VertIcal demos over Common large scale field Trials fOr Rail, energy and media Industries

D3.7 5G VICTORI Use case assessment

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Executive Summary

This deliverable documents the activities undertaken within Task 3.4 “Use case assessment”. It provides a broad assessment across five dimensions, i.e. technical, environmental, economic, social, and user dimensions, at the current development stage of deployments and services. Taking a comprehensive perspective including all five dimensions is crucial, given that the 5G-VICTORI platform and the innovative applications and services supported are expected to have substantial impact on various technical, economic and social aspects. As a key enabler for digitalization, 5G is expected to have considerable impacts on social, economic, and environmental sustainability. However, in order to develop infrastructures as well as services and applications that are able to impact sustainability positively, relevant strengths and challenges need to be identified at an early stage.

In this context, an important part of the evaluation performed focuses on performance from a technical and a user perspective. This is clearly a fundamental objective as it can dictate the success of the proposed solution. In addition, however, performance with respect to social, environmental, and economic sustainability is crucial to ensure societal acceptance, market potential, and scaling, as well as creating impact.

The general assessment framework used is a collaborative framework, integrating multiple perspectives. It consists of a generation phase, in which the dimensions were specified and the relevant assessment targets or reference levels were identified. During the generation phase it was discovered that some dimensions can be more appropriately assessed at the service level while others can be more appropriately assessed at the deployment level. As part of the evaluation process, a set of suitable Key Performance Indicators (KPIs) were defined. The objectives of the different dimensions of evaluation are summarized below:

- The goal of the **technical** assessment is to provide performance results of a 5G network dimensioned to support the use cases and applications in scope. This dimensioning exercise takes into consideration both hardware (HW) and (software) SW requirements derived from experimental tests that lead into extraction of relevant KPIs. The results obtained confirm that the 5G network can be designed and deployed to be elastic addressing Use Case (UC) demands.
- The **environmental** performance assessment focuses on a power consumption related evaluation for the 5G-VICTORI solution when deployed in a realistic context and scale for the use cases in scope. This evaluation includes dimensioning and operating the 5G-VICTORI platform (covering city scale dimensions) with realistic service demands and deriving the overall platform power consumption levels based on real (experimentally measured) power consumption data for the 5G technologies deployed by the 5G-VICTORI platform.
- The **economic** performance assessment focuses on the economic evaluation of alternative large-scale network deployments with the aim to identify cost optimizations and to investigate various technological aspects and critical parameters at early stages. The ultimate goal of the assessment is to identify economically viable and sustainable deployment options for the underlying network layer supporting the vertical/user services.
- Regarding the **social** dimension, performance was examined using a survey-based method. UC and service owners, as well as a jury, were consulted to capture the expected effects of the different services with regards to the defined KPIs. The survey results were analyzed to identify shared tendencies across services. Additionally, individual performance profiles by service were generated. These performance

profiles capture the current perspective on social performance and partly on user performance. They further provide the basis for further shaping the services.

- With regards to the **user** dimension the goal was to construct a user questionnaire to be adapted for use by specific services and applications at later development stages. This questionnaire was successfully pretested for several services through having pseudo users use the service (at its current development stage) and then fill in the survey. Besides this, UC and service owners were asked to identify current challenges their services may face regarding the user perspective and the answers were summed up.

Acronyms

General

Acronym	Description
3GPP	Third Generation Partnership Project
5G	Fifth Generation cellular system (3GPP related)
5G VNFs	Virtualized 5G network functions
5GC	5G Core
5QI	5G QoS Identifier
AP	Access Point
AS	Application Server
AW2S	Advanced Wireless Solutions and Services
B5G	Beyond 5G
BBR	Bottleneck Bandwidth and Round-trip propagation time
BBU	Base Band Unit
BF	Brownfield
BH	backhaul
BS	Base Station
BSCW	The document server used in the 5G-VICTORI project
CAPEX	Capital Expenditure
CCC	Municipality Command & Control Center
CCTV	Closed-Circuit Television
CDN	Content Delivery Network
CDR	Call Detail Records
CN	Core Network
CO	Central Office
COTS	Commercial Off-The-Shelf
CPE	Customer Premises Equipment
CPU	Central Processing Unit
C-RAN	Cloud-based Radio Access Network
CU/DU	Central/Distributed Unit
D-ITG	a tool that produces traffic at packet level
DL	Downlink
D-RAN	Distributed Radio Access Network
eCPRI	Enhanced Common Public Radio Interface
eMBB	eMBB Enhanced Mobile Broadband - enhanced MBB
EMS	Energy Management System
F1	Interface that defines inter-connection of a gNB-CU and a gNB-DU supplied by different manufacturers
FH	fronthaul
Flent	Traffic generator
FoV	Field-of-View

FRMCS	Future Railway Mobile Communication System
FS	Functional Splits
GF	Greenfield
gNB	gNodeB
GPP	General Purpose Processors
GPR	Gaussian Process Regression
GUI	Graphical User Interface
HARQ	Hybrid automatic repeat request (hybrid ARQ)
HTML5	HyperText Markup Language 5
HTTP	HyperText Transfer Protocol Secure
HV	High Voltage
HW	Hardware
ICT	Information and Communication Technology
IDT	Inter Departure Time
IMS	IP Multimedia Subsystem
IP	Internet Protocol
iPerf	Measurement tool, can be downloaded here.
ISP	Internet Service Provider
IT	Information Technology
Km	kilometerskilometers
KPI	Key Performance Indicator
KVI	Key Value Indicator
MANO	Management and Orchestration
MBB	Mobile BroadBand
Mbps	Megabits per second
MC	Mission Critical
MCL	Macro Cell
MCPTT	Mission Critical Push-to-Talk
MCS	Modulation and Coding Scheme
MEC	Multi-access Edge Computing
MIMO	Multiple Input Multiple Output
ML	Machine Learning
MLFO	ML function orchestration
mMTC	Massive Machine Type Communications
mmWave	Millimeter Wave
Ms	Milliseconds
MS	Cells of Macro Sites
MSISDN	Mobile Station International Subscriber Directory Number
N3	interface that conveys user data from the RAN to the UPF
NPN	Non-Public-Network
NPS	Net Promoter Score
NR	New Radio (3GPP term)

OAI	OpenAirInterface
O-FH	Open Fronthaul
OPEX	Operational Expenditure
O-RAN	Open Radio Access Network
OSM	Open Source MANO
P2P	Point-to Point
PDU	Protocol Data Unit
PHY	Lower layer processing functions
PS	Package Size
PTT	Push-to-Talk
QAM	Quadrature amplitude modulation
QCI	Quality Class Identifiers
QFI	QoS Flow Identifier
QoS	Quality of Service
RAN	Radio Access Network
RAU	Radio Access Unit
RB	Resource Blocks
RMS	Remote Metering Solution
RRC	Radio Resource Control
RRU	Remote Radio Units
RTT	Round-Trip-Time (=two times the latency is both directions)
RU	Remote Units
SC	Small Cells
SDG	Sustainable Development Goal
SDN	Software Defined Networking
SDR	Software-Defined radio
SFP	Small Form-factor Pluggable (SFP)
SLA	Service Level Agreement
SME	Small and Medium-sized Enterprise
SMS	Short Message Service
SUS	System Usability Scale
SW	Software
TCO	Total Cost of Ownership
TCP	Transport Control Protocol
TOC	Table Oof Content
TRL	Technology Readiness Level
TSON	Time Shared Optical Network
TWh	Terawatt-hour
UC	Use-Case
UDP	User Datagram Protocol
UE	User Equipment
UHD	Ultra HighUltra-High Definition

UL	Uplink
UN	United Nations
UPF	User Plane Function
URLCC	Ultra-Reliable Low Latency Communications
USRP	Universal Software Radio Peripheral
V2X	Vehicle-to-everything
VoD	Video-on-Demand
VR	Virtual Reality
WACC	Weighted Average Cost of Capital
ZSM	Zero touch network & service management

https://iperf.fr/iperf-download.php**5G-VICTORI and related EU projects**

Acronym	Description
5G-VINNI	The Patras ICT-19 Cluster (v)
5G-EVE	Alba Iulia ICT-19 Cluster (e)
5G-PPP	5G infrastructure Public Private Partnership
D3.5	Delivery 3.5 (within T3.3)
ICT-17	The 5G platform developed for the 5G-PICTURE EU project
ICT-19	The 5G platform developed for the 5G-VICTORI
IR	Interim Review (done 2020-10-08)
T3.3	Task 3.3 (within WP3)
WP2	Work Package 2: Description – Use cases/ Specifications
WP3	Work Package 3: Vertical Services to be demonstrated
WP4	Work Package 4: Trials of Coexisting Vertical Services, validation and KPI evaluation
WP5	Work Package 5: Standardisation, Dissemination, Commercial Exploitation and Impact Assessment

1 Introduction

1.1 Objectives

The purpose of this deliverable is to provide an assessment of both the deployment and the applications and services developed in the context of the 5G-VICTORI project, characterizing their performance at the current stage of development. The assessment points out strengths and achievements of the deployments and applications and services and, at the same time, identifies potentials for further developments and indicates room for improvement. This involves going beyond the usually considered **technical** and **user** dimension and also including all three dimensions of sustainability: social, environmental and economic sustainability.

Adopting a comprehensive perspective and considering essential aspects of sustainability is of utmost importance since 5G is a key enabler for digitalization. 5G infrastructures and the innovative applications and services based on it are likely to have a substantial impact on various societal dimensions. 5G holds the potential of contributing to social, economic, and environmental sustainability and thus working towards realizing the United Nations (UN) Sustainable Development Goals (SDGs) [1]. In today's world, all innovations and developments should be examined with respect to their potential for addressing societal challenges and working towards the goals we have set ourselves as a society, which are formulated in the SDGs. In order to maximize the exploitation of this potential it is important to assess applications and services under development as well as the emerging infrastructures with respect to their impact on all relevant aspects: technical, user, and sustainability. Including sustainability perspectives early on is also important to relevant actors from a business perspective: potential sustainability benefits provide value propositions that new technologies and services may be able to offer, while any related shortcomings are increasingly problematic in terms of reputation and accountability.

Comparable projects (such as, for example, SooGreen [2] and 5G Mobix [3]), have taken sustainability aspects into account in very laudable ways and the importance of considering sustainability aspects in cellular network technologies is increasingly emphasized [4], [5]. Yet considering all three sustainability perspectives simultaneously constitutes a novelty. 5G-VICTORI is providing a broad assessment of the proposed solutions with the aim to bring all the relevant perspectives on the table, even at early development stages, and help realize the great potential that 5G technologies hold. For all involved stakeholders, having an early idea of possible options and associated consequences helps prioritize and shape the final results and their impact. A comprehensive approach can further help discussing the transferability of solutions. Moreover, it constitutes a solid basis for the upcoming impact assessment of WP5.

1.2 Assessment dimensions

The assessment in this deliverable comprises five performance dimensions:

- Technical performance.
- Environmental performance.
- Economic performance.
- Social performance.
- User performance.

The **technical** dimension is a fundamental prerequisite for developing 5G high performance networks as well as services and applications exploiting its capabilities. It is a main task dealt with in the majority of the project technical activities and testbed development and is part of completed and ongoing work. However, from a methodology perspective the technical dimension should be also considered alongside the other four dimensions. Therefore, an assessment from the technical dimension perspective is also included here, though it does not aim to go into detail with respect to all UCs planned to be demonstrated by 5G-VICTORI.

Regarding the **environmental** dimension, 5G services and infrastructures will have a large footprint since they will contribute significantly to energy and resource consumption as well as CO_2 emissions from the Information and Communication Technology (ICT). Therefore, it is very important to design, implement and operate 5G infrastructures in the most energy efficient and environmentally friendly way. As a key enabling technology, 5G can also directly contribute to environmental sustainability in many important fields. 5G will play a key role in the transformation of the energy sector towards low carbon energy generation based on renewables, smart grids and high energy efficiency. It also holds the potential to advance the shift in the mobility sector towards decarbonized multimodal and shared mobility as well as support the transformation of production systems towards highly efficient smart factory and industry 4.0 concepts. In the framework of 5G-VICTORI a group of applications and services directly targets sustainability. However, the work reported in this deliverable focuses on identifying optimal design and operation approaches that can substantially reduce the overall energy consumption of the 5G-platform and, hence, minimize the associated environmental footprint.

Economic sustainability of a solution is a factor of ultimate importance determining the solution's commercial adoption and future-proofness. In the case of 5G-VICTORI, alternative large-scale network deployments are economically evaluated with the scope to identify cost optimizations and to investigate various technological aspects and critical parameters at early stages. The ultimate goal of the assessment is to identify economically viable and sustainable deployment options as an underlying network layer supporting the vertical/user services

Given the multitude of areas in which innovative applications and services based on 5G-infrastructures are being developed, a broad spectrum of possible **social** impacts has to be considered. For example, 5G based services can contribute to workplace safety by enabling remote steering and automation of dangerous tasks, further education and information provision through providing enhanced content delivery networks, or boost equality by providing services benefitting disadvantaged groups. However, in order for such potentials to be realized they have to be actively addressed and taken into account at an early development stage. Otherwise, there is a risk of generating unintended impacts, for example increasing inequality across urban and rural populations by providing applications benefitting only rural populations. While perspectives of environmental and economic sustainability are increasingly considered, the dimension of social sustainability is infrequently addressed, in particular at an early stage of service and application development.

While the user perspective does not directly have impacts on societal issues such as sustainability, it provides the essential basis for the creation of functioning services that provide a positive user experience and whose usage is accordingly taken up. Target of assessment

One main objective of this deliverable is to assess the concrete applications and services implemented in the four use cases of WP3. Although an important focus of the assessment is, accordingly, on the applications and services, the general impact of the 5G infrastructures and their deployment is a second main focus. Two of the assessment dimensions, the **environmental** and the **economic** dimension**,** can only be evaluated at deployment level. This is due to the framework and context relevant for the 5G-VICTORI project: 5G infrastructures and ecosystems hold great technical and economic potentials, but they are in an early development stage and at the same time highly dynamic – especially regarding technology development and regulatory matters as well as business models. With respect to the economic dimension, business models adapted to 5G ecosystems are just emerging and may take very different shapes, depending on regulation and infrastructure but also on the roles taken on by the involved actors, creating a multitude of potential development paths. Future demand regarding different services and applications is hard to estimate and dependant on a wide range of factors, not least the shape and mode in which services and applications can be commercialized, which in turn depends on where the regulatory and business model paths lead. Concerning both the **technical** and the environmental assessment, we adopt the use case driven methodology. This not only allows evaluation of the high level service performance, but also enables dimensioning of the required 5G network and ensures appropriate consideration of the underlying infrastructure with respect to technical and energy related Key Performance Indicators (KPIs).

Regarding the **social** and the **user** dimension, assessment can take place at the application and service level, allowing the creation of individual performance profiles. Since all applications and services are not yet at a stage of actual, commercial implementation and still only have low medium Technology Readiness Levels (TRLs), only potentials can be examined with respect to the two dimensions. However, these potentials can be examined at the application and service level. In the case of the user perspective, the concrete user experience is not very dependent on the scale of usage and thus can be examined once a functioning version of the application or service exists. As for the social dimension the actual impact is highly dependent on actual uptake and how widely the usage of an application and service spreads, yet the potential for these impacts can already be considered, keeping in mind that the scale and strength of these impacts is dependent on future developments.

1.3 Deliverable structure

The structure of the remainder of this deliverable is as follows. In section 2 the general use case assessment framework is introduced, and the methodological aspects shared by the different dimensions are described. Sections 3 – 7 each detail one assessment dimension. Each section includes the objective of the assessment dimension, the dimension specific methodology, and the assessment results. Section 8 consists of the assessment profiles for each application or service. Each assessment profile includes a brief description of the respective service, followed by service specific assessment results on the social and the user dimension. Section 9 concludes this deliverable.

2 General Use Case Assessment Framework

2.1 Collaborative Framework for Assessment

5G infrastructures and technologies have the potential to support a wide range of applications and services for a variety of verticals industries fulfilling the requirements of the three services classes: Enhanced Mobile Broadband (eMBB), Ultra-Reliable Low Latency Communications (Urllc), and Massive Machine Type Communications (mMTC). 5G-VICTORI aims at validating 5G solutions in large scale trials involving multiple vertical industries and accordingly contains diverse UCs and a multitude of different applications and services. Given the breadth of applications and services and the potential of 5G networks to disrupt business practices in several extensive fields, far reaching impacts on all relevant dimensions can be expected. It is, therefore, important to include a broad range of considerations and perspectives in the assessment of such services.

