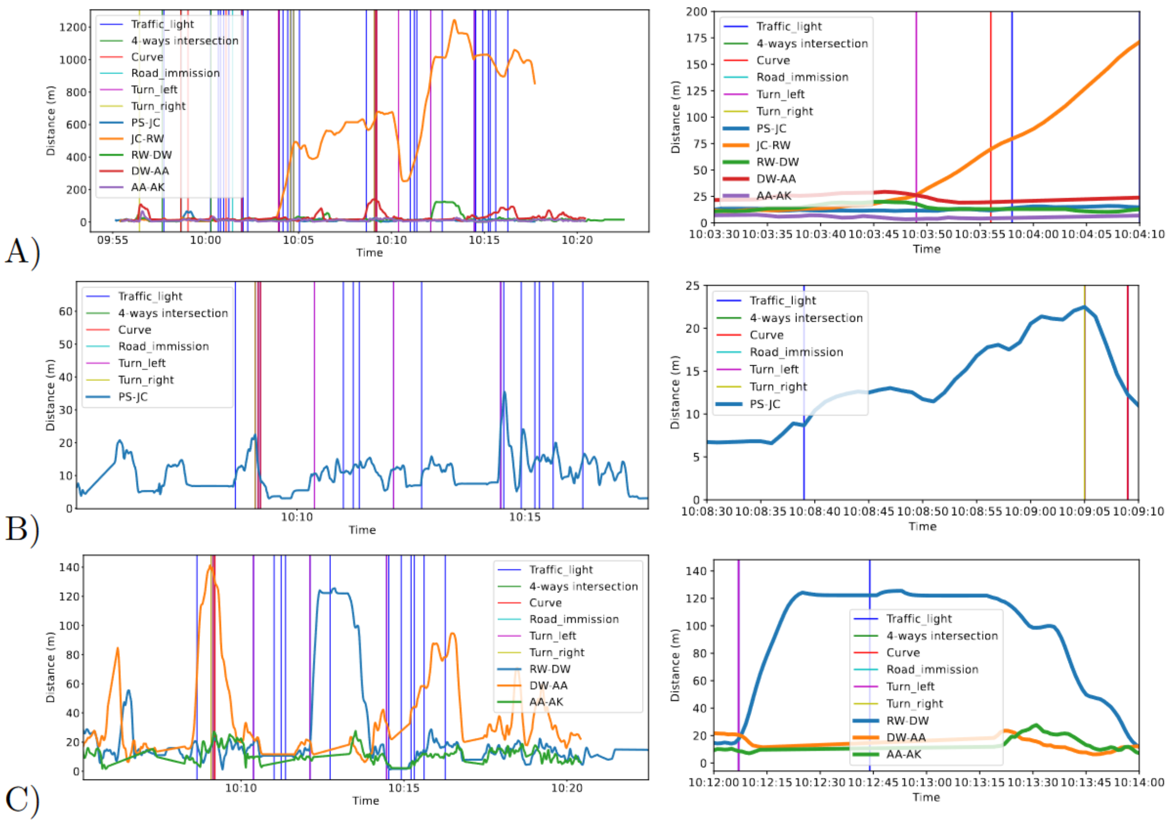


Figure 10: Analysis of inter-vehicle distances over a test drive.

In general, this preliminary analysis hints at the impact of road features on CO_2 emissions (and thus fuel consumption), and inter-vehicle distances. A better understanding of this relationship is at the basis of our work.

6.4 Understanding the impact of road features on the platoon

In this section, we describe how we assessed the impact of the infrastructure and route on the distance between the platoon's members and CO_2 emissions. The general idea is to create a regression model to explain inter-vehicle distance and CO_2 emissions by means of the encountered road features. This will allow to understand the likely impact of a traffic light or a left/right turn on vehicles' behaviour.

