

Leveraging the VITAL-5G Platform to Bring 5G Standalone Closer to Vertical Industries

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Abstract—While vertical industries play a pivotal role in contemporary production systems, their day-to-day operations still heavily rely on manual processes, thereby impacting overall efficiency. The advent of advanced mobile communication systems like 5G and beyond holds promise for vertical sectors, particularly in Transport & Logistics (T&L), by enhancing network performance and ensuring high levels of Quality of Service (QoS), crucial for automating and optimizing T&L processes. However, assessing the impact of 5G requires investments in network infrastructure, posing time and return on investment uncertainties. Addressing this, the European project VITAL-5G provides a platform for vertical stakeholders, as 3rd party experimenters, to test and validate 5G services. This paper explores the capabilities of the VITAL-5G platform, delving into technical and operational challenges associated with hosting 3rd party experiments, presenting ongoing activities, potential business opportunities, and insights from ongoing experimentation campaigns.

Index Terms—5G SA, 5G trials, 3rd party experimentation, vertical industries

I. INTRODUCTION

The Transport & Logistics (T&L) sector plays a pivotal role in modern production and distributed systems, significantly impacting people's lives. However, this industry segment faces challenges with low automation and process optimization, directly affecting the efficiency and safety of T&L operations. To address these issues, pilot trials utilizing 5G mobile communication systems, edge cloud, Software Defined Networking (SDN)/Network Function Virtualization (NFV), Network Applications [1], and OpenAPIs are being created in various European initiatives. These trials aim to develop and test various T&L vertical services in realistic conditions, making a substantial impact on the testing and validation of 5G-enhanced T&L applications.

To this end, one of the key strategic goals of the VITAL-5G project is the establishment of an open, virtualized, and flexible experimentation facility, as illustrated in Fig. 1. This facility comprises an intelligent virtual platform, three distributed 5G testbeds, and corresponding vertical infrastructure [1,2]. The primary objective is to facilitate testing and validation of T&L Network Applications under authentic conditions, leveraging 5G connectivity. VITAL-5G has identified three trial sites, namely Antwerp, Galati, and Athens, strategically chosen to replicate real-life 5G-enhanced T&L experimentation

environments in bustling ports (river and sea) and warehouse settings. Each trial site incorporates 5G testbeds, comprising a 5G network and virtualized and orchestrated infrastructure designed for deploying vertical services, in conjunction with T&L infrastructure.

The involvement of 3rd party experimenters who are not members of the VITAL-5G consortium (e.g., entrepreneurs, Small and Medium-sized Enterprises (SMEs), research centers, and larger companies) in the experimentation and/or the Network Application development, is a key aspect of the H2020 ICT-41 call and hence of the VITAL-5G project. VITAL-5G has the objective of engaging with diverse stakeholders, with the main focus being SMEs and entrepreneurs, but also research centers and larger industries, interested in developing vertical services and/or Network Applications. In the context of fostering digital inclusion for entrepreneurs, SMEs, and research centers that may lack access to digital T&L services, as well as large companies, VITAL-5G offers access to diverse experimentation assets for 3rd party experimentation across its three pilot sites. This includes features of the VITAL-5G Platform provided to 3rd party experimenters, enabling them to test and validate their services straightforwardly, without necessarily understanding the network. They can utilize either the vertical services developed within the project or combine them with their own, creating more complex services. In particular, VITAL-5G offers tailored and virtualized access to the network and T&L infrastructure resources via a user-friendly interface. This enables the dynamic provisioning of customized services to 3rd party experimenters, allowing them to validate their applications over resources that would otherwise be inaccessible. This approach enhances confidence in application performance before the actual deployment of services and investments in network infrastructure.