The methodological concept used for the UC assessment in Task 3.4 is based on a collaborative assessment framework integrating all relevant dimensions and perspectives. This approach has been also successfully applied to community projects directly involving citizen stakeholders [6]. In the context of 5G-VICTORI, we adapt this approach building on the manifold expertise present in the project through the different industrial and academic partners in the process of constructing the assessment framework. The assessment process was structured in three phases: the **generation phase**, where the dimensions where specified and operationalized for 5G-VICTORI and dimension specific KPIs were defined, the **specification phase**, in which KPI specific indicators were identified and the methodological approaches were decided on, and the **evaluation phase**, where the 5G-VICTORI deployments and services and applications were evaluated along the five dimensions.

2.2 Generation Phase

The five assessment dimensions (see Table 2-12) were already agreed upon in the process leading up to the proposal submission and the initial 5G-VICTORI Grant Agreement. Working groups (WGs) were created for all five dimensions, combining different areas of expertise and thus enabling the discursive involvement of multiple perspectives. In regular online meetings the WGs set to work in a first step operationalizing the dimensions, defining more closely the relevant aspects within these dimensions in the context of 5G-VICTORI and the main aspects to focus on. Goals for each dimension were formulated; an overview is given in Table 2-12. These constitute the level 1 goals (see Figure 2-1 for an example). As mentioned in the introduction, the focus of the assessment dimensions differs: the technical dimension focuses on the use case and deployment level. The environmental and economic dimension focus on the deployment level: given the dynamic nature of 5G networks and related technological and business model development, these dimensions are highly dependent on contingent developments and therefore cannot be meaningfully assessed at the application and service level.

The dimensions also differ with regards to the stage of assessment, i.e. what it is that at this stage can be assessed (see Table 2-12). The technical assessment aims at providing performance results of a 5G network dimensioned to support the use cases and applications in scope. This dimensioning exercise takes into consideration both HW and SW requirements. The environmental assessment performance focuses on a power consumption related evaluation for the 5G-VICTORI solution when deployed in a realistic context and scale (city level) for the UCs in scope. This evaluation includes dimensioning and operating the 5G-VICTORI platform with realistic service demands and deriving the overall platform power consumption levels based on real (experimentally measured) power consumption data for the 5G technologies deployed by the 5G-VICTORI platform. In the case of the economic dimension, alternative large-scale network deployments are economically evaluated with the scope to identify cost optimizations and to investigate various technological aspects and critical parameters at early stages. The ultimate goal of the assessment is to identify economically viable and sustainable deployment options as an underlying network layer supporting the vertical/user services. In the case of the social dimension, at this stage of development potentials for socially relevant consequences and effects are assessed. For the user dimension the focus is on developing an assessment framework for future usage once the services are more developed and reviewing current work on the user dimension by the use case owners.

In a second step, the KPIs within the respective dimensions were defined (see Figure 2-1 for an example). While the types of KPIs, how they were identified and the metrics differ greatly across the dimensions, and will therefore be discussed in the respective sections, they all share core properties of KPIs. Selected KPIs need to fulfill three important criteria: helpfulness, relevance, and validity [7]. They need to be helpful in the sense that they provide information on the progress towards realization of the project objectives. In order to fulfill the criterion of relevance the focus should be on few crucial indicators not on many less important ones (ibid.). Validity entails a measuring system that is repeatable and reproducible (ibid.). As Cruz Villazón et al. put it [8], KPIs need to be measurable and controllable and therefore must take a form that allows for qualitative or quantitative values.

Table 2-12 The Five Assessment Dimensions

Assessment Dimensions			
Dimension	**Goal**	**Assessment target**	**Assessment stage**
Technical performance	Provide performance results of a 5G network dimensioned from HW and SW point of view to support the use cases and applications in scope	UC, deployment	Assessment of KPI that have to stay in a specific range or below or above a specific threshold
Environmental performance	Power consumption related evaluation for the 5G-VICTORI solution when deployed in a realistic context and scale for the use cases in scope	Deployment	Overall platform power consumption requirements
Economic performance	Identifying economically viable and sustainable deployment options as an underlying network layer supporting the vertical/user services.	Deployment	Assessment of deployment options for the key target verticals of 5G-VICTORI (the Railway and the Smart City)
Social performance	Realizing socially beneficial potential to the maximal extent	Service/ applications	Assessment of potentials
User performance	Providing services that supply a continuously easy and pleasant usage experience	Service/ applications	Preliminary assessment/ development of assessment framework

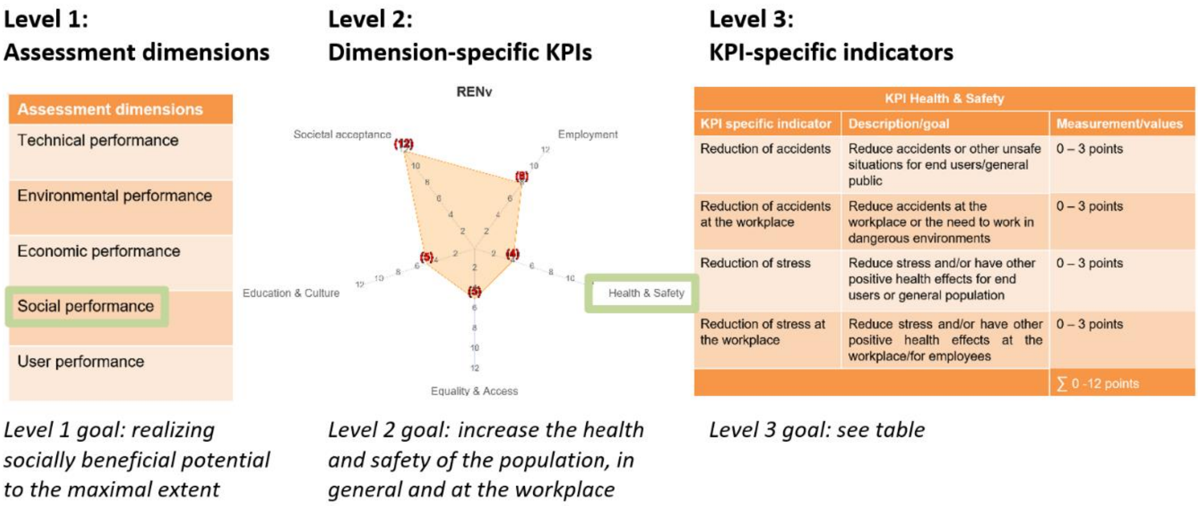


Figure 2-1 Assessment Levels[1]

The goals of measuring performance via KPIs are, firstly, to identify success as well as existing problems and aspects where improvements need to be made. Secondly, KPIs can aid projects in getting a greater understanding of processes, and have the potential to shed light on potentials and challenges not previously seen [9]. This underlines the importance of adding the four additional assessment dimensions besides the technical dimension to provide a comprehensive assessment. Gaining an understanding of potentials and challenges along the environmental, economic, social and user dimension early on can be exceedingly helpful in realizing potentials and adapting to meet challenges, in particular as digital services and infrastructures increasingly permeate every area of life, with explicit and implicit effects. Once the KPIs were defined a goal for each KPI was formulated. For the technical dimension, this translates into verifying that the KPIs are within the range to be able to support the Quality of Service (QoS) required by the use-case under test, while for the environmental assessment it provides KPIs offering insights regarding the overall platform energy efficiency characteristics.

2.3 Specification phase

After completion of the generation phase, the WGs on the five dimensions started to identify the KPI-specific indicators (see Figure 2-1 for an example). For each KPI-specific indicator a corresponding goal (level 3 goal, see Figure 2-1) was formulated.

In the specification phase, the methodological approaches for measuring the KPI-specific indicators and the KPIs were chosen. While technical, environmental and partly economic KPIs can make use of well-established quantitative measurement systems, KPIs for the social, and user dimensions rely, at least partly, on qualitative measurement systems (more on this will be described in the sections on the respective dimensions). A mix of quantitative and qualitative measurement systems is becoming more common as issues such as social and environmental sustainability are increasingly integrated in overall performance assessments [9].

Performance is generally measured by comparing achieved values to reference values. Depending on the dimensions and the KPIs reference values from different origins are used. The first approach is to use explicit reference values from the literature whenever possible. A second approach is to compare achieved values to 'implicit or related' reference values coming from other settings, but which have comparable test arrangements. The third

[1] The levels are here shown for the social dimension as an example.

approach, if the prior to approaches are not feasible, is to establish reference values from 5G-VICTORI services or put the achieved values into context without comparison to explicit reference values.

2.4 Evaluation Phase

In the evaluation phase, each WG finalized the assessment on their respective dimension, evaluating the overall performance of the 5G deployments, UCs, and services/applications developed in the 5G-VICTORI project. Since the evaluation phase differed greatly across the different dimensions the description of this phase is given in the sections on the dimensions. For the social and user dimension, where an assessment at the application and service level is possible, performance profiles for each service were constructed.

3 Technical Performance

The technical performance phase contains the details of the methodology used, the tests settings and the results obtained. The last chapter focuses on the generalization of the results obtained.

3.1 Scope and objective

The objective of this assessment and evaluation is to provide performance results of a 5G network to support the UCs and applications that are to be validated in the 5G-VICTORI project. This is achieved thanks to a 5G in-lab setup and on-field trials and some generalization exercises.

This study is extensible over different dimensions:

- **In-lab versus on-field tests**: we show how an in-lab testbed can be useful for this purpose, and which are the differences with respect to on-field tests and how we can reconcile them into our model.
- **UCs generalization**: we show how a specific UC assessment (UC #1.2 - outdoor bus surveillance: Alba Iulia) can easily be extended to cover a large number of UCs that are requiring a connection to a private network, based on the KPIs chosen.
- **Multi-vendor generalization**: we show how the 5G setup validated in this project can also be extended in a multi-vendor scenario for the different network components.For example, supporting different commercial Remote Units (RUs) and Fronthaul (FH) split as well as different Core Network (CN) providers and Commercial Off-The-Shelf (COTS) User Equipment (UEs) [43].

3.2 Specification of dimension

The main KPIs identified for the technical performance assessment of the 5G Network are the throughput and the Round Trip Time (RTT). The throughput is the measure in Mbps (Megabits per second) of the data traffic that can be handled by the network, for both directions Uplink (UL) and Downlink (DL) and for different traffic types; the RTT is related to the two ways latency in milliseconds (ms) and is measured for a packet flowing from the Core Network (CN) to the User Equipment (UE), and back to the CN.

The combination of the two metrics gives an indication regarding the class of services/UCs that can use this kind of network. The “3GPP Standardized Quality Class Identifiers (QCI) Characteristics for the 5G network” Table 3-1 helps in identifying a class of services/applications can run on the network based on performance parameters.

Table 3-1: 3GPP Standardized Quality Class Identifiers (QCI) Characteristics for the 5G network

5QI Value	Resource Type	Default Priority Level	Packet Delay Budget	Packet Error Rate	Default Maximum Data Burst Volume	Default Averaging Window	Example Services
1	GBR (guaranteed flow bit rate)	20	0	0	N/A	0	Conversational Voice
2	GBR	40	0	0	N/A	0	Conversational Video (Live Streaming)
3	GBR	30	0	10^{-3}	N/A	0	Real time gaming, V2X messages
4	GBR	50	0	0	N/A	0	Non-conversational Video (Buffered Streaming)

65	GBR	7	75 ms	0	N/A	0	Mission Critical user plane Push to Talk voice (e.g. MCPTT)
66	GBR	20	0	0	N/A	0	Non-Mission Critical user plane Push to Talk Voice
67	GBR	15	0	0	N/A	0	Mission Critical Video user plane
71	GBR	56	0	0	N/A	0	“Live” Uplink Streaming (TS 26.238[76])
72	GBR	56	0	0	N/A	0	“Live” Uplink Streaming
73	GBR	56	0	0	N/A	0	“Live” Uplink Streaming
74	GBR	56	0	0	N/A	0	“Live” Uplink Streaming
76	GBR	56	0	0	N/A	0	“Live” Uplink Streaming
5	Non-GBR	10	0	0	N/A	N/A	IMS Signalling
6	Non-GBR	60	0	0	N/A	N/A	Video (Buffered Streaming) TCP-based (e.g. www, e-mail, chat, FTP, p2p file sharing, progressive video etc.)
7	Non-GBR	70	0	0	N/A	N/A	Voice, Video (Live Streaming), Interactive Gaming
8	Non-GBR	80	0	0	N/A	N/A	Video (Buffered Streaming) TCP-based (e.g. www, e-mail, chat, FTP, p2p file sharing, progressive video etc.)
9	Non-GBR	90	-As above-	-As above-	-As above-	-As above-	-As above-
69	Non-GBR	5	0	0	N/A	N/A	Mission Critical Delay Sensitive Signalling (e.g. MC-PTT Signalling)
70	Non-GBR	55	0	0	N/A	N/A	Mission Critical Data (e.g. example services are the same as 5QI 6/8/9)
79	Non-GBR	65	0	0	N/A	N/A	V2X messages (TS 23.287[121])
80	Non-GBR	68	0	0	N/A	N/A	Low Latency eMBB applications Augmented Reality
82	Delay Critical GBR	19	0	0	255 bytes	0	Discrete Automation (TS 22.261[2])
83	Delay Critical GBR	22	0	0	1354 bytes	0	Discrete Automation; V2X messages
84	Delay Critical GBR	24	0	0	1354 bytes	0	Intelligent transport systems (TS 22.261[2])
85	Delay Critical GBR	21	5 ms	0	255 bytes	0	Electricity Distribution high voltage, V2X messages
86	Delay Critical GBR	18	5 ms	0	1354 bytes	0	V2X messages (Advanced driving: Collision Avoidance, Platooning with high LoA)

3.3 Methodology

There are three main dimensions (traffic types, mobility scenario and Network settings and conditions) that impact the evaluation of the network performances KPI mentioned (throughput and latency) in a lab setting as well as in the field trial setting. We will look at different combinations of these to provide the reference points to validate the use-cases and generalize to others not included in the list of UCs.

3.3.1 Traffic types

Different traffic patterns can be generated leveraging different tools in the lab environment to simulate on-field conditions.

The pattern "Up-Link (UL) and Down-Link (DL) throughput in Transport Control Protocol (TCP)" measures the throughput under the most common traffic type. For example, HyperText Transfer Protocol (HTTP), which is used to surf the internet, runs on top of TCP. This allows us to measure best effort throughput results. For this purpose, it is possible to use the Iperf tool.

The pattern "UL and DL throughput in User Datagram Protocol (UDP)" measures the network reliability in terms of lost segments and network introduced jitter. It provides the throughput, segment loss and jitter under different traffic bandwidth sizes. This measurement can be then referred to the 5G QoS Flow Identifier (QFI) table of Section 3.2 to determine which service it is possible to support and with which threshold. For this purpose, it is possible to use Iperf tool.

Buffer bloating scenarios: a Flent traffic generator can be used to measure buffer bloating scenarios, giving different settings on the generated traffic type.

Stochastic processes traffic at packet level: D-ITG is a tool capable to produce traffic at packet level, accurately replicating appropriate stochastic processes for both IDT (Inter Departure Time) and PS (Packet Size) random variables (exponential, uniform, 26auchy, normal, pareto, etc.).

For the RTT, we will apply different packet sizes and inter departure times of the packets to measure the performances under different traffic loads. It can also be used while running a traffic generator to measure the RTT variation under different traffic types. RTT latency can be measured using the Ping tool.

Different traffic types and latency performances can also be additionally tested changing the number of connected UEs in the network.

3.3.2 Mobility scenarios

Different mobility scenarios can vary the channel conditions dynamically, for example using low mobility, or statically, by positioning the UE close or far from the gNB or by using an attenuator in the controlled lab environment.

- Static / no mobility. Evaluation of the network performances under the same channel condition (example ideal, medium, poor).
- Low mobility scenario. Evaluation of performances under dynamic channel quality variation.

3.3.3 Network settings and conditions

The in-lab assessment aims to measure the network performances of the real setup in an ideal environment, thanks to the radio isolation provided by a Faraday cage. This gives a reference point for the achievable results and possible application that can be run in the given private network.

Trials in the in-field scenario aim to use the network in a real environment. This allows to evaluate the performances in non-ideal outdoor conditions with channel fading, interferences, power limitations, components temperature, cell coverage range, etc.

3.4 Measurements and results – UC #1.2 – outdoor bus surveillance – Alba Iulia

In this section we report the KPI results for the use case **UC #1.2** – outdoor bus surveillance – Alba Iulia performed in a lab setting at Eurecom and in an in-field setting in Alba Iulia (Romania).

The results and performances reached with this in-lab deployment, model the deployment to any commercial private network (e.g. Industry 4.0, Factories) or research networks that uses the same topology with some limitations. The identified limitations for the modelling are mostly related to environmental factors like antenna positioning for the cell coverage, temperature in which the tested components will be supposed to work, different servers running the software and possible interferences in the selected frequency range.