To set up the independent variables of the regression model, for each couple of vehicles, we computed road features (i.e., four-way intersections - F W, curves - C, road immissions - RI, traffic lights - T L, and left and right turns - LT, RT) encountered at each time step. These are modelled as dummy variables having value 1 the feature is in front of the vehicle at a distance of less than 50 meters, 0 otherwise. Moreover, we considered the inter-vehicle distance in the previous time steps (PREV_D). These variables generally represent the features being encountered and the platoon formation. As a dependent variable, we assumed the inter-vehicle distance between platoon members (DIST) and the measures CO_2 emission. Overall, we obtained the following regression equations:

$$DIST = \gamma_1 * FW + \gamma_2 * C + \gamma_3 * RI + \gamma_4 * TL + \gamma_5 * LT + \gamma_6 * RT + \gamma_7 * PREV\_D$$

$$CO_2 = \beta_1 * FW + \beta_2 * C + \beta_3 * RI + \beta_4 * TL + \beta_5 * LT + \beta_6 * RT + \beta_7 * PREV\_D$$

Figure 11: Regression function

The results of this regression (i.e., the regression coefficients) allow to understand the impact of different road features on the distance between platoon members and the CO_2 emission. Separately, we tried to compute the impact of the length of the drive on CO_2 emissions. Specifically, we isolated parts of the drive without any road feature and compute average CO_2 emissions in those segments. The result $\alpha = 0.1$ is the average CO_2 emissions per Km without the impact of the previous features. This is in line with data available online assessing CO_2 emissions per Km for different vehicles around 100g per Km, see EEA report (2019). The idea is that, while the regression analysis analyses the impact of road features, this simple mean captures the contribution of the travelled distance.

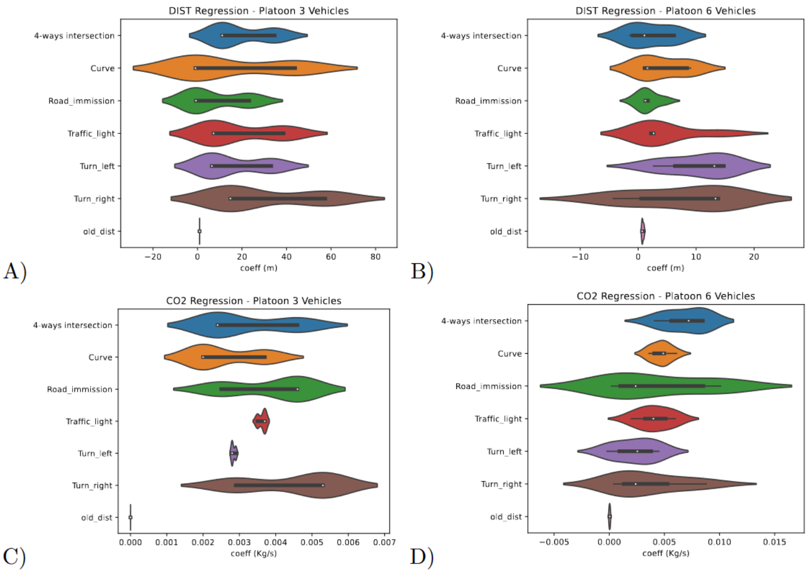


Figure 12: Distribution of values of regression coefficients.

Figure 12 shows overall distribution of values of all the regression coefficients. A) and B) are DIST regression coefficients for 3 and 6 vehicles' platoons respectively. C) and D) are CO_2 regression coefficients for 3 and 6 vehicles' platoons respectively.