II. VITAL-5G SYSTEM

By providing end-to-end latencies as low as 5 ms, achieving data rates of up to 20 Gbps, and ensuring ultra-high reliability of 99.999%, 5G is enhancing the capabilities of various industry sectors, including the T&L sector, as highlighted in our previous work [1]. 5G technology is expected to significantly enhance efficiency and safety in T&L operations, thus positively impacting modern production and distribution systems. This improvement will be realized through the automation and optimization of processes and resource utilization. However,

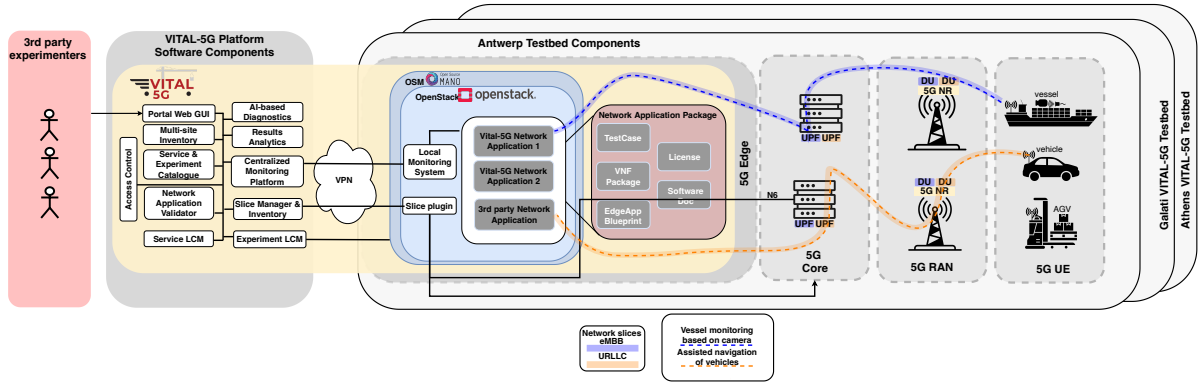


Fig. 1: VITAL-5G System consisting of the Platform and underlying network and T&L infrastructure.

for optimal benefits from 5G, it is imperative that the design, development, and management of T&L services explicitly incorporate 5G connectivity requirements and features tailored to the specific use cases within the T&L industry.

To this end, the VITAL-5G project utilizes the concept of Network Applications as the foundational elements of 5G-enabled T&L services. These Network Applications serve to simplify the complex vertical services by abstracting the inherent network complexity, thereby bridging the knowledge gap among vertical stakeholders, network experts, and application/service providers. Additionally, these Network Applications specify service-level information unique to the vertical sectors and articulate 5G requirements, encompassing both 5G slices and 5G Core services. The concept of Network Applications stands as a pivotal component of VITAL-5G, as we envision them as the fundamental units composing T&L service chains atop 5G-enabled infrastructures.

In this section, we delve into the technical aspects of the experimentation, focusing on the VITAL-5G system. Illustrated in Fig. 1, the VITAL-5G system comprises an overarching platform, 5G testbeds, and underlying T&L infrastructure. This integrated system facilitates 3rd party experimenters in creating and deploying Network Applications. These applications interact with T&L infrastructure and User Equipment (UE), including vessels, vehicles, Automated Guided Vehicles (AGVs), and various Internet of Things (IoT) platforms, depending on the testing scenario.

A. System components

The high-level architecture of the VITAL-5G system is shown in Fig. 1, and it consists of three main pillars:

- **VITAL-5G Platform**, which is used by all VITAL-5G users, including the 3rd party experimenters, to access the testbed resources, design Network Applications, and deploy them in different environments. It provides the various users with unified access to all the VITAL-5G experimentation services. More details are presented in Section II-B.
- **5G testbeds**, which deliver a 5G network infrastructure with virtual computing capabilities and SDN/NFV technologies in three different types of T&L facilities. Using the testbeds, VITAL-5G users can run their experiments and trials in realistic environments and interact with real equipment.

- **T&L infrastructure**, which combines T&L equipment from the shipping and warehouse verticals, such as vessels in the case of Antwerp and Galati trial sites, AGVs in the case of the Athens trial site, along with onboard sensors, cameras, and 5G communication setups that enable connectivity between T&L infrastructure and Network Applications running on the 5G testbeds. In addition, VITAL-5G provides i) the availability of emulators specialized for the T&L sector to enable more scalable system validation mixing real and emulated data, and ii) the availability of open datasets from T&L environments, for both network and application data, to facilitate Machine Learning (ML) models training for Artificial Intelligence (AI) applications.

B. VITAL-5G Platform

The VITAL-5G Platform facilitates the management of network and computing resources, which are available at any network infrastructure, i.e., a 5G testbed connected to it via southbound interfaces. Through the management of those resources, the VITAL-5G Platform is in charge of the deployment and management of vertical services (and constituting Network Applications), allowing 3rd party experimenters to install their vertical services in the 5G network and connect them with the T&L facilities of interest. In this section, we briefly discuss the subset of platform components that altogether create a set of capabilities and offerings to 3rd party experimenters, as listed in Table I.