Eurecom Open5Glab displayed in Figure 3-1 hosts a small-scale reproduction of the testbed in Alba Iulia used to demonstrate the outdoor bus surveillance 5G-VICTORI use case. It is composed of OpenAirInterface (OAI) 5G CN and Central-Distributed Unit (CU-DU) connected to a COTS RU provided by AW2S over a 10Gbps FH link. The RU is transmitting in 5G NR B78 in 2x2 MIMO over a 50MHz channel bandwidth. The UE is a Quectel module. Those modules could be also sourced by a mix of different vendors if they respect the standards O-RANs and 3GPP.

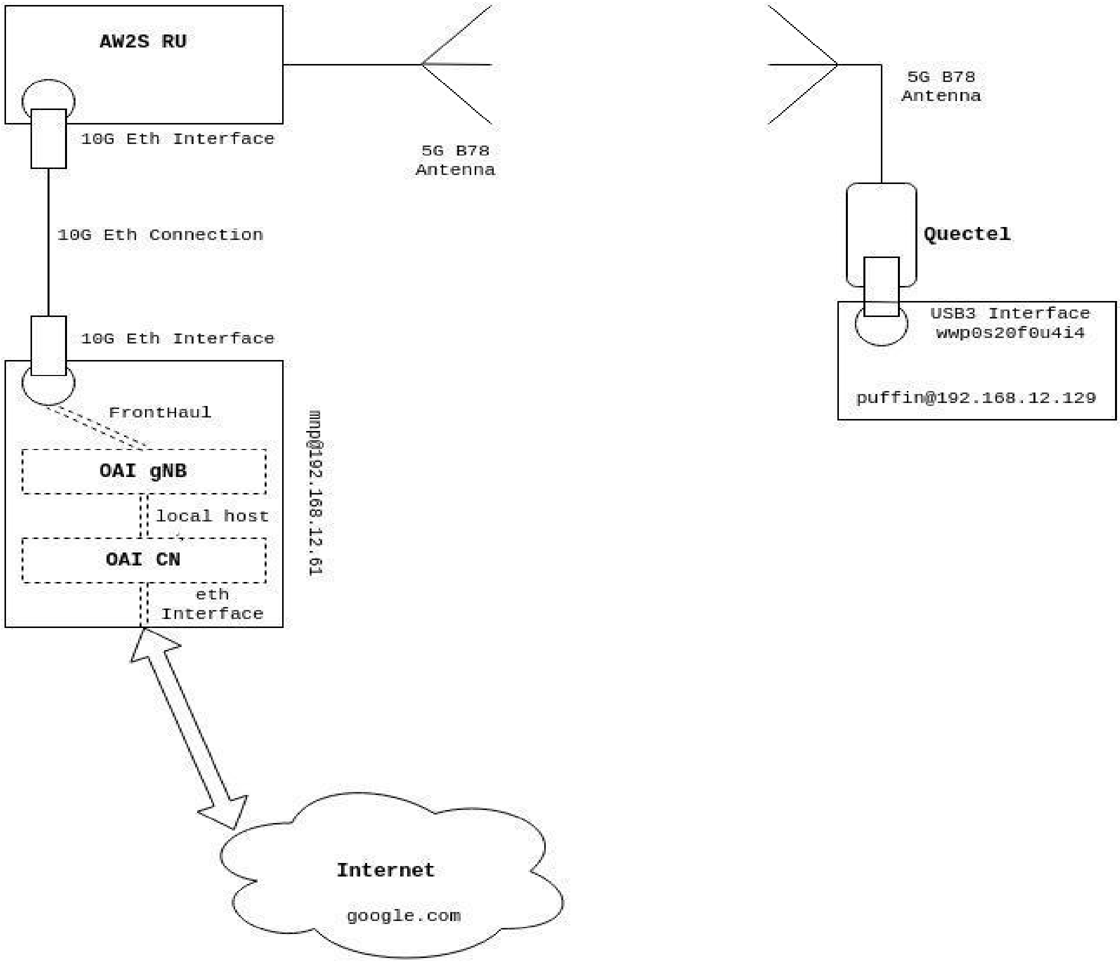


Figure 3-1 Eurecom Open5Glab setting

Measurements of the KPIs have been produced using the iperf3 and ping tools between the CN machine and the UE. They will be displayed in a tabular form: for the throughput it will highlight the traffic capacity and the reliability of the communication using the measured data error rate, for the RTT the table will contain the maximum, minimum and average measured values.

3.4.1 Throughput: TCP performances

We used TCP Bottleneck Bandwidth and Round-trip propagation time (BBR) congestion control to transmit the downlink data flows to arrive as close as possible to the theoretical limit.

DL TCP measured values Using 256 QAM MCS 20 with theoretical throughput of 143 Mbps	
Application rate [Mbps]	143
Throughput [Mbps]	141

For the uplink, the theoretical limit is not achieved as the maximum uplink MCS was limited to 9 (see the table below). Closer results to the theoretical limit of 36 Mbps can be obtained by using UL MCS 16 (35.5 Mbps), which as reported above may cause issues of TCP retransmissions to the UE in bad radio conditions.

UL TCP measured values Using 4 QAM MCS 9 with theoretical throughput of 36 Mbps		
Application rate [Mbps]	10 M	20 M
Throughput [Mbps]	10	18,6
packet loss [%]	0	0,17
jitter [ms]	1,338	5,462

3.4.2 Throughput: UDP performances

UL UDP reflects TCP results in terms of achievable throughput (around 18 Mbps), so we do not report here the values. For imposed higher bandwidth (e.g. 30M, 40M) the maximum achievable throughput remains 18Mbps with an increase in packet loss.

DL UDP, shown in the table below, can reach 40 Mbps with 0% packet loss rate, until 60Mbps with a packet loss rate in the order of 10^{-3}, until 100Mbps a packet loss rate in the order of 10^{-2} and above that threshold the throughput can increase but the packet loss goes above 10^{-2} which is the maximum tolerable by our network requirements as shown in Table 3-2.

Table 3-2 DL UDP measured values

DL UDP measured values Using 256 QAM MCS 20 with theoretical Throughput 143 Mbps											
Application rate [Mbps]	30M	40M	50M	60M	70M	80M	90M	100M	110M	120M	130M
Throughput [Mbps]	30	40	50	60	69,8	79,6	89,6	99,3	107	118	123

packet loss [%]	0	0	0,02	0,027	0,32	0,48	0,45	0,74	2,7	1,3	5,6
jitter [ms]	0,549	0,362	0,24	0,206	0,178	0,151	0,122	0,126	0,522	0,122	0,086
Loss Rate	N/A	N/A	10^{-3}	10^{-3}	10^{-2}	10^{-2}	10^{-2}	10^{-2}	10^{-1}	10^{-1}	10^{-1}

3.4.3 Latency: RTT

We also measured the round-trip time for different packet sizes and inter-departure time that are shown in Table 3-3 below in-lab and on-field.

In-lab results:

Table 3-3 RTT

RTT										
	packet size									
	128			780			1300			bytes
idt	min	avg	max	min	avg	max	min	avg	max	
1	5.829	6.648	7.549	8.376	10.265	14.935	8.396	10.241	15.082	ms
0,5	5.334	6.601	10.558	8.304	10.284	14.350	8.291	9.926	14.075	ms
0,2	5.226	6.937	11.330	8.224	10.214	14.795	8.623	10.169	14.915	ms
ms										

On-field RTT values during the outdoor testing in Alba Iulia (RO) using Inter departure time (idt) = 1ms and Packet size = 64 bytes provide instead:

RTT ms	measure
8,83	avg
6,69	min
26,3	max

As expected, due to the channel quality dynamic variation in the outdoor scenario, the average RTT increases with respect to the in-lab case {idt=1ms, ps=128 bytes (double of the packet size as in the outdoor)}, as well as the difference between the maximum and minimum measured values even with the better injection conditions of ps=64 bytes.

3.5 Other UCs under 5G-VICTORI scope

The same methodology can be reproduced for any other use case that makes use of a private network having the same network requirements. In fact, what changes among the various use cases are just the throughput and RTT (network requirements). The throughput and RTT is provided by the network thanks to the topology chosen (i.e. MIMO and Bandwidth / Radio Resource Control - RRC): the topology can be changed to accommodate the network requirements asked by the UCs. Given that dimensioning of the 5G network from both the SW and HW point of view has been done to support a specific UC network requirement, the extension to other UCs with different network requirements would require either to check that the relevant Service Level Agreement (SLA) fall into the measured KPIs or re-dimension the network based on the given SLA.

4 Environmental Performance

4.1 Introduction

The relevance of evaluating energy consumption and efficiency of ICT services and infrastructures is based on its tremendous growth. Global computing power for internet-connected devices, high resolution video streaming, emails, surveillance cameras and a new generation of smart TVs is increasing at a rate of 32 % p.a. One of the fastest growing segments is wireless ICT driven by an increasing demand for mobile broadband. The growth rate of global mobile data traffic is 63% p.a. [10]. With increasing demand, wireless network infrastructures are rapidly expanded on a global scale. These developments lead to a steep increase in energy consumption and related carbon emissions of ICT in general and high performance wireless network infrastructures in particular. A considerable and still growing amount of worldwide energy is already consumed by ICT: around 7 % of the global electricity consumption equaling roughly 2.000 TWh p.a. in 2020 and are expected to rise to 3.200 TWh in 2030 [11]. Up to now, wireless systems have been optimized in terms of spectrum efficiency and transmission reliability. Their environmental performance and especially energy efficiency and environmental impact have been largely overlooked. Against the background of the high growth dynamics described above, energy-efficient design and operation of high performance wireless communication systems such as 5G is an issue of utmost importance and has to be systematically addressed. Optimizing energy efficiency of wireless communication infrastructures not only reduces environmental impact, but also reduces overall network costs.

In response to this, several 5G-PPP projects address issues related with energy consumption associated with the operation of 5G infrastructures, for example 5G-PICTURE, 5G-PHOS, 5G TRANSFORMER, blueSPACE, IoRL, METRO-HAUL and 5G-MEDIA [12] and the CELTIC-Plus project SooGreen [13].

Recognising the impact of 5G infrastructures on the CO_2 footprint of the planet 5G-VICTORI also performs an environmental assessment of the proposed platform. This assessment aims at evaluating the performance of the 5G-VICTORI platform in terms of energy efficiency considering the use cases in scope. More specifically, it focuses on a power consumption related evaluation for the 5G-VICTORI solution when deployed in a realistic context and scale (city level) for the UCs in scope. This evaluation includes dimensioning and operating the 5G-VICTORI platform with realistic service demands and deriving the overall platform power consumption levels based on real (experimentally measured) power consumption data for the 5G technologies deployed by the 5G-VICTORI platform.

4.2 Experimental evaluation of the virtualized RAN

During the first part of the analysis, we focus on the evaluation of the power consumption of the virtualized gNBs under different configuration settings. The gNB considered in 5G-VICTORI is hosted in a RAN cluster deployed in a private cloud facility. The operation of the gNB is supported by General Purpose Processors (GPPs) (x86) that can be accessed through appropriate interfaces (i.e., O-FH, F1). To optimally design the overall system, it is very important to identify the computational requirements of the virtualized gNB processing functions. This is important as with this input we can analyze the specificities and characteristics of the individual processing functions forming the BaseBand Unit (BBU) Service Chain. In the next step, the findings of our studies are extrapolated to determine the overall power consumption of the system under large scale deployments.

To perform our study we rely on an open-source implementation of its protocol stack using OpenAirInterface (OAI). Based on this platform, the BBU processing requirement of its individual PHY elements is analyzed for various wireless access requirements and traffic load scenarios. The performance of the gNB is monitored using the Prometheus Node Exporter module, while all measurements are stored in influxDB. The numerical results have been extracted using actual traffic generated from 5G Customer Premises Equipment (5G-CPEs). A snapshot of the generated traffic used as input to the 5G system is shown in Figure 4-1. We initially evaluate the processing requirements of the gnB for different data rates. The system has been deployed in a compute system using an Intel i7 12900K CPU with 12 cores overclocked to 3.4GHz. For this experiment 8 out of 16 cores have been allocated to the system hosting the gNB operations.

The allocation of the different gNB processing tasks to the various CPU core nodes is shown in Figure 4-2. We observe two main trends: a) tasks processed by CPU4 are traffic independent and remain constant for the whole duration of the experimentation. These tasks are generated by the lower layer functions (PHY) of the gNB which have strict performance requirements. b) tasks allocated to CPU3 are network traffic dependent and are related to functionalities of the upper layer protocols of the gNB.

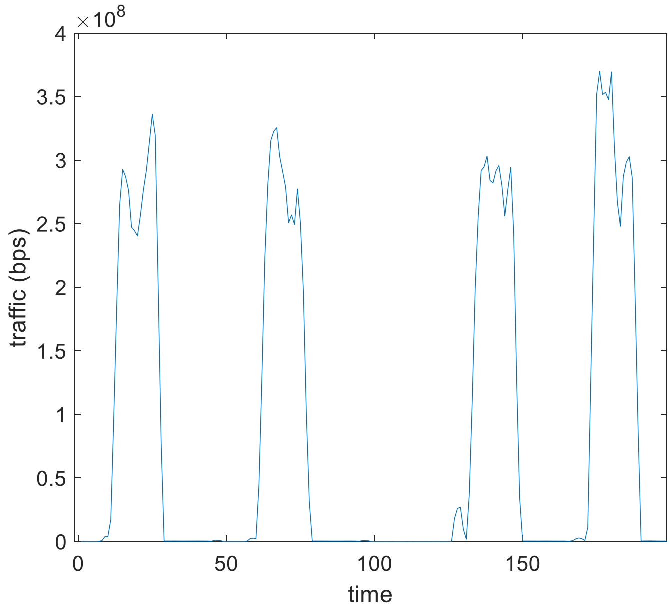


Figure 4-1 Timeseries of traffic used as input in the 5G system.

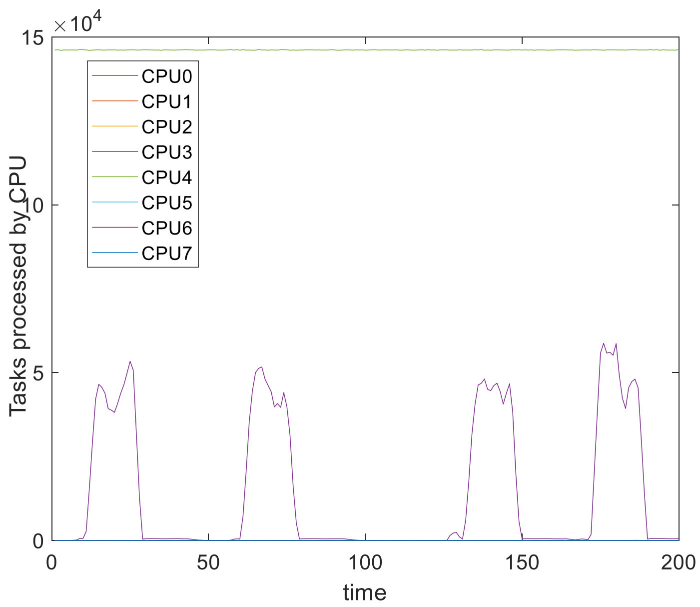
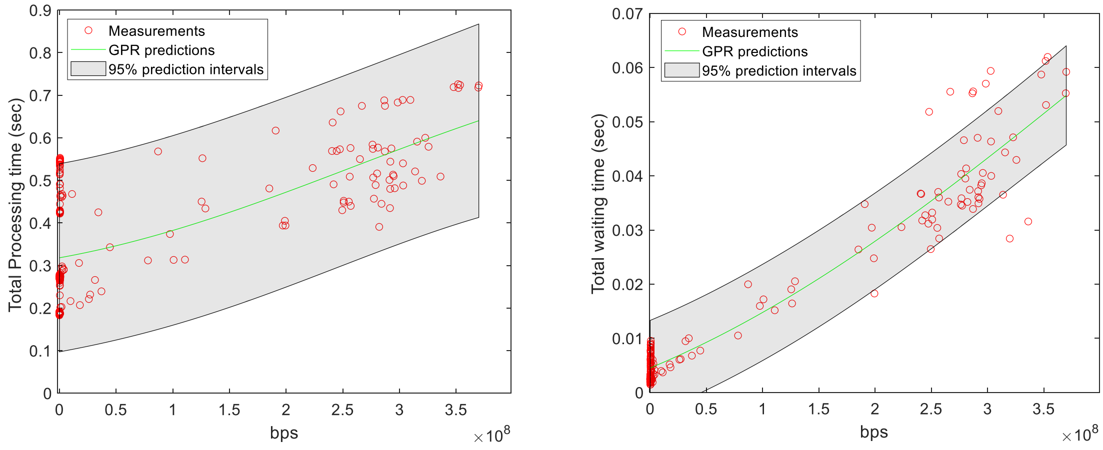


Figure 4-2 Allocation of gNB processing time to the cores of the CPUs



a) b)

Figure 4-3 Profiling of gNB processing requirements: a) total processing time by all CPUs for all gNB tasks, b) total waiting time in the CPUs for all gNB processing time.