6.5 Data-driven routing for platoons

On the basis of the results of the above part, we developed routing mechanisms to optimise inter-vehicle distance and CO_2 emissions by avoiding those road features (e.g., traffic light, right turns) affecting negatively the platoon formation. Standard routing approaches, based on assigning weights to the road graph, cannot be directly applied in this context as they do not typically have separate weights for different turns at intersection (intersections are typically vertices of the road graph and weights are typically assigned to the segments leading/departing from the vertex without differentiating between turns or crossings). Therefore, our approach is based in three steps:

- a candidate set of N routes was generated using standard Dijkstra algorithm (i.e., the set of N shortest different routes).
- For each route, we compute its weight in terms of:
  - inter-vehicle distance in the platoon by using the number of road feature being encountered multiplied by the regression coefficient being obtained in inter-vehicle distance regression:
    $DIST = \gamma_1 * FW + \gamma_2 * C + \gamma_3 * RI + \gamma_4 * TL + \gamma_5 * LT + \gamma_6 * RT + \gamma_7 * PREV\_D$

- ○ CO_2 emissions by using the number of road feature being encountered multiplied by the regression coefficient being obtained in CO_2 distance regression and the average CO_2 emissions (computed separately without road features) multiplied by the path length.
  $CO_2 = \beta_1 * FW + \beta_2 * C + \beta_3 * RI + \beta_4 * TL + \beta_5 * LT + \beta_6 * RT + \beta_7 * PREV\_D + \alpha * PATH\_L$
  It is worth noticing that this last term $\alpha * PATH\_L$ is used only in CO_2 computation as the amount of CO_2 is a naturally additive measure, thus strongly depends on overall path length.
- Then, we take the route minimising either inter-vehicles distance (DIST) or CO_2 emissions.

In order to run our routing mechanism, we downloaded from Open Street Map the map of Hamburg. We identified and geo-localized road features (i.e., four-ways intersections, curves, road immissions, traffic lights) on the basis of OSM files. Then, after standard shortest-path routing, we derived road features (i.e., left and right turns) Then, we conducted experiments both on real and simulated data to test the behaviour of the routing mechanism.

As a first validation step, we applied the weighting part of the routing mechanism to the test drives being collected. The goal is to verify whether the routes weight both in terms of inter-vehicle distance and CO_2 emissions are in line with collected data. Figure 13 shows the results of this experiment. Basically, this figure is the analogous of Figure 7, Figure 8 and Figure 10A using modelled data (coming from the routing algorithm) instead of the real one. It is possible to see that all the results are in line with real data. CO_2 and inter-vehicle distance exhibit spiky patterns corresponding with different road features being encountered. This analysis shows that the weighting mechanism of the routing algorithm provides results in line with experimental data.

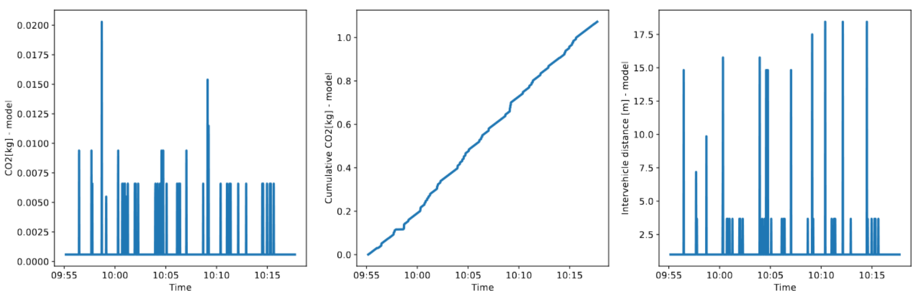


Figure 13 : Model results.

Then we compare the performance of shortest-path routes and routes optimising for inter-vehicle distance and CO_2 emissions. We show that the proposed approach allows to improve platoons' cohesion by 12%, using the inter-distance optimized route instead of the shortest-path route, and reduce CO_2 emissions by 5%, using the CO_2 emissions' optimized route instead of the shortest-path route.