When a 3rd party experimenter requests deployment of a certain Network Application, **Service Lifecycle Manager** (see Fig. 1) is activated. This is a platform module responsible for processing this incoming service creation and deployment request. To perform the task, this module mainly interacts with the i) NFV orchestrator on a selected 5G testbed, which further executes the orchestration operations on the actual NFV resources, ii) **5G Slice Manager and Inventory**, to allocate or create the 5G slice by interacting with the 5G Core and associate it to the service, and iii) **Centralized Monitoring Platform**, which performs real-time monitoring of the infrastructure, network, and service, metrics during the experiment runtime.

Furthermore, **Multi-site inventory** module is used for determining the capabilities of the underlying network and T&L infrastructure when deciding where and how to deploy a new

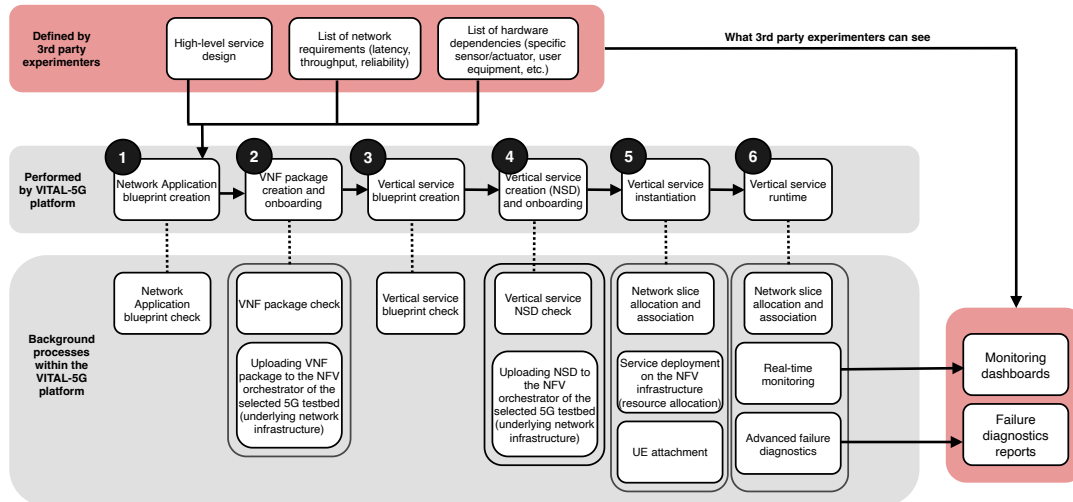


Fig. 2: Simplified VITAL-5G schema.

TABLE I: VITAL-5G Platform capabilities offered to 3rd party experimenters.

Capability	Description
Facilitation of the deployment of a vertical service in the 5G network	To deploy their vertical services on the 5G SA infrastructure and start experimenting, 3rd party experimenters only need to be aware of their network requirements and hardware dependency.
Multi-platform edge computing for scalable and secure vertical services	The 3rd parties can deploy their Network Applications and vertical services over multi-platform edge environments, embedding security, high availability, and autoscaling functionalities, with support for VM and container-based applications while offering specialized hardware capabilities.
Full orchestration across IoT, mobile network & edge domains	The 3rd parties can focus on their software (SW) application logic, with the VITAL-5G Platform handling the complexity of orchestrating together network and edge resources and enabling secure and unified access to IoT devices on the field.
Open catalogue of re-usable Network Applications to act as building blocks for new services development	Open and documented interfaces, extreme modularity, common design patterns, and usage of open-source SW tools. Relying on these design principles, VITAL-5G Network Applications can be easily re-used, extended, customized, and combined together to build new services.
Network Application blueprints, templates, open datasets, and SW libraries to enable the development of new applications	The VITAL-5G catalogue is open to hosting new Network Applications to be shared with the community. Our asset comprises blueprints, templates, atomic SW components, and libraries, T&L datasets, and AI/ML tools, and thus provides a comprehensive starting kit for developing new 5G applications both for T&L and also for diverse vertical sectors.
Enhanced network performance by utilizing network slicing	3rd party experimenters can utilize the available slices available in the three VITAL-5G testbeds when deploying their vertical services. In particular, the VITAL-5G Platform analyses the minimum network performance requirements specified, and it accommodates the requested service with the required network and service quality.
Real-time monitoring of the network and service performance	As soon as the service is deployed and initiated, experimenters can start collecting performance metrics, such as network, service, infrastructure, and platform, in real-time.
Advanced failure diagnostics	The VITAL-5G Platform incorporates advanced Artificial Intelligence (AI)/Machine Learning (ML) processes to diagnose failures that happen at service runtime. The output of such services provides more insights into how the vertical service performed and what are the reasons for service termination.