The total processing and waiting times for gNB tasks allocated to all CPU cores are shown in Figure 4-3 a) and Figure 4-3 b), respectively. The corresponding measurements are indicated with the red dots. As expected, an increase in the network traffic increases the number of tasks that need to be processed resulting in an overall increase of the total processing and waiting time at the CPUs. For this configuration, the maximum throughput that can be achieved by the 5G platform is 350Mbps: above this threshold the CPU does not have the necessary capacity to handle the incoming processing tasks. Therefore, the total waiting and processing time of the gNB violates the timing delays imposed by some protocols of the 5G-NR stack (i.e., Hybrid automatic repeat request (hybrid ARQ) - HARQ) resulting to timeouts and packet retransmission. At this point it should be mentioned that in addition to the measurements obtained from the experimental 5G platform, an analysis has been also performed to identify a set of models characterizing the relation between total processing and waiting times with the network load. This type of analysis will be then used to generalize the results obtained and investigate the performance of 5G-VICTORI platform under large scale deployments. To achieve this, we have used the collected measurements to train a specific Machine Learning (ML) model called Gaussian Process Regression (GPR). The relevant GPR model is indicated with the green line while the grey area indicates the prediction intervals with 95% confidence.

Finally, the total power consumption of the gNB as a function of network traffic is shown in Figure 4-4. When the gNB is in idle mode, its total power consumption is approximately 145 Watt with measurements ranging between 142 and 151Watt. This variation in attributed to background tasks executed by the containerization platform which cannot be isolated. Under full loading conditions, the maximum power consumption of the gNB is 164 Watt. As before, to extract the relation between the power consumption and the input network traffic a GPR model has been also trained indicating an almost linear relation between network traffic and power consumption verifying our previous results reported in [14].

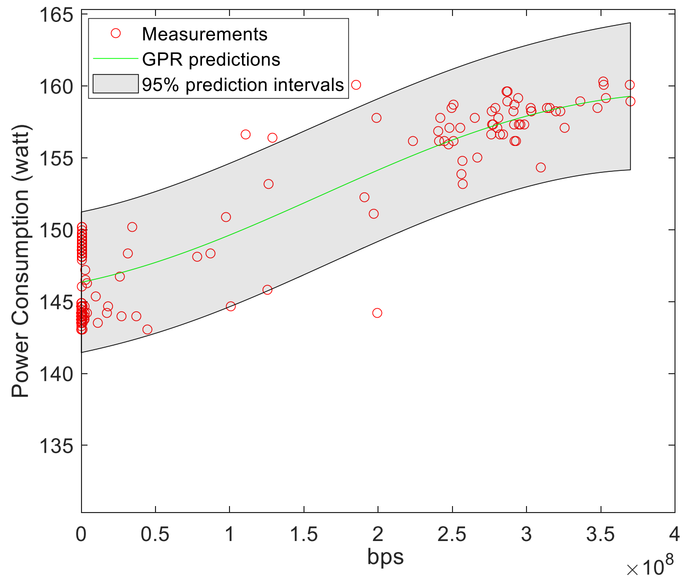


Figure 4-4 Power consumption of the gNB

4.3 5G Core Network

The next part of the analysis focuses the performance evaluation of the 5G core network components. A high level diagram of the environment used to evaluate the 5GC elements is shown in Figure 4-5 a). This includes the set of *physical resources* (compute nodes and SDN controlled switches), the pool of *virtual resources* managed by OpenStack which are used to create the public cloud environment and, *the virtualized 5G network functions (5G VNFs).* To automate the whole service provisioning phase, the Management and Orchestration (MANO) framework has been also deployed – based on Open Source MANO (OSM). All building blocks of the system are monitored using Prometheus node exporters while metrics characterising the performance of either a physical or a virtualized compute node are extracted and stored to a timeseries database. In addition to this, the power consumption of the physical infrastructure is monitored using metered outlet Protocol Data Units (PDUs). All metrics stored in the Monitoring Platform can be also virtualized using appropriate dashboards.

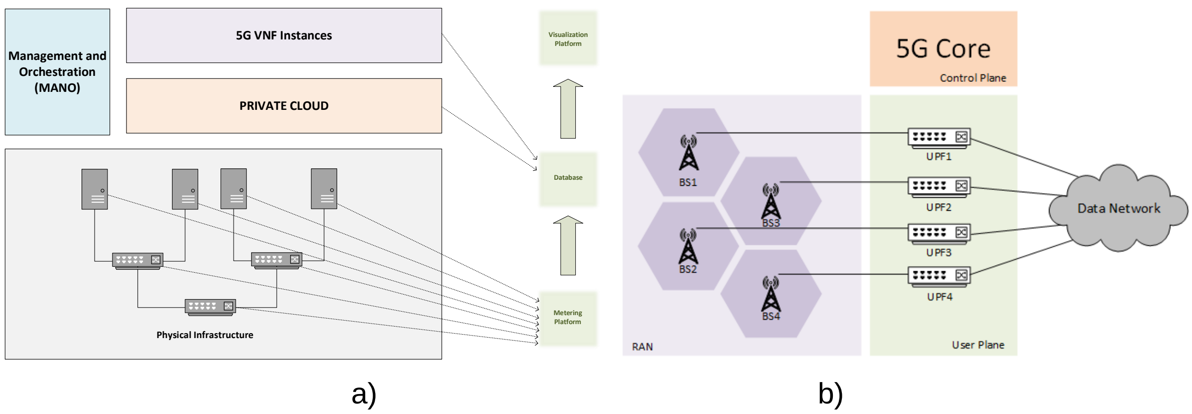
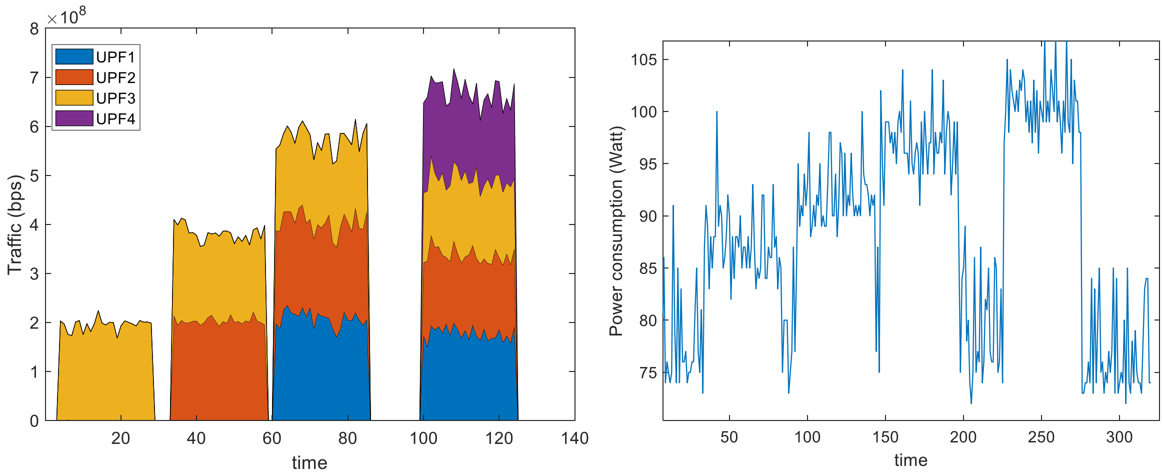


Figure 4-5 a) Cloud Environment hosting the 5G VICTORI platform b) 5G Network Connectivity

The environment shown in Figure 4-5 a) is used to support the provisioning of end-to-end service slices over a variety of 5G network deployment options and topologies. A typical example of a network topology used to evaluate the efficiency of the 5G-VICTORI solution is shown in Figure 4-5 b). For the RAN segment, a combination of actual gNBs – based Software-

Defined Radio (SDR) devices using NI B210 and N310 USRPs – and emulated RAN elements have been used interconnected with multiple virtualized User Plane Functions (UPFs). Instantiation and configuration of the full system is performed through an OSM platform. To evaluate the performance of the 5GC elements, UE connections are initiated in all four gNBs that trigger data traffic generation, which flows through the UPF nodes by the N3 interface. Initially, we create a static traffic flow of approximately 200Mbps using an iperf connection from the UE to an iperf server hosted in the Data Network (right part of Figure 4-5 b). We repeat the same process by gradually increasing the number of UPF nodes that operate in the system. In our experimentation process, MANO has been configured to deploy all UPF entities in the same physical machine. During this traffic flow we monitor the resource consumption of the whole environment, as mentioned above. Figure 4-6 a) shows a sample of the network traffic generated in the RAN segment terminated at the different UPF nodes. For this time period, the corresponding power consumption time series of the server hosting the UPF nodes is shown in Figure 4-6 b).



a) b)

Figure 4-6 Samples of a) Network traffic reaching the 5GC and b) power consumption time series as measured by our experimental platform.

The total power consumption model of the UPF as a function of network traffic is shown in Figure 4-7. We observe that, when the UPF is in idle mode, its total power consumption is approximately 78 Watt with measurements ranging between 70 and 85 Watt. This variation in attributed to background tasks executed by the virtualization platform. Under full loading conditions, the maximum power consumption of the UPF is 109 Watt. As before, to extract the relation between the power consumption and the input network traffic a GPR model has been also trained. The relevant GPR model is indicated with the green line, while the grey area indicates the prediction intervals with 95% confidence.

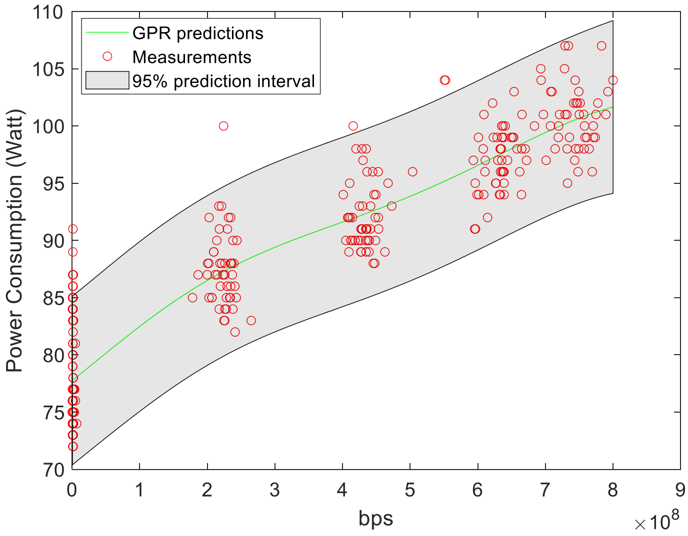


Figure 4-7 Power consumption model for the UPF nodes as a function of the network load

Finally, the total processing and waiting times for UPF related tasks allocated to all CPU cores is shown in Figure 4-8 Figure 4-3 a) and Figure 4-8 Figure 4-3 b), respectively. The corresponding measurements are indicated with the red dots. As expected, an increase in the network traffic increases the number of tasks that need to be processed resulting in an overall increase of the total processing and waiting time at the CPUs.

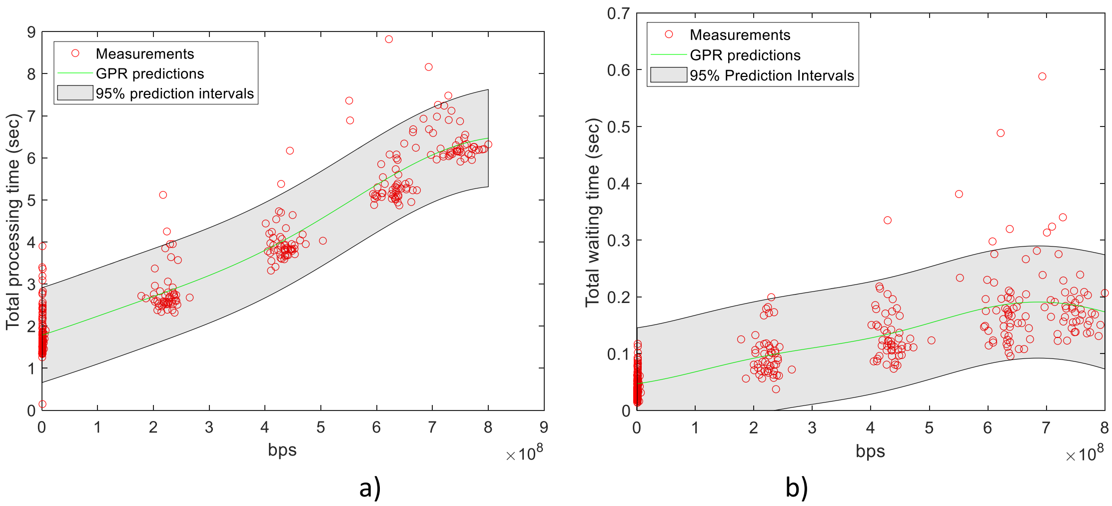


Figure 4-8 Profiling of UPF processing requirements: a) total processing time by all CPUs for UPF tasks, b) total waiting time in the CPUs for UPF elements

4.4 End-to-end Lab Scale Evaluations

In the present section, a small scale evaluation of the whole system in a lab scale environment is performed [15]. To achieve this, we consider a Beyond 5G (B5G) system comprising a set of multi-vendor Software Defined Networking (SDN)-controlled optoelectronic switches with different capabilities (in terms of number of ports, capacity per port, latency) interconnecting Remote Units (RUs) with compute nodes hosting 5G data plane functionalities implemented based on OAI (https://openairinterface.org/). The opto-electronic transport network is organized in a hierarchical manner (Figure 4-9a) offering RU connectivity, collecting and aggregating transport traffic from various cells to a central location. The access network is equipped with low energy consuming switching nodes having limited number of input ports and relatively small capacity (capacity 1/10GbE per port, with SFP, SFP+ and RJ 45 transceivers). High-end switches with higher capacity and density (10G/40G/100GbE/ports) are placed in the aggregation and core network segments offering much higher energy efficiency (lower bit/Joule) under high utilization compared to low-end switches. For the compute domain, we consider edge servers attached to the access switches and central cloud servers connected to the aggregation/core switches. Depending on the mobile service latency requirements, various functions can be placed at different network locations. For this system set-up, a critical decision taken by the 5G-VICTORI orchestrator is where and through which paths RU demands will be routed to the appropriate compute facilities.

As traffic demands have specific requirements in terms of isolation, security and QoS guarantees, appropriate management and end-to-end orchestration mechanisms play a key role. These mechanisms are supported by the top layer of the proposed architecture (Figure 4-9 a) offering tools that allow design of new services, monitoring and management of services throughout their lifetime as well as service onboarding. In accordance with the Zero touch network & Service Management (ZSM) framework [16] and in order to address the highly complex environment of B5G networks, an intelligent/semantic management plane is introduced that interacts with all building blocks of the system enabling appropriate decision making for optimal system performance. This is achieved through a purposely developed intelligent management framework developed by the 5G-VICTORI project relying on a set of building blocks aligned with the ITU-T Y.3172 [17] standard providing a set of microservices including: i) design of custom ML pipelines, ii) orchestration of ML pipelines through the ML Function Orchestration (MLFO).