6.6 The Impact of Road Features on the Platoon

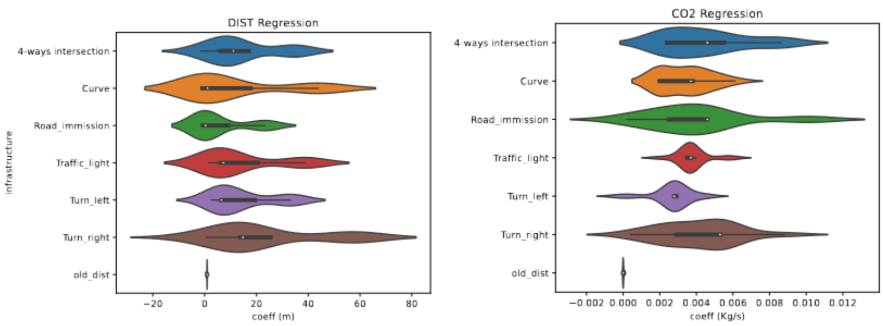
Then we created regression models to analyse the impact of road features (and previous inter-vehicle distance) on current inter-vehicle distance and on CO_2 emissions. Figure 14 shows an example of the results of the linear regression for a test drive of a platoon of 3 vehicles (former 2 columns) and a platoon of 6 vehicles (latter 2 columns). Columns 1 and 3 use inter-vehicle distance (DIST) as the target variable, and columns 2 and 4 use CO_2 emissions as target variables. Focusing on inter-vehicle-distance regression, we have $R^2 > 0.7$ for both test drives, and almost all independent variables are significant, except for Curve (C) and Road immission (RI) in the 6-vehicles test drive. These results indicate a clear impact of road features on the platoon's cohesion (measured by inter-vehicle distance). For example, left turn (LT) and right turn (RT) are typically associated with an increase of inter-vehicle distance of about 4.371 meters and 7.895 meters for the selected 3 vehicles test drive and 14.773 meters and 13.829 meters for the selected 6 vehicles test drive.

	3 Vehicle platoon		6 Vehicle platoon	
FEAT	DIST	CO2	DIST	CO2
FW	5.218***	0.003***	6.186**	0.008***
	(1.541)	(0.001)	(2.869)	(0.001)
C	5.157***	0.001	1.123	0.005***
	(1.487)	(0.001)	(1.816)	(0.001)
RI	9.430***	0.010***	1.242	0.010***
	(1.152)	(0.001)	(1.878)	(0.001)
TL	5.887***	0.002***	2.677***	0.006***
	(0.544)	(0.000)	(0.409)	(0.000)
LT	4.371**	0.002**	14.773***	0.004
	(1.715)	(0.001)	(4.969)	(0.003)
RT	7.895***	0.004***	13.829***	0.009***
	(1.399)	(0.001)	(1.254)	(0.001)
PREV_DIST	0.610***	0.000***	0.694***	0.000***
	(0.025)	(0.000)	(0.020)	(0.000)
Observations	911	911	1,310	1,310
R^2	0.760	0.558	0.772	0.580
Adjusted R^2	0.758	0.554	0.771	0.578
Residual Std. Error	8.653	0.004	9.932	0.005
F Statistic	409.122***	162.914***	629.556***	257.050***

Note: *p<0.1; **p<0.05; ***p<0.01

Figure 14: Summary of regression results for multiple platoons' driver.

Similarly, the fact that the coefficient associated to PREV_DIST is less than 1 shows that drivers try to catch-up with forward vehicle in absence of other road features. Focusing on CO_2 regression, The R^2 is greater than 0.5 and the only variable which is not significant is C for the 3 vehicles test drive, and LT for the 6 vehicles case. These results indicate a clear impact of road features on platoon CO_2 emissions. For example, when the platoon encounters a right turn the CO_2 emission increase by 0.0040 Kg/s on average (0.009 Kg/s in the 6 vehicles case). For context, we computed that the average CO_2 emissions per Km without the impact of the previous features computed over segments of the path that do not present any features is 0.1 Kg/Km. This is in line with data available online assessing CO_2 emissions per Km for different vehicles around 100g per Km, see EEA (2019). Therefore, the impact of road features is rather significant.