Network Application and vertical service. This module is a centralized repository that contains information about all testbeds connected with the VITAL-5G Platform via southbound interfaces. This information includes details about T&L devices available at the pilot site (e.g., sensors, cameras, localization modules, and AGVs), endpoints of NFV orchestrators, and slicing capabilities of testbeds (whether they support dynamic or static slice configuration).

Finally, the **Portal Web GUI** is a graphical user interface that allows users to access experimentation facilities and spawn vertical services. The 3rd party experimenters use this interface to design experiments, choose existing Network Applications from the VITAL-5G catalogue, create descriptors, and monitor network/infrastructure/service performance.

III. 3RD PARTY EXPERIMENTATION

All 3rd party experimenters are provided with secure access to the VITAL-5G Platform and its entire set of experimentation tools and functionalities. This includes the VITAL-5G catalogue of available Network Applications, tools for onboarding and validation of new Network Applications, automated service provisioning, management and monitoring, test execution, results analysis, and diagnostics, which are enabled by the VITAL-5G Platform components briefly described in the previous section. All these features have been designed to facilitate experimentation activities, without requiring prior knowledge of 5G technologies. This is expected to promote engagement for application developers and service providers.

The provision of simplified mechanisms for results analysis will facilitate the extraction of useful insights regarding service

and/or Network Applications when deployed in operational 5G environments.

A. Objectives of 3rd party experimentation

The main objectives of 3rd party experimentation are:

- To facilitate the availability of 5G experimental infrastructures across Europe, promoting not only their concept but also the business offerings of 5G Testing-as-a-Service. This will lower the barriers to introducing new services and new technologies, making it more affordable for stakeholders who have difficulties in building their own 5G testing infrastructure.
- To support research advancements, making them more sustainable in the long term, by facilitating the efficient replication of similar initiatives in geographically distributed environments, and enabling more scalable testing infrastructures, through the creation of compatible sites with unified interfaces and common experimentation methodologies that facilitate multi-site federation.

To deploy their vertical services on the 5G Standalone (SA) infrastructure and start with experimentation, 3rd party experimenters need to define their network requirements and hardware dependency. As shown in Figure 2, this initial step involves, i) the Creation of the OpenStack/container image, ii) Defining the minimum network performance of their Network Application, and iii) Defining the hardware requirements of their Network Application. After this, all the next steps will be taken care of by the VITAL-5G Platform itself, thereby hiding the complexity, through the provision of an abstraction layer for the experimenters. The onboarding package consists of the Network Application blueprint containing the software image of the Network Application that the VITAL-5G Platform leverages to define the intrinsic logic of the Network Application itself.

After successfully onboarding the individual Network Applications that constitute the vertical service to be deployed, 3rd party experimenters with the support provided by the VITAL-5G project partners, can initiate the onboarding process for the composed vertical service. Once the vertical service is up and running, the experiment is initiated, and 3rd party experimenters can monitor network and service performance in real time, as well as get insights into advanced diagnostics in case of service or network failure. All aforementioned benefits for 3rd party experimenters are summarized and described in Table I.

B. Technical and Operational Challenges of Hosting 3rd Party Experimenters

Despite the benefits of advanced experimentation capabilities described in the previous section, the process of successfully engaging 3rd party vertical industries in 5G experimentation imposes several technical and operational challenges. The first challenge to address is the *training* of the 3rd parties focusing on i) the capabilities and advantages introduced by 5G, and ii) the services offered by the VITAL-5G Platform and the capabilities and T&L infrastructure of each testbed. It is worth highlighting the activities in i) are usually a complex challenge since the knowledge required is outside the area of expertise of the verticals, which are more knowledgeable on the specifics of the service and less so on the capabilities of 5G. Therefore, more support is needed from the experts (e.g., VITAL-5G representatives) in the form of informative sessions and tutorials, which describe what 5G can do for the 3rd parties,

so they make the most of 5G network performance when using their applications.