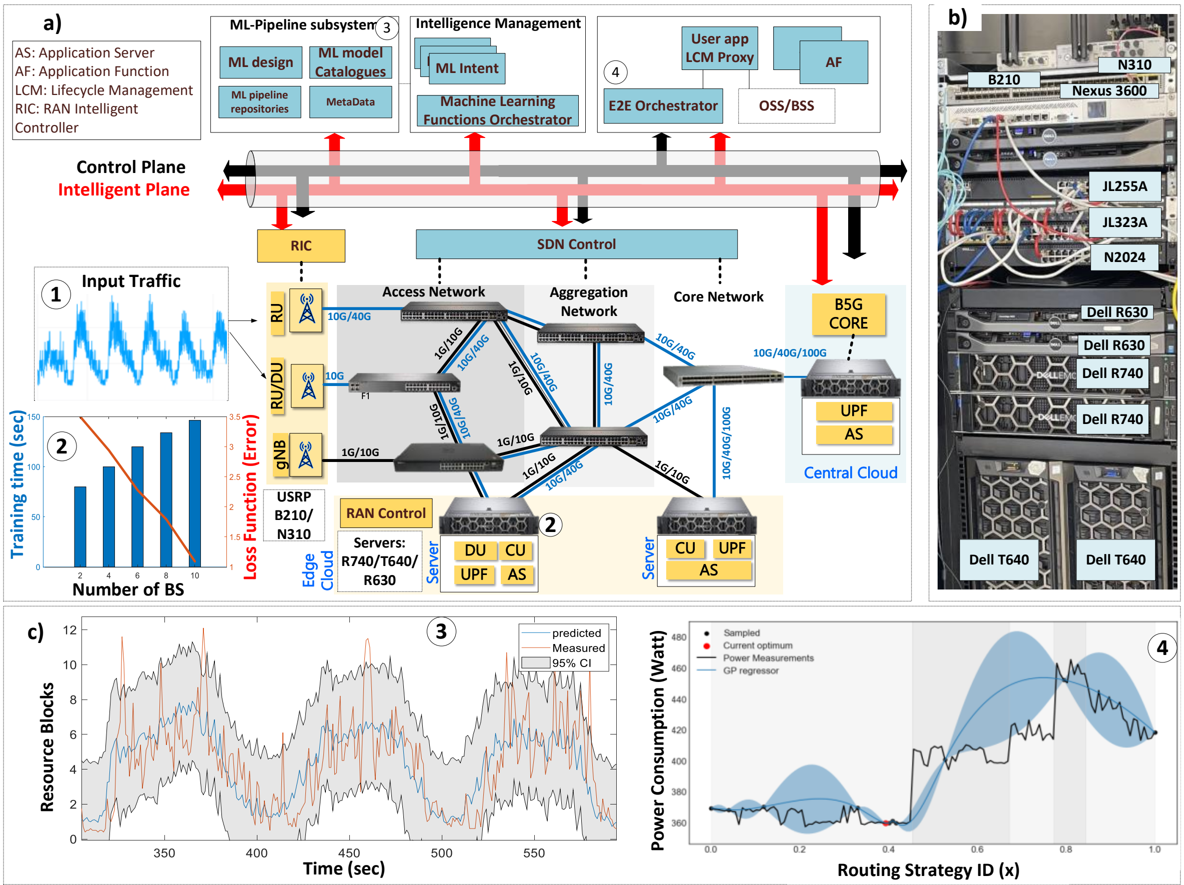


Figure 4-9 a) Network configuration, b) Experimentation infrastructure, c) ML pipeline for energy minimization: 1) Input traffic flows, 2) Optimal Placement of ML functions, 3) GPR model estimating RBs in RAN, 4) E2E Energy-aware optimization: The Bayesian solver identifies optimal routing strategy (red dot) minimizing power consumption. Results extracted for incoming traffic 150Mbps.

To minimize the power consumption of 5G systems, an ML-pipeline has been designed and deployed in the testbed of Figure 4-9 a). This pipeline performs a set of operations including [45]:

1) collection of energy, traffic, and resource utilization statistics. This functionality is achieved through appropriate interfaces implemented across the different layers of the platform. Monitoring data are transferred using a dedicated slice ("intelligent plane") as shown in Figure 4a) with 1sec sampling frequency. The relevant metrics are stored in a distributed manner either at the edge or at the central cloud facility. The decision where each collected measurement is stored is taken by the MLFO after validating the tradeoffs between accuracy and complexity. An example is shown in Figure 4-9 a) (2) where the tradeoff between prediction accuracy (measured in terms of Loss-function) and complexity (training time) for different number of base stations (BS) storing their statistics in a collocated edge server is depicted. Numerical evaluations have been carried out using a GPR model predicting mobile network traffic with optimized hyperparameters.

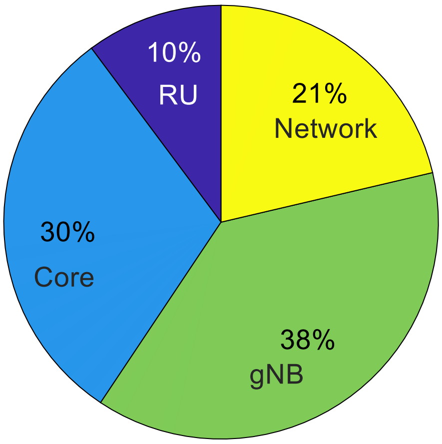
2) Predictive Analytics ML model training: In the second step of the ML pipeline, descriptive and predictive statistics of the 5G platform affecting the provisioned service are extracted. Typical examples are shown in Fig.1c) where two GPR models have been trained predicting the resource blocks (RB) of a specific BS in the RAN and the waiting delay in the CPU of the containerized DU/CU functions [44]. The relevant trained ML models are stored in the ML-repository which can be then used by the end-to-end orchestrator as constraints.

3) Prescriptive analytics: In the next step of the ML pipeline, an ML model that optimizes the system for energy efficiency is created. This is achieved applying Bayesian Optimization techniques with the objective to identify optimal strategies (optical transport routing paths) minimizing energy consumption. The relevant problem can be written as a constraint Bayesian Optimization problem of the form [46]: $min\, \mathcal{E}(\mathbf{x})\, , s.t.\; \mathrm{c}(\mathbf{x}) \leq \Lambda\, ,$

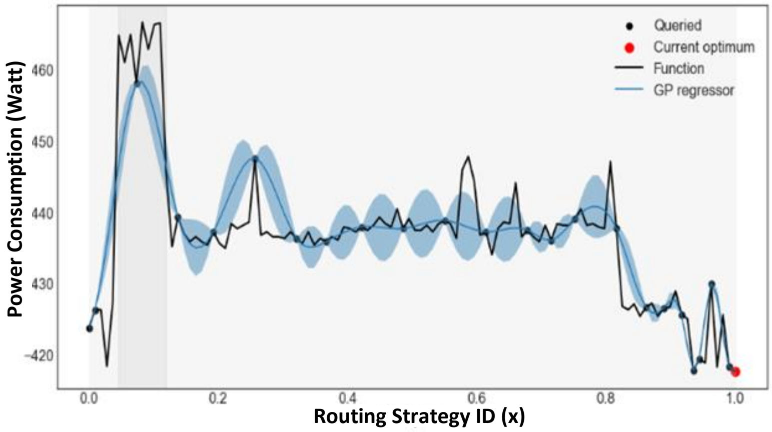
where $\mathcal{E}(\mathbf{x})$, is the energy consumption function under routing strategy $\mathbf{x}$ and $\mathrm{c}(\mathbf{x}) = [c_1(\mathbf{x}), \dots, c_m(\mathbf{x})]$, $\Lambda = [\lambda_1, .., \lambda_m]$ is the set of inequality constraints that need to be satisfied for the system to operate. These functions are estimated using the corresponding GPR models available through the previous step of the ML pipeline. The Bayesian optimizer available through the ML repository solves the problem and identifies the optimal routing paths $\mathbf{x}$. As shown in Figure 4-9 c (4), GPR is used to approximate $\mathcal{E}(\mathbf{x})$ with specific probability under different routing strategies $\mathbf{x}$ and the Bayesian solver finds routing policy $\mathbf{x}$ that minimizes power consumption.

4) Deployment: In the final step, the decision is communicated to the SDN controller to apply optimal routing policies.

We evaluate the performance of the whole 5G system configuration using the testbed shown in Figure 4-9 b). The power consumption of the system is monitored through metered outlet power distribution units. The input traffic was generated using iperf. Figure 4-10 a) shows the average power consumption per segment. The RU corresponds to the power consumption of the USRP N310. The network consumption accounts approximately for 21% of the total energy consumption. It should be noted that all measurements have been carried out using short reach transceivers. Figure 4-10 b) shows a snapshot of the Bayesian optimization process for a scenario where the incoming mobile traffic per gNB is 300 Mbps. Through sampling history measurements, the Bayesian solver approximates power consumption as a function of the available routing strategies and determines the specific routing policy (pointed out with the red dot) that minimizes the total power of the system. Finally, a comparison between the proposed policy and a preconfigured static routing policy is shown in Figure 4-10 c). The proposed model setup tunnels between the RUs and the application server (AS) through the most energy efficient paths in the optical domain reducing by an average of 50% of the optical network power consumption and 10% of the total system consumption.



a)



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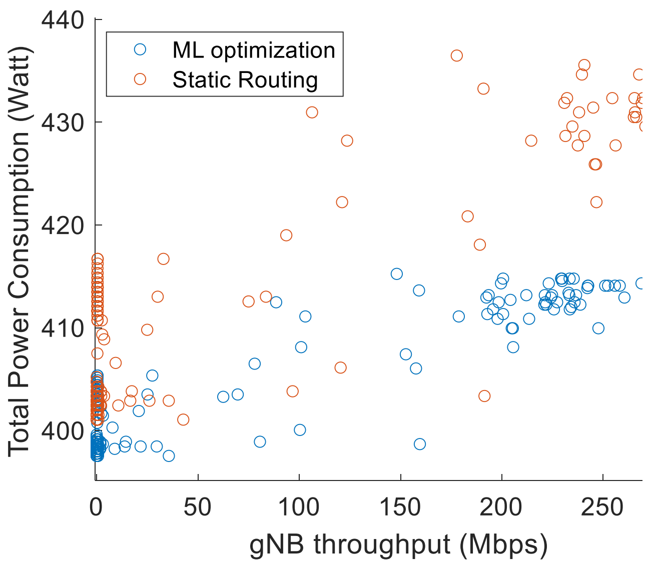


c)

Figure 4-10 a) Power consumption per domain, b) Energy-aware optimization using Bayesian techniques: Example for traffic/gNB 300Mbps, c) Total power consumption as a function of traffic/gNB for the static and dynamic routing using ML optimization

4.5 City-Scale Evaluations

To evaluate the performance of the 5G-VICTORI platform in a city scale enviroment we use a dataset for the city of Milano available online through [14] that includes a set of Call Detail Records (CDRs) of subscribers (see Figure 4-11).

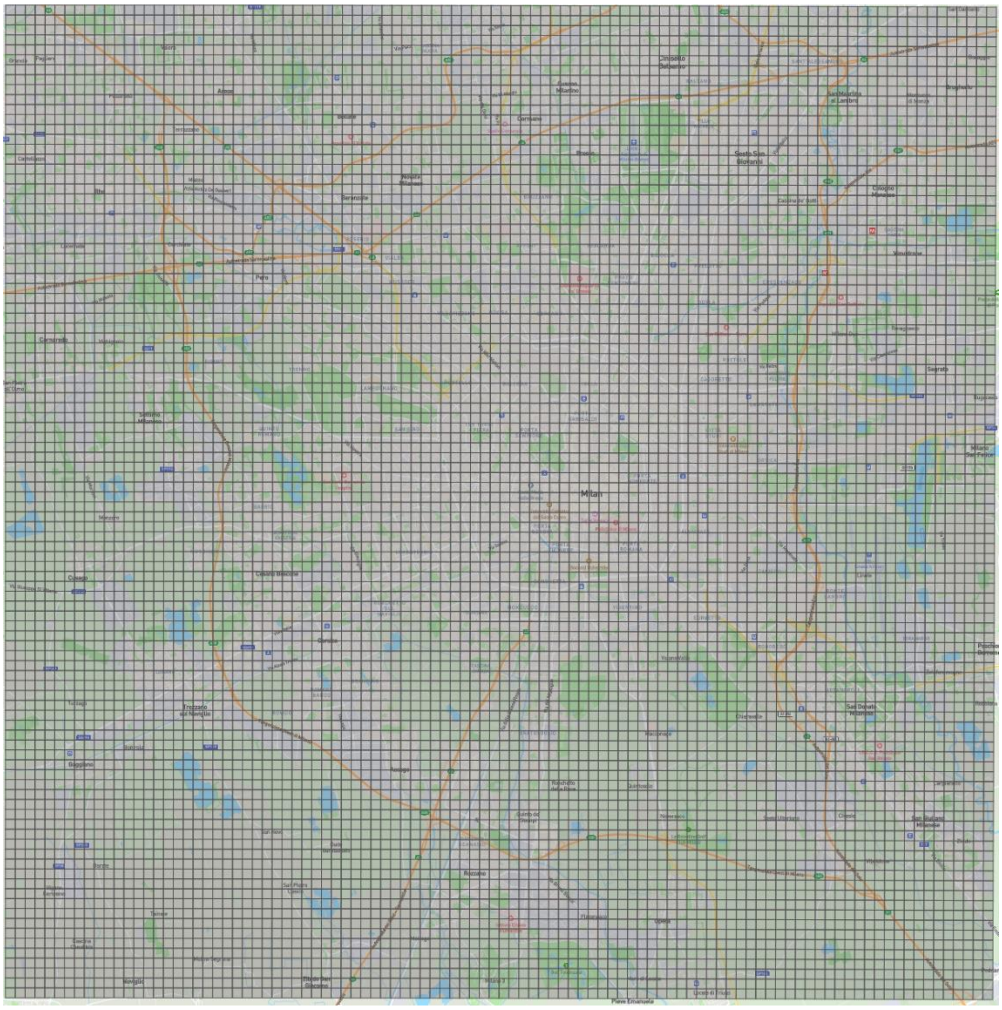


Figure 4-11 City of Milano data grid

To investigate the spatio-temporal behaviour of mobile UEs, CDRs are organized in geographical grids where for each grid users' activity is recorded.

A typical sample of the dataset that are used in the analysis is shown in Table 4-1. The first column contains the grid location (Cell-ID) being a unique number which can be used to identify the cell location where measurements have been collected. The second column contains the timestamp, the third column is the international call prefix (phone code of the country to which the data are addressed to). Phone code 0 is referred to all the countries for which there is no specific mention. That means, for each cell in each 10-minute interval there may be more than 1 rows that describe telecom activity towards different countries. Finally, it should be noted that Internet traffic is undivided, and it is solely noted in the row with code 39 (important for later on). For the remaining table columns the following information is recorded:

- Activity of incoming SMS. CDR is increased every time a user receives an SMS, in the given Cell-IDs and time intervals.
- Activity of outgoing SMS. CDR is increased every time a user sends an SMS, in the given Cell-IDs and time intervals.

- Activity of incoming calls. CDR is increased every time a user receives a call in the given Cell-IDs and time intervals.
- Activity of outgoing calls. CDR is increased every time a user initiates a call in the given Cell-IDs and time intervals.
- Internet activity. CDR is increased every time a user connects to the Internet, in the given Cell-IDs and time intervals. Moreover, CDRs are born every time an Internet connection lasts for more than 15 minutes or uses more than 5 MB from the network.

Table 4-1 Sample Mobile Network Traffic Statistics

Cell ID	time	Country Code Prefix	Incoming SMS	Outgoing SMS	Incoming calls	Outgoing calls	Internet activity
4869	1383433200000	0	3.063576	0.018883			
4869	1383433200000	20				0.230165	
4869	1383433200000	33		0.345323	0.294651		
4869	1383433200000	359				0.172661	
4869	1383433200000	39	4.81253	9.655957	2.398834	3.336626	142.1432
4869	1383433200000	51				0.230165	
4869	1383433800000	0	2.588877	0.018883			
4869	1383433800000	216			0.877525	0.438387	
4869	1383433800000	39	2.59446	8.277308	1.896983	1.977639	137.5197
4869	1383434400000	0	0.121491	0.018883			
4869	1383434400000	20				0.230165	
4869	1383434400000	39	3.785591	12.50916	2.091885	4.291354	121.4759
4869	1383434400000	86				0.018883	
4869	1383435000000	0	0.249048	0.018883			
4869	1383435000000	1	0.438387				
4869	1383435000000	39	1.26319	6.582697	1.10694	1.570166	128.09
4869	1383435000000	86				0.018883	
4869	1383435600000	0	0.668552	0.018883			
4869	1383435600000	39	0.242982	11.87167	0.172661	0.485168	125.8149
4869	1383436200000	0		0.018883			
4869	1383436200000	39	0.876775	12.28317	1.774238	0.93802	107.977
4869	1383436200000	51				0.741213	
4869	1383436800000	0	1.126573	0.018883			
4869	1383436800000	39	2.405424	6.817175	2.96866	2.610719	120.7997
4869	1383437400000	0	0.018883	0.018883			
4869	1383437400000	39	0.876775	8.633492	0.524317	0.85212	118.4779

For the access, aggregation and core network topologies we consider a variation of the synthetic mobile carrier network topology for the city of Milano proposed in [15] and illustrated in Figure 4-12.