FEAT	AVG. DIST COEFF.	AVG. CO2 COEFF.
FW	14.226844	2.21060
C	11.905875	4.26728
RI	6.016369	1.63860
TL	14.301731	4.71094
LT	14.338138	10.34392
RT	23.148687	7.44626
PREV_DIST	0.910150	0.80110

Figure 15: Distribution and mean of the regression coefficients over all test drives.

Figure 15 shows a summary of all the regression results for multiple platoons' drives (17 test drives in total). The figure (violin plots) shows the distribution of the values of coefficients, the Table below reports their average. Of course, there is some variability depending on traffic and, for example, whether the platoon encountered a green or red traffic light, however, results show that regression coefficients are rather stable over multiple drives. This shows robustness of the analysis and the fact that road features have similar impact always, at least in our experimental set-up.

6.7 Platoon Route Optimisation

Overall, the above results indicate that road features encountered by the platoon have a strong impact on its performance, therefore it could be valuable to optimize the route taking into account such features. We developed a routing algorithm weighing the road features analysed above (four-ways intersections - FW, curves - C, road immissions - RI, traffic lights - TL, and left and right turns - LT, RT) according to their impact in platoon cohesion and CO_2emissions (see section Methods). Then, we conducted experiments both on real and simulated data to test the behaviour of the routing mechanism. To understand then potential benefits of our approach we developed a simulation framework to evaluate routing impact of multiple origin destination (O-D) paths. We randomly selected 500 O-D points in the urban setting of Hamburg and computed platoon routes between them. Specifically, for each O-D, we computed shortest-path, minimum inter-vehicle avg. distance, and minimum CO_2 emissions routes.

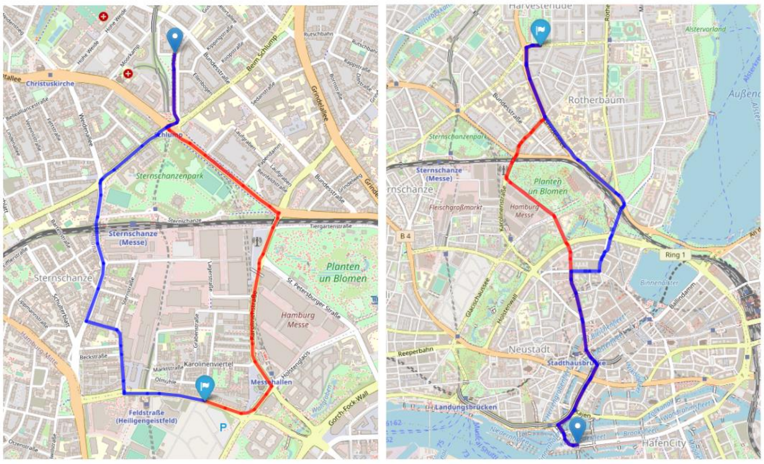


Figure 16: Example of shortest-path (red) and minimum CO2 emissions (blue) routes.

Figure 16 shows the result of a specific O-D pair. minimum inter-vehicle avg. distance, and minimum CO_2 emissions routes can be longer than the shortest-path one, because they try to avoid road features that disrupt the platoon formation, thus improving on inter-vehicle distance and CO_2 emissions.