Once the 3rd parties acquire the required knowledge regarding 5G capabilities and services, the VITAL-5G team can better communicate with the 3rd parties regarding the *finalized technical solution*. The VITAL-5G team can then address the technical challenges associated with i) the functional blocks and software assets of the 3rd party Network Applications to be onboarded into the VITAL-5G Platform, ii) interfaces of the 3rd party Network Applications towards VITAL-5G provided Network Applications, T&L infrastructure, and 5G networks, and iii) services of the VITAL-5G Platform to be used. This is a challenge that is addressed in close coordination between the project representatives and each of the 3rd parties, to assess the technical feasibility and to align with possible business scenarios of the involved parties. Moreover, possible extensions to the VITAL-5G Platform may be proposed to overcome some specific technical limitations for a 3rd party/vertical.

The engaging of 3rd parties for experimentation activities also imposes a set of operational challenges to be addressed after overcoming the technical difficulties related to the trial design. First of all, secure channels and credentials need to be created for each 3rd party to access the VITAL-5G Platform and the underlying testbed facilities to enable the onboarding of the software images into the testbed and the correspondent descriptors into the Platform. In some cases, a 3rd party may require some physical equipment to be deployed at the infrastructure, which requires coordination with the trial site representatives. Finally, the overall planning and coordination of the 3rd party requires a tight synchronization of the 3rd party, the project contact, the trial site owners, and the VITAL-5G Platform maintainers.

IV. EXPLORING POTENTIAL FOR BUSINESS OPPORTUNITIES

The implementation of 5G technology in the T&L market sector is creating the opportunity for innovations targeting sector-wide efficiency gains. This is an important market to address considering the estimated 2028 global market value of approximately €920 billion and a current Compound Annual Growth Rate (CAGR) of approximately 52.4% [3]. Moreover, this vertical contributes approximately 5% of Gross Domestic Product (GDP) in Europe and is seen as critical for the competitiveness of European companies, as it is estimated that transport and storage expenses make up approximately 10–15% of European product costs [4]. Some of the key business challenges in this market relate to reducing delivery times, enabled by optimized delivery processes, and addressing cost inefficiencies at critical hubs in the supply chain, such as the ports and warehouses being targeted in VITAL-5G. The project aims to enable T&L stakeholders to take advantage of recent technology trends in the digitalization of their operations to address these challenges.

The goal is to support the T&L industry in the adoption of advanced 5G technologies, facilitating the optimization of T&L processes. The resulting efficiency gains can ultimately provide a competitive advantage for the companies involved, increasing profitability.

A. Key Opportunities

This section focuses on how the VITAL-5G assets were leveraged during the project's market engagement activities. Therefore, the following provides an overview of how 3rd

TABLE II: Key business benefits enabled by the VITAL-5G Platform.

Business Opportunities enabled by VITAL-5G	Stakeholder(s)
Delivery of consulting services for end customers. These services include integration, onboarding, performance evaluation, and configuration of 5G-enabled vertical services.	Information and Communication Technology (ICT) Integrators
Provision of standardized tools that encourage scaling the roll-out of increased numbers of vertical services. The Platform facilitates rapid deployment of applications and vertical services, avoiding the need to create complete custom applications each time new services are required.	Mobile Network Operators (MNOs)
Enabling detailed understanding of application-specific performance challenges. For the emerging 5G-enabled T&L sector, detailed technical knowledge is critical for SMEs to offer customized/specialized solutions to clients to remain competitive, especially versus larger, global operators.	SME Software Developers
Development of additional / enhanced network applications that can be shared and reused through the Platform's online repository. <ul style="list-style-type: none"> This enhances the demand for the VITAL-5G Platform services among application developers and vertical service providers, who could be offered a wider range of network applications through the VITAL-5G repository. The repository facilitates business opportunities for software developers through revenue-sharing mechanisms. Encouraging such ecosystem effects is essential for platform-based business models to thrive. 	VITAL-5G Platform Operator, Network Application Developers, Vertical Service Providers

parties engaged with the project and highlights the market needs directly addressed by the project assets:

- The majority of the 3rd party experimenters were interested in testing their own applications on the 5G SA network, to understand the benefits of 5G in terms of e.g. sensor density, edge computing, and the core network metrics achievable.
- Re-use of VITAL-5G network applications was requested in order to accelerate the development of the 3rd party services.
- The VITAL-5G Platform was employed to ease the onboarding of applications on the 5G network and to conduct in-depth application performance analysis using the platform's monitoring capabilities (see Section II-B).