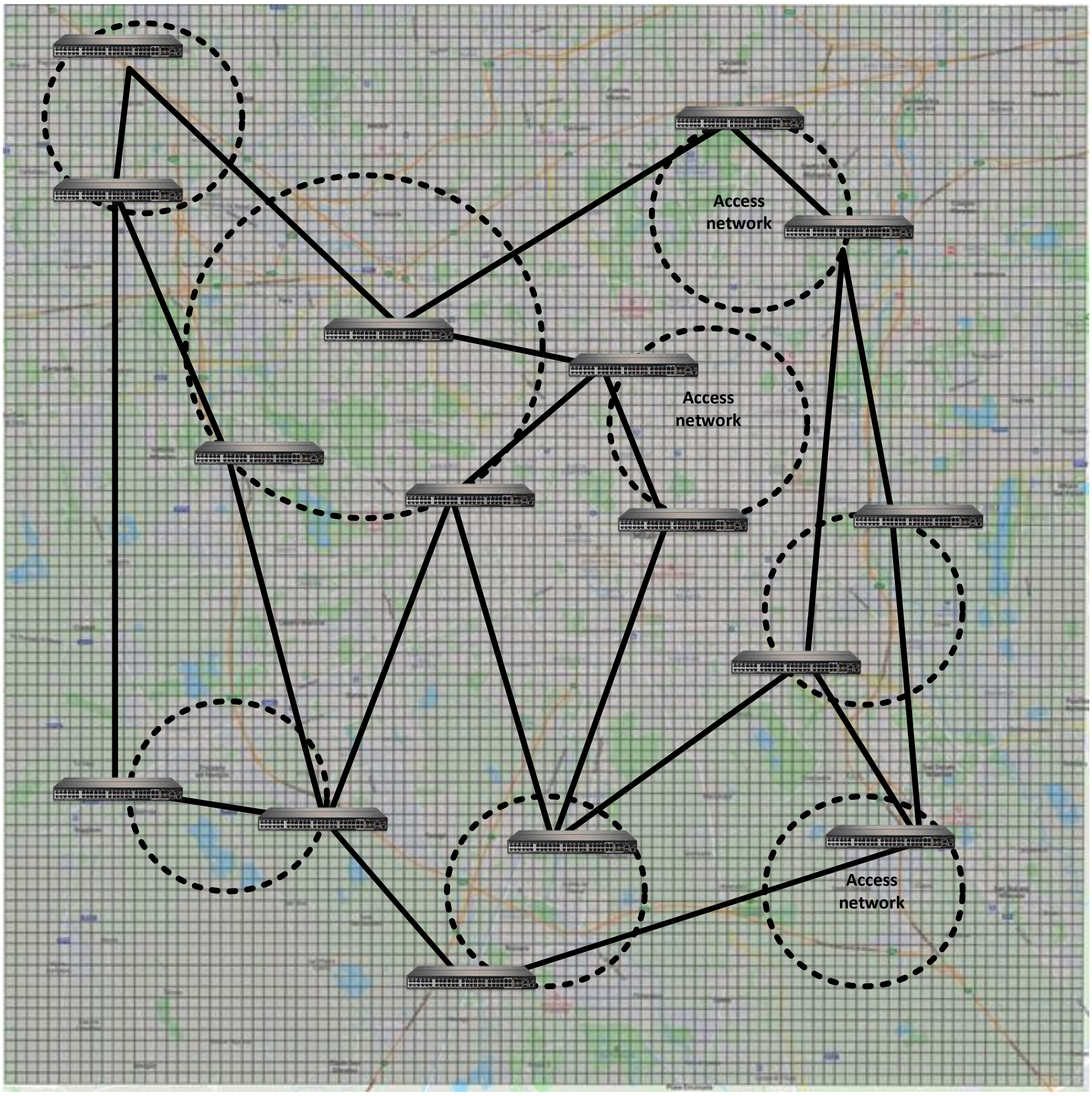


Figure 4-12 City mobile carrier network topology for the city of Milano proposed in [15]

For the input traffic statistics, we use the Milano data grid statistics reported in [14]. The corresponding spatio-temporal measurements for different time instants are shown in Figure 4-13. Overall, we observe that during peak hours (12:00-18:00) traffic is maximized in the city centre of Milano while in the suburban areas traffic the measured mobile network traffic is at low levels. During off-peak hours (i.e. 21:00) mobile network traffic is distributed across a much larger geographic area.

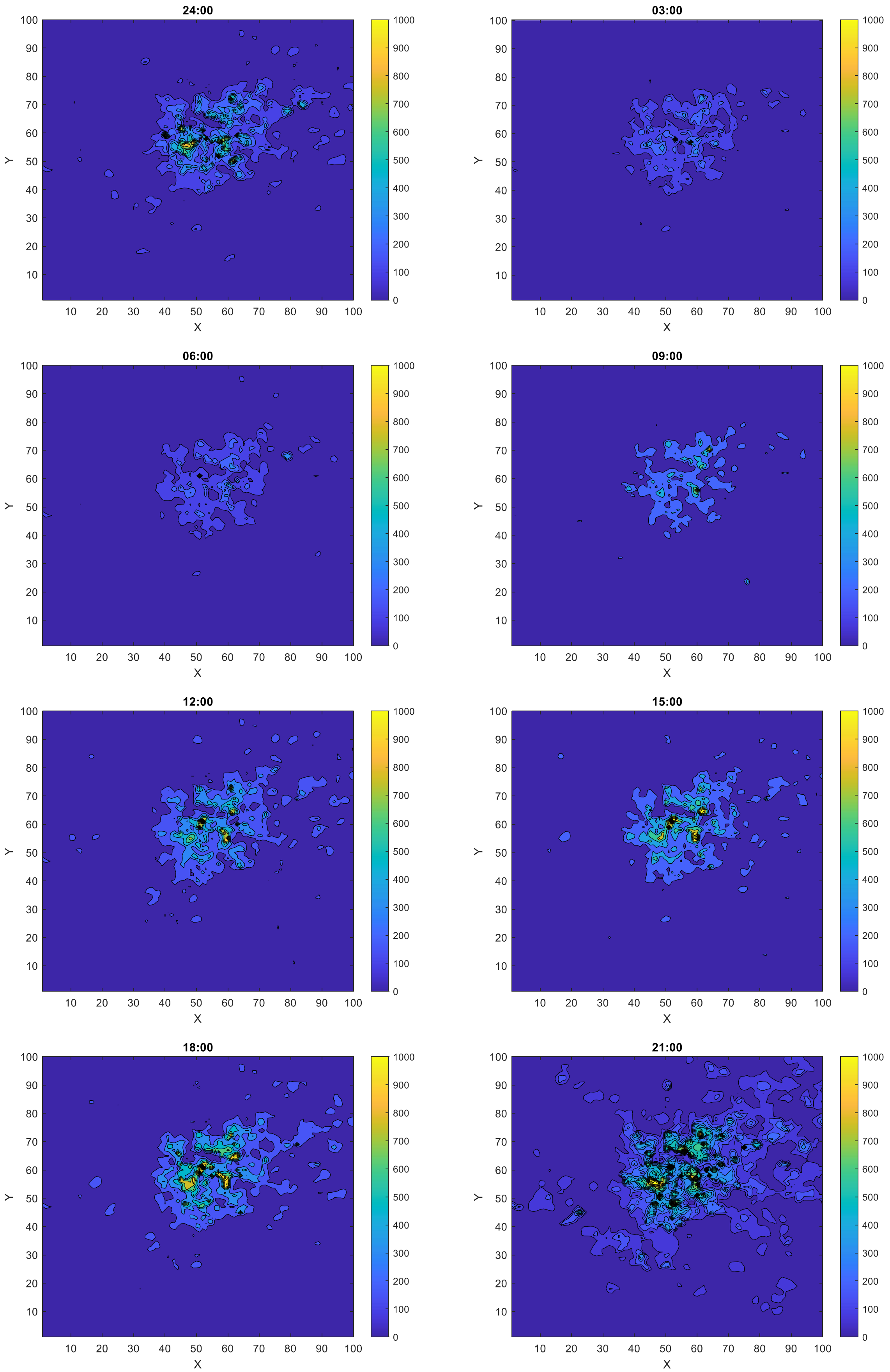
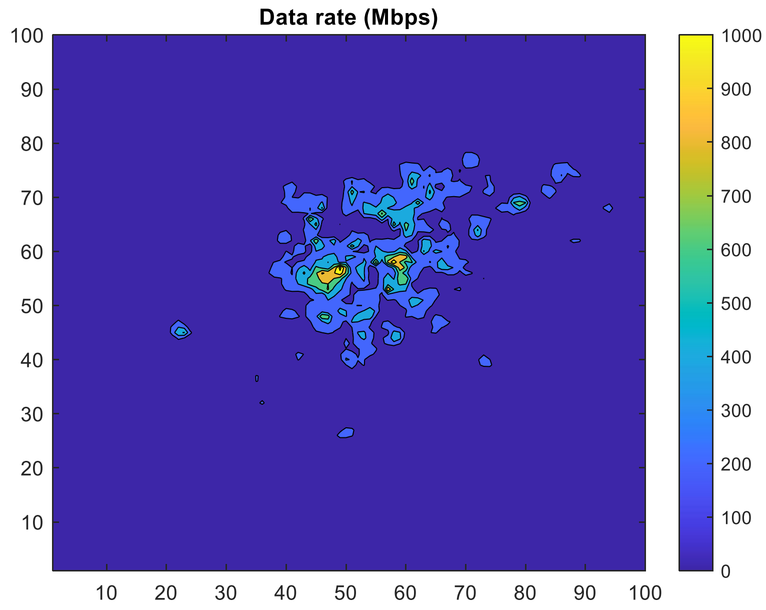
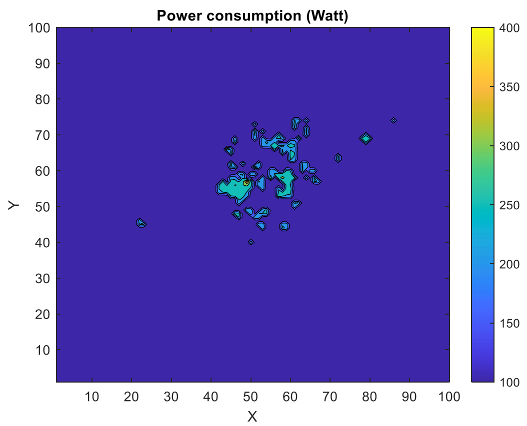


Figure 4-13 Spatio-temporal mobile network traffic statistics for the Milano data grid

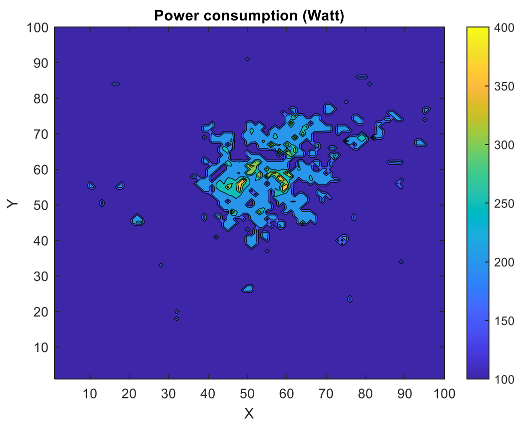
Based on these statistics we compare the power consumption of the mobile communication when the proposed solution is applied compared to the conventional approach where dynamic reconfiguration of the system resources is not possible. The relevant results for a specific traffic input snapshot are shown in Figure 4-14.



a)



b)



c)

Figure 4-14 a) Mobile network traffic snapshot measured over the Milano Grid at 23:00h, Expected Power consumption for the city of Milano when applying b) the 5G-VICTORI solution and c) the Conventional approach

We observe that the 5G-VICTORI solution can achieve a much lower power consumption level (of the order of 20-30%) compared to the conventional scheme as it can dynamically reconfigure compute and network resources of the end-to-end 5G system to meet the input traffic requirements. This is achieved by optimally configuring:

- The RAN segment by assigning the appropriate configuration setting (i.e. RBs) to match traffic requirements in a specific region
- Network resources taking optimal routing decisions for the interconnection of the gNBs with the CN
- the data plane by sizing and placing UPF nodes to the appropriate location

5 Economic Performance

5.1 Scope and objective

5G and beyond access network deployments are expected to appear in various (physical/ vertical) environments as access network extensions of public networks or as Non-Public-Networks (NPN). In many cases the physical/ vertical environments and the necessary network deployments may be very dissimilar to the wide area coverage deployments of existing public networks, raising new challenges in the deployment of the networks. Such cases can be the railway environment or particular Smart-City deployments (e.g. along rivers or roads).

At the same time, it is a fact that 5G and beyond network services will pose stringent coverage and data-rate requirements to access network segments. For transport network segments it will be necessary to support high capacity Cells of Macro Sites (MS), dense layers of high capacity Small Cells (SCs), or/and versatile Distributed and Cloud-based Radio Access Network (C-RAN, D-RAN, O-RAN) setups. For this purpose, the transport network needs to be equipped with mechanisms to support flexible and scalable access network deployments, and converge FH and backhaul (BH) traffic of various functional splits (FS) over a single infrastructure consisting of various wireless and optical technologies.

To this end, delivery of radio access and transport network deployments that are capable to serve the 5G service requirements is not a straightforward task. In practice, many factors need to be taken into account, such as area specifics, deployment feasibility, long-term service roadmaps, traffic demand and growth patterns/forecasts, as well as infrastructure availability, scaling capabilities and the implicated costs. The scaling capabilities and the identification of the implicated costs need to also consider the various deployment phases (over time), in order to pre-estimate the critical, high cost factors and to extract deployment guidelines at network pre-planning stages – prior to the definition of the specific network deployments to be realised.

In this context, the techno-economic evaluation of large-scale alternative network deployments is necessary to identify cost optimizations and to investigate various technological aspects and critical parameters at early stages towards delivering economically viable and sustainable deployments.

5.2 Specification of dimension

The techno-economic evaluation of 5G-VICTORI addresses the infrastructure and network deployment (level) as this constitutes the main, necessary investment for any service provisioning on top at the premises of the verticals under study. The key factors (KPIs) that are evaluated are:

- CAPEX of alternative network deployments.
- OPEX of alternative network deployments.
- Total Cost of Ownership (TCO) of alternative network deployments.

These factors – KPIs, are broadly used in the conduction of techno-economic studies as also mentioned in [18].

As next step, there are two approaches to be followed in the evaluation of the techno-economic viability of 5G-VICTORI deployment paradigms. The first one is to directly compare the 5G-VICTORI deployments with legacy technology deployments. However, this would not be meaningful as the KPIs and operational requirements are not achievable with legacy technologies. The second one, followed in 5G-VICTORI is to assess comparable deployments and analyze the results to optimize techno-economic factors.

5.3 Methodology

In general, performing techno-economic analysis is seldom a straightforward task, the underlying reasons being many and versatile. Some of these reasons are related to the scope and goal of the analysis, the level of detail of input information in terms of deployment area specifics, the network segment and the technologies in focus, the scale of the system and so on. Therefore, there are various types of analysis applied at different stages of a solution commercialisation, with different focuses depending also on the entity performing the analysis (external or internal department, strategy/financial or technical department etc.). An overview of the versatility of techno-economic analyses is provided in [18].

In the context of 5G-VICTORI, the methodology that was implemented with the techno-economic analysis tool comprises the following steps (Figure 5-1):

1 Definition of the area / vertical premises under study. This step aims to define the coverage area (as distance or as surface) and model the physical / vertical premises environment specifics. 5G-VICTORI analysis focuses on two main environments: the Railway area along tracks and on platforms, and a Smart City area especially along roads. The Railway area modelling and evaluation is provided in detail in the following sections. Similarly, the Smart City area deployments can be analysed and assessed using the same methodology and deployment modelling principles.

2 Definition of the service scenarios in terms of coverage area/routes, traffic demand to be served, services to be provided etc. and their scaling over years.

3 Definition of the access and transport deployment blueprint, providing a general model of alternative RAN / BH / FH / Edge / Core Network Options that can co-exist in a deployment.

4 Definition of the scaling rules for each technology and the dimensioning rules for each segment. In practice this includes:

- RAN segment dimensioning: as access network nodes' elements calculation based on capacity and coverage increase over years; considering access radio units capacity, gNBs disaggregation model etc.
- Transport segments dimensioning: as capacity and required links calculation considering the adoption of various Functional Splits, various transport aggregation levels, various transport technologies link capacity/ range/ hops etc.
- Edge segment dimensioning: as compute resources calculation considering the application services and Network Functions requirements, loading factors, etc.
- Core segment placement and dimensioning of UPFs to serve the Edges.

5 Definition of the cost information and its scaling rules for all elements that are modelled/ analysed.

6 Setting of analysis timeframe; commonly set to 5-10 years for telecom network deployments.

7 Definition of the deployment scenario in terms of technologies mix, including selection of Functional Splits, wireless / optical technologies, etc.

8 Iteration of all steps and collection of analytical cost results, in order to identify key factors influencing cost and extract deployment recommendations.

Model Input	
Service	Coverage area - Distance or Surface
	Traffic - Services
Access Network	Cell radius
	Cell capacity - Datarates coverage
	gNBs configuration (#cells/BBU)
	Cell loading
Transport Network	Aggregation levels
	FS Overhead
	mmWave/ Sub6 capacity per link
	Fiber capacity per link
	Average # hops
	Loading factor of transport nodes
Edge	Compute resource reqs per App / Function
	Server capabilities / capacity
	Loading factor of resources
Cost	Elements unit cost
	Equipment instalation cost
	Maintenance & service Cost
	Trenching costs of new fiber deployment /m
	Tax Deduction (% Equipment cost)
	Weighted Average Cost of Capital - WACC

Tool Processing

For one Service Scenario, multiple Access, Transport & Edge Deployment Scenarios can run.