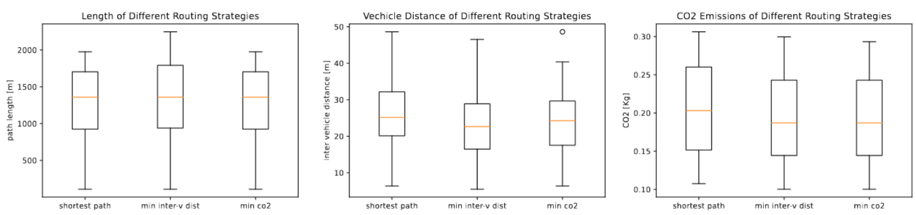


Figure 17: Performance comparison of different routing strategies

Figure 17 presents comparison among different routing strategies: shortest path, the path minimizing inter-vehicle distance, the path minimizing CO_2 emissions. We analyse the performance in terms of path length, average inter-vehicle distance, average CO_2 emissions. From the boxplots, it is possible to see that the routing algorithm allow to optimise for inter-vehicle distance and CO_2 emissions without significantly affecting the length of the path. Results show that the proposed approach allows to improve platoons' cohesion by 12%, using the inter-distance optimized route instead of shortest-path route. Such improvement happened in 26% of the routes, in the other cases, there is no improvement. Similarly, our approach reduces CO_2 emissions by 5%, using the CO_2 emissions' optimized route instead of shortest-path route. Such improvement happened in 10% of the routes, in the other cases, there is no improvement. It is worth noticing that optimizing CO_2 over the shortest path route is very difficult as vehicles additively emit more CO_2 as they travel (0.1 Kg/Km as discussed above).

This approach produces best results over short paths. This is rather expected as in short paths the impact of road features is very relevant. In longer paths the CO_2 emissions simply related to driving longer distances dominates. This result shows that the proposed approach is particularly suited for short urban platoons.

6.8 Discussion

Platoon driving holds significant promise for CO_2 reduction in urban settings, making it a crucial consideration in sustainable transportation strategies. In congested urban areas, where traffic flow inefficiencies and stop-and-go patterns prevail, platoon driving can bring about remarkable fuel efficiency gains. By harnessing vehicle-to-vehicle communication, platoons can maintain consistent speeds, optimize braking, and coordinate lane changes, leading to a smoother and more synchronized traffic flow. Moreover, with the integration of electric and hybrid vehicles within platoons, the CO_2 savings can be further augmented, as the energy usage of eco-friendly automobiles is optimized when employed in such formations. As the scientific community continues to emphasize the urgency of mitigating climate change, urban planners, policymakers, and researchers must recognize the vital role of platoon driving in achieving CO_2 reduction targets and fostering sustainable urban mobility. Further advancements in technology, infrastructure, and collaboration between various stakeholders are necessary to fully realise the potential of platoon driving as an effective tool in the fight against urban carbon emissions. In this work we presented a novel approach to analyse the behaviour of a platoon in urban traffic and understand the impact of road features on platoons' cohesion and CO_2 emissions. On this basis, we created a data-driven approach to optimize platoon routes across an urban traffic in order to optimize platoon-based driving pattern and sustainability. Results indicate that platoon optimized routes can improve cohesion by 15% and reduce CO_2 emissions by 16% on average. Naturally, to create a complete solution, the results of the analysis and the routing algorithm, have to be integrated in an intelligent transportation system' architecture. The simplest case is related to a "statically-configured" platoon in need to traverse a predefined path. In this case the proposed method can be executed off-line, and vehicles' systems can be set with the proper route. A much more challenging and interesting scenario consists of dynamically and opportunistically create the platoon on the basis of vehicles' independent destination. For example, a group of vehicles targeting different destination could decide to join in a platoon for a part of their paths (Hardes & Sommer (2019); Kammer (2013); Larson et al.). Autonomous vehicles' coordination would be the primary application scenarios for these algorithms (see Gong and Du, 2018). In this context, it is fundamental to understand design decision related to vehicles' interactions and communication. In traditional platooning approaches, each vehicle adopts an On-Board Unit (OBU) operating independently and responsible for reading sensors data, deciding which manoeuvre to initiate and transferring to neighbouring vehicles through Vehicle-to-Vehicle (V2V) or Dedicated Short Range Communication (DSRC) technologies using for example Cooperative Awareness Messages (CAMs) in Europe and Basic Safety Messages (BSMs) in USA. As properly highlighted in Quadri et al. (2020), on the one hand the main benefit of a fully distributed V2V solution is that it is not dependent on any network infrastructure at all allowing vehicles to build and participate to platoons and communicates. On the other hand, these approaches have some disadvantages mainly related to the absence of a central management node that can affect scheduling policies in particular if combined with interference between vehicles, the contention of communication channels and the management of longer platoon. Furthermore, the missing presence of a coordination node can also limit the introduction of new orchestration algorithms focused for example to enhance optimization (e.g., the environmental impact), learn from urban data, integrating multiple data sources and dynamically reacting to events (e.g., the split of a platoon in two sub-groups). Recently, the diffusion of Cellular-controlled V2V (like LTE-V2V) and in particular the introduction of Multi-Access Edge Computing (MEC) (Porambage et al., 2018) technologies combined with the standardization effort of ETCI MEC (Sabella et al., 2016) opened to the possibility to design and build feasible, low-latency and performing Vehicle-to-Network (V2N) ITS applications (Picone et al., 2021). Exploiting the MEC and V2N paradigms each vehicle is able to communicate with the edge service provider directly through the Radio Access Network (RAN) overcoming the channel contention problems of V2V approaches and opening to a scalable and flexible management allowing the solution to evolve over time, extend supported capabilities with the aim to build a real intelligent urban platoon coordination system.