V. LESSONS LEARNED AND FUTURE WORK

The comprehensive trials conducted within the VITAL-5G project, both internal and 3rd party ones, have highlighted a range of unique challenges and valuable lessons, effectively showcasing the diversity and potential of the various use cases enabled by the VITAL-5G Platform. A diverse array of Network Applications is currently being developed and tested on top of the VITAL-5G testbeds, utilizing the monitoring platform of the project to its full capacity. These developments are not only indicative of the robustness and versatility of the VITAL-5G Platform but also highlight the innovation ecosystem that the project has fostered.

This paper outlined several relevant challenges that need to be taken into account when creating opportunities for 3rd party experimentation. Before any experimentation, it is of utmost importance to create proper training and exploration sessions for interested parties. These sessions are usually held by

technical and non-technical experts (e.g., business developers) who are capable of exemplifying the benefits of using advanced network capabilities via experimentation platforms such as the VITAL-5G one, to enhance the operational efficiency of their respective industrial processes. In addition, 3rd parties coming from diverse industrial and academic environments need to sustain their privacy and secure their network and application resources during experimentation. For that purpose, the VITAL-5G Platform offers secure channels and credentials needed for each experimenter to access any resource from the underlying network and T&L infrastructure.

Given that the resulting efficiency gains of creating vertical services in the 5G ecosystem bring competitive advantages for the parties involved and increase profitability, it is important to highlight specific business opportunities that emerge from such activities. In particular, the 3rd party ICT providers and innovative SMEs are specifically interested when it comes to exploring potential business opportunities, as their core business relies on developing innovative solutions for T&L companies. Some of the identified business opportunities refer to i) the delivery of consulting services for end-customers in case of ICT integrators, ii) enriching the pool of standardized services MNOs offer, which can encourage increases in the number of vertical services and offer new business cases, iii) creating a knowledge-base for SMEs that are interested in application-specific performance challenges, and iv) design and development of innovative Network Applications by software developers, which will boost various vertical sectors.

In terms of 3rd party experimentation, the focus of the remaining months is to conclude the experimentation of the onboarded parties and to streamline and finalize the role of those still in the onboarding process. Special attention is required in case increased computational resources need to be allocated to satisfy the experiment requirements and where additional support is required on the back end to accommodate the changes.

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REFERENCES

- [1] N. Slamnik-Kriještorac, G. Landi, J. Brenes, A. Vulpe, G. Suci, V. Carlan, K. Trichias, I. Kotinas, E. Municio, A. Ropodi, and J. M. Marquez-Barja, "Network Applications (NetApps) as a 5G booster for Transport & Logistics (T&L) Services: The VITAL-5G approach," in *2022 Joint European Conference on Networks and Communications & 6G Summit (EuCNC/6G Summit)*, pp. 279–284, 2022. doi: <https://doi.org/10.1109/EuCNC/6GSummit54941.2022.9815830>.
- [2] V. Charpentier, N. Slamnik-Kriještorac, L. Xiangyu, J. F. N. Pinheiro, C. Costa, and J. Marquez-Barja, "On Enhancing Transport & Logistics Sectors with 5G Testbeds and Edge Network Applications (EdgeApps)," in *IEEE INFOCOM 2023 - IEEE Conference on Computer Communications Workshops (INFOCOM WKSHPS)*, pp. 1–6, 2023. doi: <https://doi.org/10.1109/INFOCOMWKSHPS57453.2023.10226086>.
- [3] Markets and Markets, "5g services market," 2023. Online [Available]: <https://www.marketsandmarkets.com/Market-Reports/5g-services-market-226908556.html>, Last accessed on 2024-2-10.
- [4] EU Science Hub, "Transport sector economic analysis," 2023. Online [Available]: <https://ec.europa.eu/jrc/en/research-topic/transport-sector-economic-analysis>, Last accessed on 2024-2-10.