Output	
Access Network Dimensioning	Deployment capacity
	#gNBs elements (Cells, BBUs)
Transport Network	# mmWave elements @ various transport segments
	# Sub-6 elements
	# Optical elements @ various transport segments
	Fiber Deployment in Km (if needed)
Edge & Core	# Distinct locations
	#Units of Compute equipment (RAM, CPU)
	#Units of Edge & Core NFs (e.g. #UPFs)
Cost	CAPEX
	OPEX
	Comparative results of scenarios

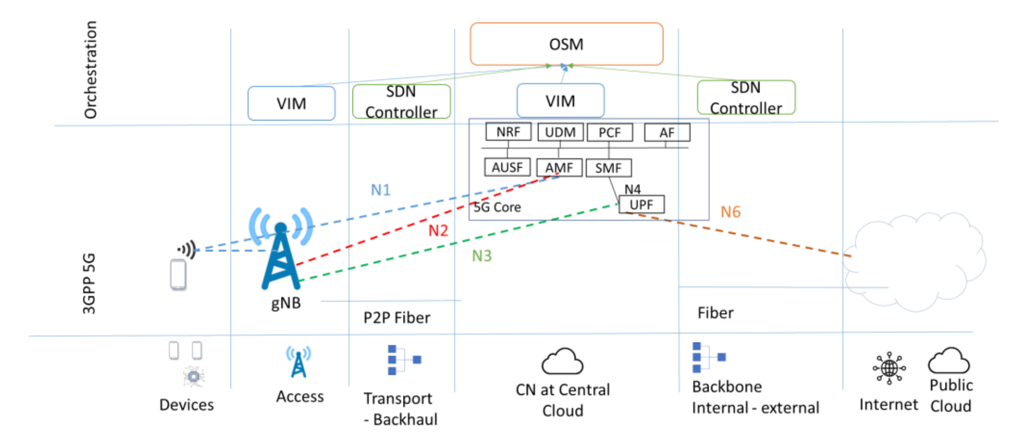
Figure 5-1 5G-VICTORI Techno-economic Analysis Input and Output

The methodology and the fully parameterized expandable techno-economic analysis tool developed in the context of the 5G-PPP Project 5G-PICTURE, http://www.5g-picture-project.eu/index.html [19], [20], were modified to serve for the techno-economic evaluation of the architectural options and technologies of 5G-VICTORI.

5.4 5G-VICTORI Deployment Blueprint and Modelling Aspects

The aforementioned techno-economic methodology at Steps 3 and 4 implies modelling the physical architecture of a 5G network, comprising the necessary access network, the various segments of the transport network, the edge and core network segments. The common set of principles underpinning the 5G network architectures consider 5G networks comprising multiple network and compute infrastructure setups, at finest granularity, including multiple disaggregated pools of network, compute and storage resources. The baseline principles of the physical and logical/functional architecture adopted also by 5G-VICTORI have been described in detail deliverable D2.4 [21], along with various deployment options such as those presented in Figure 5-2.

Deployment Option 1: NPN (using Autonomous Edge)



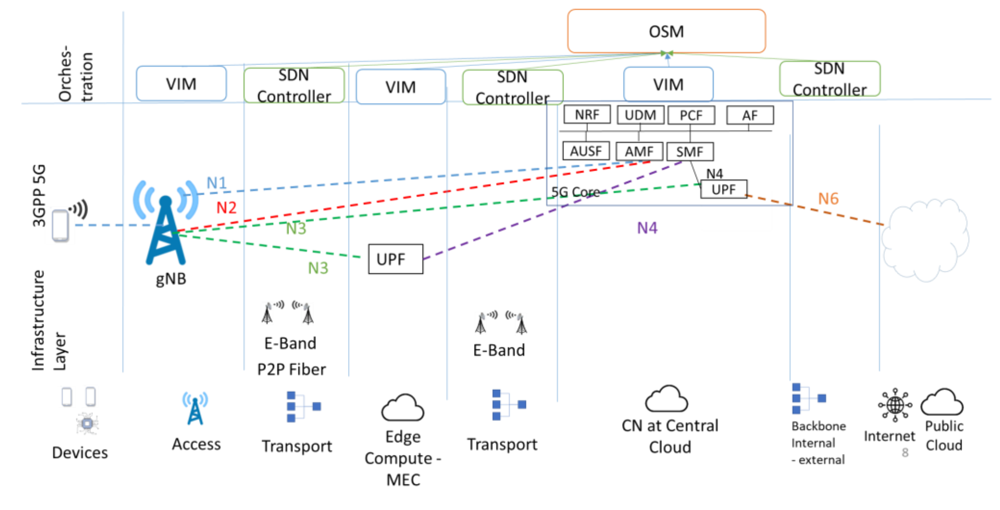
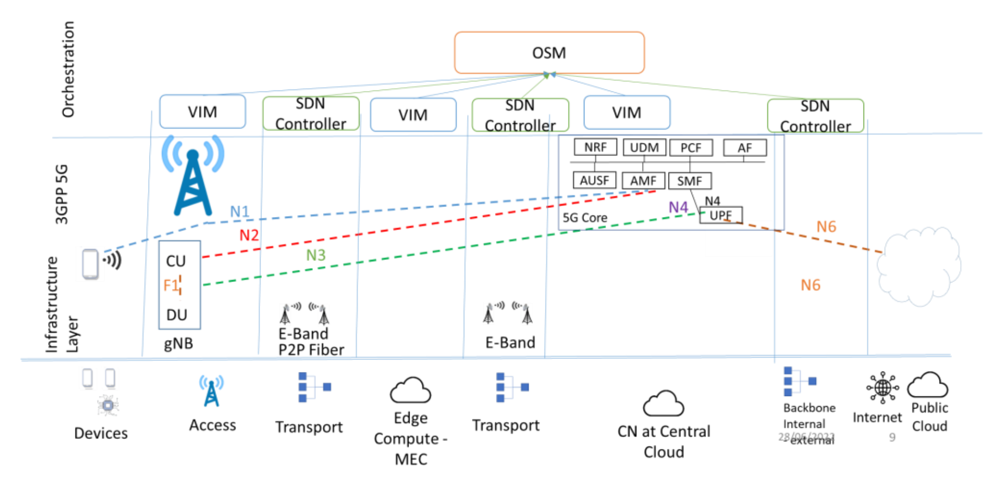
Deployment Option 2: NPN (with distributed data plane – multiple edges)	
Deployment Option 3: Fully disaggregated 5G architecture	

Figure 5-2 5G-VICTORI Deployment Options

The principles and these deployment options are reflected in a general deployment blueprint. The blueprint takes also into consideration the widely adopted network roll-out principle for transport network deployments that comprise multiple hierarchical transport network segments. In general, considering the current trend of minimizing the number of segments from the access to the core network nodes as well as the fact that the deployments under analysis refer to vertical deployments; thus medium scale NPNs, the transport network model comprises three levels/ segments – the access transport segment, the aggregation transport segment and the core transport segment. To model also the case of the extension of access network nodes on-board the trains, the blueprint considers also the option of last-mile transport segment. The overall blueprint that has been used in 5G-VICTORI techno-economic analysis is the following (Figure 5-3):

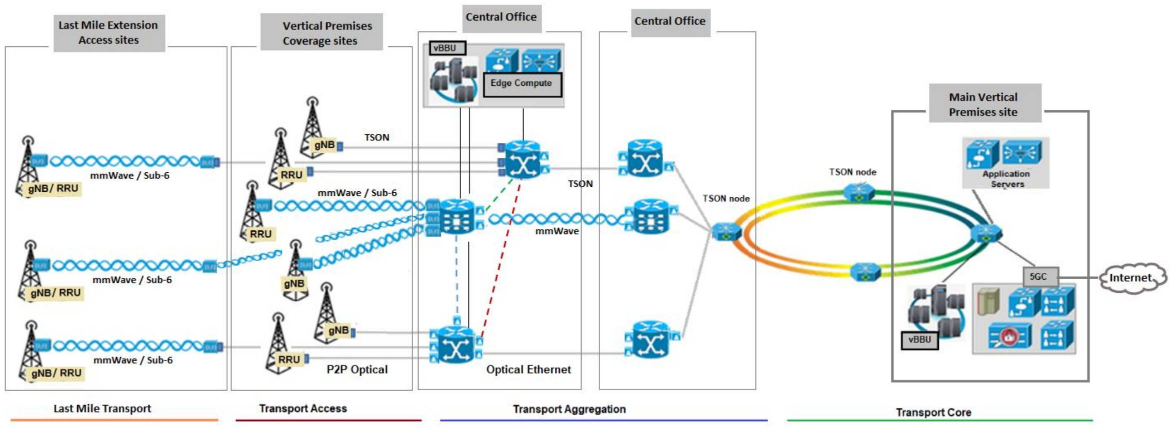


Figure 5-3 5G-VICTORI Physical Architecture Blueprint

5.4.1 Access Network Deployment Principles/Assumptions

Especially, the 5G access network segment comprises a dense layer of small range access network nodes (RRUs and Small Cell gNBs) to serve the high traffic demand at specific hotspot areas of the vertical premises. This layer is complemented by a macro layer of access network nodes (RRUs or macro gNBs) for maximizing coverage over the wider vertical premises area. It shall be noted that the discrimination between RRUs and gNBs is modelled with the transport network modelling where various functional splits (FSs) are considered; at radio network the access nodes' radio coverage characteristics are modelled.

The key technical characteristics of the SCs and MSs that have been modelled are related to:

- SCs/MSs cell capacity – vendor specific input.
- SCs/MSs cell datarates achieved at cell-edge and range of cell-edge; Network Operator specific constraint deriving from communication service-driven radio network planning.
- SC/MSs maximum expected loading factor – Network Operator specific constraint.
- Average number of cells per MS (it can be different per area type: Dense Urban, Urban, Sub-urban, Rural) – vendor and Network Operator specific input.
- Different Functional Splitting (FS) options (referring to eCPRI A to E options).

The access network deployment dimensioning is performed taking into account generic radio-coverage calculations for a certain area especially given a service to be provided at cell edges, as well as forecasts of traffic demand density –especially over a hotspot area.

5.4.2 Transport Network Deployment Principles/Assumptions

Adhering to general transport network deployment principles, the transport network comprises three main segments:

- Transport Access, providing connectivity from the access network nodes to the 1st level aggregation sites (Central Offices)
- Transport Aggregation, aggregating transport access connections at next hop Central Offices
- Transport Core (3rd level transport aggregation) is normally used in large scale, public networks, providing connectivity/routing traffic between COs to the Core network). Given that this techno-economic analysis considers small scale vertical premises deployment, the Transport Core is essentially a single element-interface constituting the last aggregation point of all traffic towards the Core network.

Transport Network Deployment Options

In general the 5G data-plane architecture considers an integrated optical (P2P) and wireless (mmWave and Sub-6) network topology and infrastructure to support jointly backhauling of gNBs, and, fronthauling of various functional Splits of Remote Radio Units (RRUs) to Baseband Units (BBUs). The 5G-VICTORI transport access deployment options are related to the usage of different FSs, to the usage of various wireless and optical technologies and to other deployment specificities.

Deployment Options related to Multiple FSs

More specifically, the 5G-VICTORI concept, architecture and functionality support the coexistence of different FSs over the same infrastructure, namely eCPRI A, eCPRI B, eCPRI C, eCPRI D, eCPRI I_d, eCPRI II_D/I_U, eCPRI E. In practice, the throughput overhead of each functional split needs to be considered in the dimensioning of the transport links between the access network node and the BBU. A simple formula, calculating the transport links throughput on the basis of the access network nodes data bandwidth or capacity and of the splitting option overhead, has been used as follows:

$$T_{FH} = (aT_{cell} + bC_{cell})\left(1 + OH_{split_i}\right)$$

where:

- a,b = {0,1}
- Tcell : data throughput of the cell
- Ccell : maximum cell capacity
- OHsplit_i : overhead, depending by the adopted splitting option

Indicative values of parameters for some functional splitting options are shown in Table 5-1.

Table 5-1 Indicative Functional Splits parameters

Splitting options	a	b	OH
Split E: CPRI / eCPRI	0	1	600%
Split II_D / I_U : load-dependent FH	1	0	80%
Split A: BH with centralized scheduling	1	0	25%

Deployment Options related to Various Transport Access Technologies

Considering the general 5G networks' deployment models and the most widely considered technologies, and taking 5G-VICTORI's ones as such paradigm, the network deployment options and technologies scaling rules for the transport access are [22]:

- mmWave links for BH and/or FH providing ~1Gbps average data rates per link; depending highly on the spectrum (frequency, bandwidth), the distance between the two nodes and the radio environment. mmWave links are implemented by pairs of transceivers, while links' capacity scales by adding new pairs of transceivers for the IHP mmWave solution and by adding capacity SW keys up to the 10Gbps for the ICOM mmWave solution.
- Sub-6 links for FH or BH of 1Gbps data rates per link; again depending highly on the spectrum (frequency, bandwidth), the distance between the two nodes and the radio environment. Sub-6 links are implemented by pairs of Sub-6 nodes, while links' capacity scales by adding new pairs of transceivers.
- P2P optical connections for BH/FH links at 10Gbps. It shall be noted that although in the context of 5G-VICTORI wireless technologies are used for the demo activities, the techno-economic analysis included also the use of optical technologies for

comparative analysis purposes. In particular P2P (optical Ethernet) connections of 10Gbps have been considered as an alternative, given the wide penetration of this technology in the market, and the availability of the relevant information. Scaling of these links is performed by adding connections interfaces and connecting them to optical Ethernet switches. The latter include on average 48 ports of 10Gbps and 2 aggregation ports of 100Gbps.

The scenarios can differ in the grade at which each of these technologies is used.

The wireless (both mmWave and Sub-6GHz) transport connections may consist of one or multiple hops, defined as deployment options in the techno-economic analysis. Moreover, multiple links per connection/hop may be considered, in case the traffic to be served exceeds the capacity limits of the equipment.

These access transport links are aggregated at 1st level at COs (edge sites), and then at 2nd level at the Main Vertical Premises site where also the CN resides. At 1st aggregation level we consider mmWave hubs aggregating up to 10 links, Elastic Time Shared Optical Network (TSON) components aggregating up to 10 links and Optical Ethernet switches aggregating up to 48 P2P optical interfaces with the limitation of 100Gbps aggregate capacity in two 100Gbps ports.

We consider TSON components to be used at transport core segments to aggregate, at 2nd level, (Optical) Ethernet interfaces with flexible degrees of aggregation (reaching aggregation of 12x10Gbps interfaces to 100Gbps optical Ethernet) [23].

For all the transport segments, other deployment specifics are modelled, such as the maximum link utilisation (usually set to 75%) for the access transport links, the maximum loading factor for the aggregation nodes connected interfaces, etc.

Deployment Options related to Fiber Deployment

Given the fact that the main technology competitors to wireless backhauling are the optical network technologies, as well as the fact that fiber deployment is continuously expanding to the deployments' last mile optical network technologies are modelled in the various transport segments. To this end, given that fiber deployment is not ubiquitous, instead it incurs extra costs where not present, various fiber deployment scenarios/options are considered - in terms of cost of civil works. Typically, two main scenarios:

- ***Greenfield scenario:*** This scenario assumes that there is no previously deployed infrastructure and it is necessary to take into account not only the fiber as such, but also different elements that intervene like digging and trenching, law permits, technical personnel. The deployment cost depends highly on the type of area to be covered, as well as the applicable construction costs, which vary highly between countries/areas, etc.
- ***Brownfield scenario:*** In this scenario, the deployment assumes an existing fiber infrastructure, thus what is modelled is the aforementioned cost for the required extension of the fiber deployment.

5.4.3 Deployment Options related to Usage and Placement of vBBUs and MEC

Compute resources are present at various physical and logical locations of the network for hosting applications and/or network services such as vBBUs and UPFs. These are indicated as Edge Compute at locations denoted as "Central Offices (COs)". Similarly to large scale deployments' common practice, COs host the transport aggregation equipment.

By modifying the deployment parameters, different access network, access transport and aggregation transport deployment scenarios can be defined, dimensioned and evaluated.

Table 5-2 Technologies Deployment Options for Access, Aggregation and Core Transport

Network segment	Technologies / devices	
Transport access	Wireless • mmWave • Sub-6GHz	Optical • P2P Optical
Aggregation	• mmWave • TSON • Optical Ethernet Switch	
Transport core	• TSON	

5.4.4 Other Input – Modelling related Information

Space in Central Offices – Rack Footprint Cost

The footprint cost per year (OpEx) of a rack needs to be considered, corresponding to expenses for cooling, personnel, security, etc.

Installation

Installation costs can be either modeled as a percentage of the equipment CapEx, usually 2%. In case the value is 0%, the cost is considered embedded into the CapEx.