Fostering this vision, we believe that the proposed algorithms and approaches can be effectively integrated into MEC centralized platoon-controlled architectures benefiting of both a simplified communication infrastructure and a Platform as a service (PaaS) paradigm allowing the execution of multiple services able of exploiting collected data and interacting with platoon's members for their intelligent coordination. Furthermore, the adoption of a MEC platoons' solution extends the environmental optimisation opportunities through the support of an increased number of vehicles, eases the management of multi-platoons (or split platoons) scenarios, allows an extended covered area and the integration with other ITS applications such as urban data harvesting, traffic and emergency management (Chen et al., 2022; Lee et al., 2009).

7 CONCLUSION

In this deliverable, we proposed an updated evaluation framework which allowed us to assess the economic, environmental, and economic impacts of 5G-LOGINNOV UC. We proposed an updated evaluation methodology and presented the qualia-quantitative evaluation framework consisting of a multicriteria analysis based on the results of two deliverables (D1.4 and D4.3) and the analysis of existing literature.

D3.4 analysed the second round of the stakeholder assessment survey and compared it with the first round of results. We found that 5G services and applications are considered more important. Finally, regarding the importance of the impacts (micro-criteria) for the successful execution of the UCs, the respondents confirmed they are all equally important for the success of the UCs.

D3.4 investigated the existing literature on 5G impacts on logistics and compared these findings with the impacts (micro-criteria) identified in D1.4. Based on this comparison, we defined the micro-criteria for the economic, social, and environmental impact macro-areas. Successively, we created a matrix by analysing the impacts of each UC reported in D1.4 and D4.3 and assigned a score based on this analysis. We performed a multicriteria analysis and evaluated the use cases in the three scenarios.

We found that UC10 and UC11 of Hamburg and UC4 of Athens generate the highest positive impacts on the labour market, quality of life, safety and security (social scenario). UC8/9 of Hamburg and UC2 of Athens help to optimise resources, increase the efficiency of operations and improve traffic flow (economic scenario). Finally, UC8/9 generates the highest environmental impacts because it enables the reduction of CO2 emissions and fuel consumption (environmental scenario).

Finally, we concentrate on the UCs demonstrated in Hamburg LL and propose a routing algorithm to optimise for inter-vehicle distance of a platoon and CO2 emissions. We showed that our approach allows us to improve platoons' cohesion by 12% and to reduce CO2 emissions by 5%, using the CO2 emissions optimised route instead of the shortest-path route.

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AUTPILOT D1.4 “Methodology for Evaluation”

AUTPILOT D4.3 “Final Technical Evaluation”

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