Maintenance

In order to simplify the cost evaluation, expenditures for maintenance are assumed to be equal to 2% of CapEx for each year.

Cost information and Financial Figures

To proceed with the cost estimation of a specific deployment, input is required regarding the per-unit equipment cost and its escalation model, installation and maintenance/service costs for each technology, along with the estimated annual prices erosion or escalation. These costs are kept as Confidential among the Project members. Other financial figures introducing or representing extra costs such as Weighted Average Cost Of Capital (WACC) and Tax Deduction (% of Equipment Cost) are also considered.

5.5 Deployment Scenarios Modelling for the Railway Vertical

The stepwise methodology was used to perform a techno-economic assessment of the various network deployments at a railway vertical premises, especially at the Athens-Patras railway area as an example case, for a 5 year timeframe.

Step 1: Definition of the area / vertical premises under study.

The first step for the evaluation is the definition of the area of deployment. The definition refers to the total surface (km^2), or/ and the distance (Km) that needs to be covered. In particular, in the case of the Athens-Patras railway area, as area under coverage/study we consider the total distance of the railway tracks between the two main stations (ends), and the surface of all platforms between the two ends.

The definition of the area refers also to additional information related to the vertical premises that can facilitate the network planning, e.g. the areas where traffic is expected to appear, the traffic patterns –usually known especially in the case of the vertical industries- etc. In the case of the railway deployment the additional information that can provide useful input in the network planning process is: the number of platforms, the number of trains that are simultaneously in operation, the number of passengers per train etc.

Based on the area definition and the assumed equipment used in the access network nodes, the radio coverage parameters (i.e. coverage radius of access network nodes) can be evaluated as average pre-planning assumptions. Auxiliary information such as the current or tentative deployment of cabinets as "Central Offices" (COs) is also defined at this point. In the case of the Athens-Patras railway area, the assumptions are presented in Table 5-3.

Table 5-3 Athens-Patras Railway Area under study - Assumptions

Area under study		Railway tracks
Railway Area	Km of tracks	208000
Platforms	#Platforms	15
	Platform Area m^2	12000
	Total Platform surface	180000
Trains	# Trains in operation per day	10
	Increase of #trains	5%
	#Trains Operating/ Total #Trains	90%
	# Passengers per Train	300
	Total Passengers = Users *2	16000
	Average Users per train	417
Deployment related	Average MS radius (m)	1000
	Average SC radius (m)	70
	Average distance to cabinet (m)	13900
	#COs	15

Step 2: Definition of the service scenarios in terms of coverage and traffic demand.

At this step, also the targeted radio coverage and traffic serving assumptions are recorded. This relates to the coverage area percentages and the expected traffic demand. In the case of the Athens-Patras railway area we consider 100% coverage along the tracks and at the platforms from the 1st year, and a cell overlapping factor of 10%, given the criticality of coverage for the train automation services.

The traffic demand is considered as 1.5 Gbps peak on train the 1st year reaching 4Gbps peak on train the 5th year, and 3Gbps peak at each platform the 1st year reaching 10Gbps at each platform the 5th year. The assumptions are presented in detail in section **Error! Reference source not found.**.

Step 3: Definition of the Access and Transport deployment blueprint.

This step is based on the 5G-VICTORI deployment blueprint analysed in section 5.4, with the following area specific assumptions:

- A cabinet/ CO is located in all platforms of this railway area. The COs host vBBUs and UPF (15 in total), as well as application services. The traffic associated with these application services can be locally served at relevant COs.
- At access network segment, small cells (SC) are used to provide coverage at the platforms, while macro cells (MCLs) are used along the tracks. The model also considers two access network deployment options along the tracks:
    1. Deployment of access network nodes (gNBs or RRUs) on poles along the tracks; where no last mile access transport is needed.

2. Deployment of access network nodes on-board trains (gNBs or RRUs); where along the tracks we consider wireless access transport nodes as an additional hop to deployment option 1.

Step 4: Definition of the technology scaling and deployment dimensioning rules.

This step is based on the 5G-VICTORI deployment blueprint analysed in section 5.4.

Access Network Deployment Definition

The Access Network Deployment (5-years roll-out) definition follows the 5G network architecture and common access network deployment principles. The access network dimensioning is performed in terms of actual number of MCLs and SCs needed for the deployment, calculated on the basis of rough radio-coverage estimations and traffic forecasts given the average coverage radius and average capacity estimation of cells at the coverage edges. The number of MCLs/SCs can be also defined using external sophisticated radio network planning tools and inserted as input in the techno-economic-analysis tool. Further configuration information that is considered includes:

- The average number of cells per site; where we assume two cells per site for the deployment along the tracks and one cell per site at the platforms.
- The average number of RRUs per BBU in the case that a cell is using the D-RAN technology; where we assume an average of 10 RRUs per BBU.
- The capacity of the SC and MCL over the years, taking into account the access network capacity expansions, e.g., due to upgrades; where for the SCs we assume average capacity of 2Gbps (average datarate 1Gbps at cell edge) reaching 3 Gbps at 5th year, and for the MCLs we assume capacity of 1Gbps reaching 2Gbps at 5th year.
- The average maximum cell loading of MCLs/SCs (i.e. the average load percentage above which we consider an expansion with additional network elements) per area type and per year taking into account the traffic demand increase and the planning principles of the operator of the network.

In the case under study, since 100% coverage is assumed from the 1st year, dimensioning and expansions over years are considered as increase in capacity or in number of cells at the same sites.

Transport Network Deployment Definition

Adhering to the 5G-VICTORI deployment blueprint and the modelled deployment options in the transport network segments, the deployment options are defined in the form of:

- Distribution (%) of usage of different Functional Splits (FS i.e. eCPRI Split A, eCPRI B, eCPRI C, eCPRI D, eCPRI ID, eCPRI IID/IU, eCPRI E) in MCLs.
- Distribution (%) of usage of different access transport technologies, per FS in MCLs.
- Distribution (%) of usage of different FS in SCs.
- Distribution (%) of usage of different access transport technologies, per FS in SCs.
- Distribution (%) of usage of different aggregation and core transport technologies.
- Average number of hops of access transport links per technology.
- Average number of hops of aggregation transport links.
- It shall be noted that in the area under study we assumed a uniform topological distribution of the access transport links along the railway tracks, as well as a uniform topological distribution of the platforms along the Athens-Patras route.
- The processing of various FSs at the Edge or Core network segments; directly related to the positioning of the vBBUs.

Also the following details are configurable per scenario:

- Transport links utilization (as % of link capacity) defined per technology.
- Aggregation and core transport equipment loading factors (interfaces loading) defined per technology per year.

Regarding the fiber deployment, various scenarios are considered ranging from Greenfield (0%) to Brownfield (50%) scenarios. The extent of the deployment is calculated taking into consideration the total number of sites to be (fiber) reached.

Transport network dimensioning rules consider technologies' capabilities/restrictions/default dimensioning rules (as aforementioned in section 5.4) and telecom operator imposed principles such as the component's threshold loading factors before scaling. The dimensioning is calculated in terms of transport equipment elements, for the various transport network links/ segments/ technologies.

Step 5: Definition of the cost information.

For the economic part of the analysis, input is required regarding the per-unit equipment purchase cost, installation cost and maintenance/service cost for each technology, along with the estimated annual prices erosion or escalation. The per-unit costs can be calculated then for a 5 years' timeframe. In the context of the current analysis, cost information is collected from the industry partners. This information is confidential as it may vary depending on the requested equipment volumes, possible bilateral Business-to-Business agreements, etc.

Other financial figures introducing or representing extra costs such as Weighted Average Cost Of Capital (WACC) and Tax Deduction (% of Equipment Cost) can be also considered.

Step 6: Setting of analysis timeframe.

For telecom network deployments a 5-year timeframe is usually considered.

Step 7: Definition of the deployment scenario and extraction of results. & Step 8: Iteration of all steps and collection of analytical cost results.

The definition of the deployment scenario to be evaluated constitutes in setting the values in the aforementioned assumption parameters in the aforementioned steps 1-4. Based on the assumptions, the Tool provides:

- Dimensioning of radio and last mile/ access / aggregation / core transport segments in terms of number of transport links, equipment units per year.
- Cost estimation of the deployment scenario per segment, including CAPEX/OPEX breakdown per technology/year, etc.
- Comparative cost results of a number of deployment scenarios.

In the context of the Athens-Patras area under study, various scenarios are evaluated. The tool output/results will be elaborated in the following section.

5.6 Techno-economic Analysis Scenarios and Results

In general, the scenarios on which our study has focused assume radio network capacity and traffic increase over the 5-year period, and radio network deployment performed at Year 1. However, over the 5 -year period the radio network capacity increase and the transport network dimensioning increase (in terms of links addition and capacity expansion) is considered. The following paragraphs detail the analysed scenario sets and the results analysis. Indicative actual cost results are provided in **Error! Reference source not found.**.

Scenarios Set 1: Optical network deployment Greenfield vs Brownfield

This set of scenarios focus on the evaluation of a Greenfield optical network deployment compared to various Brownfield options. To compare realistic scenarios, we consider that fiber deployment is already existing in the platforms, so no extra mile is needed for the platforms to be connected to ISPs circuits. However, we do not assume that all platforms are directly connected via fiber. The Brownfield options thus refer to the existence of fiber deployment along the tracks with existing fiber deployment in 100% and 50% of the MSs along the tracks. To assess also the full scale of needed deployment we consider the GF vs BF scenarios in pure optical deployments – no wireless technologies are assumed in any transport network segment. In other words the transport network technologies assumptions are the following: 100% P2P optical in the access transport segment and 50% Optical Ethernet and 50% TSON in the transport aggregation segment. The deployment scenarios that have been compared are included in

Optical Transport Deployment			Scenarios
	Existing fiber deployment @ Platforms	Existing fiber deployment along tracks	Functional Splits
BF - 100	100%	100%	eCPRI A
			eCPRI IID/ IU
			eCPRI E
BF -50	100%	50%	eCPRI A
			eCPRI IID/ IU
			eCPRI E
GF	100%	0%	eCPRI A
			eCPRI IID/ IU
			eCPRI E

For each scenario

Cost Structure
Access Transport
Aggregation Transport
Fiber Deployment
Total CAPEX
Total OPEX
TCO

Figure 5-4.

Optical Transport Deployment			Scenarios
	Existing fiber deployment @ Platforms	Existing fiber deployment along tracks	Functional Splits
BF - 100	100%	100%	eCPRI A
			eCPRI IID/ IU
			eCPRI E
BF -50	100%	50%	eCPRI A
			eCPRI IID/ IU
			eCPRI E
GF	100%	0%	eCPRI A
			eCPRI IID/ IU
			eCPRI E

For each scenario

Cost Structure
Access Transport
Aggregation Transport
Fiber Deployment
Total CAPEX
Total OPEX
TCO

Figure 5-4 Scenarios Set 1 - Definition

Apparently, the selection of FS and the existence of fiber deployment affects the transport network cost. The radio access network and 5G network cost remains the same for all the scenarios above. The comparative CAPEX, OPEX, TCO and Transport cost distribution per segment for the aforementioned scenarios are shown in the following diagrams:

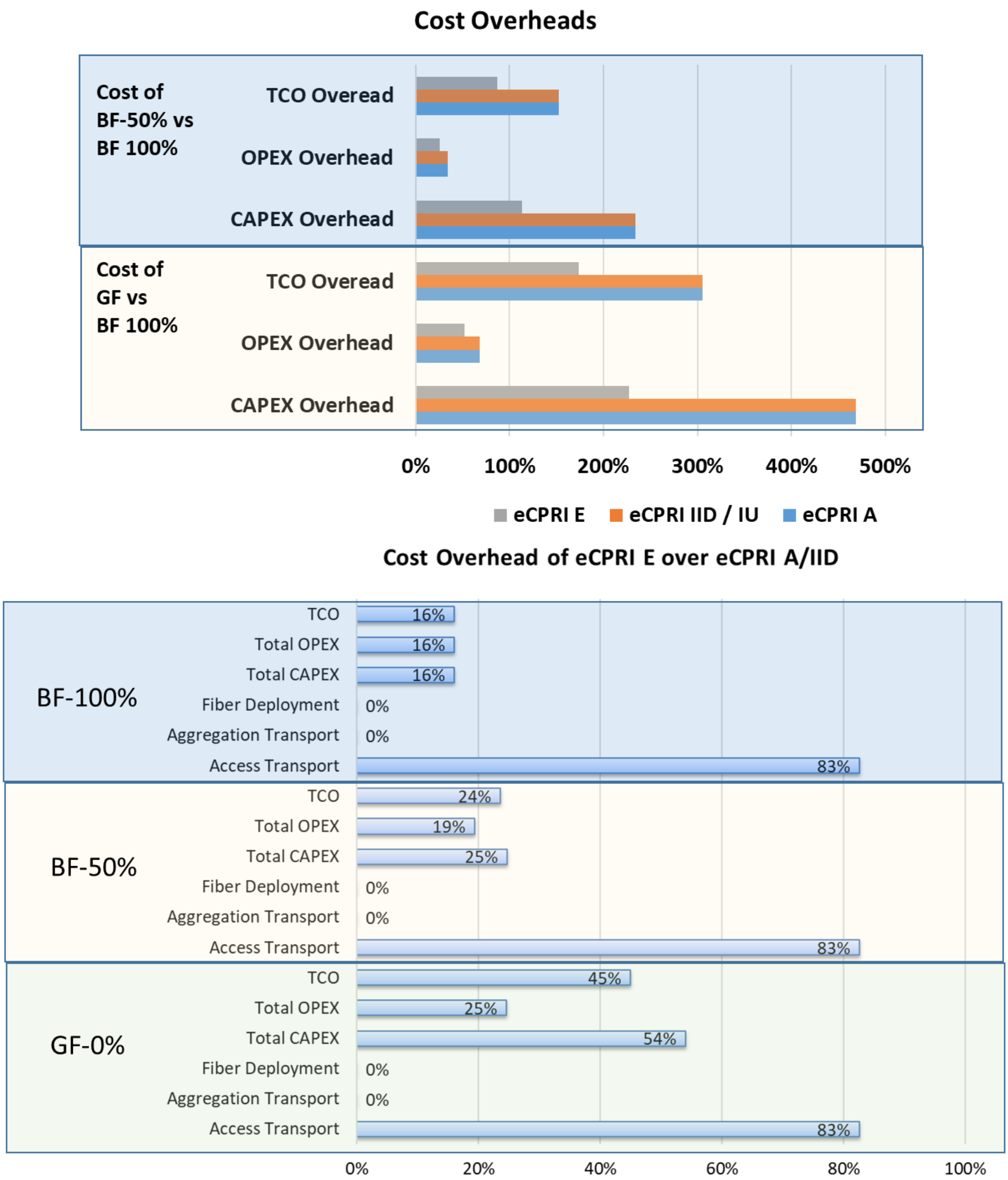


Figure 5-5 Scenarios Set 1 – Comparative Results

As indicated by the comparative analysis results, the cost of fiber deployment for a pure optical deployment is a critical cost factor which can determine further the selection of the network deployment in terms of functional splitting. Given common average fiber deployment prices lack of fiber deployment along the target route may result in an increase of network deployment cost reaching even 4 times the cost of the whole network deployment. Further, the cost of using eCPRIE even in the case of high capacity fiber links is almost 80% higher than that of all other eCPRI schemes (A to IID).

Scenarios Set 2: Wireless - Optical transport deployments This set of scenarios focus on the evaluation of a variety of optical-wireless technologies mix for the transport network deployment in the area under study. The deployment scenarios that have been compared are the following:

Table 5-4 Scenarios Set 2 – Definition

Transport Network Technologies Mix - Scenarios		Functional Spliting
Only Optical	Access Transport: P2P optical Aggregation Transport: Optical Ethernet Switching 50% & TSON 50% Optical Scenarios BF -100%, BF-50%, and GF correspond to Scenarios of Set 1	eCPRI A
		eCPRI IID / IU
		eCPRI E
Only Wireless	Access Transport Wireless: Along Tracks: 30%Sub-6, 50% mmWave IHP, 30%mmWave ICOM, At Platforms: 80%Sub6, 20%mmWave Aggregation Transport: mmWave 50% & TSON 50%	eCPRI A
		eCPRI IID / IU
		eCPRI E
Optical -Wireless	Access Transport Wireless: Along Tracks: 20%Sub-6, 30% mmWave IHP, 10%mmWave ICOM, 40% P2P optical At Platforms: 40%Sub6, 20%mmWave, 40% P2P optical Aggregation Transport: mmWave 40%, Optical Switching 20%, TSON 40%	eCPRI A
		eCPRI IID / IU
		eCPRI E

Table 5-5 Scenarios Set 2 – Cost Overheads Analysis between various Wireless and various Optical only scenarios

	Cost Overheads	eCPRI A	eCPRI IID / IU	eCPRI E
Optical -Wireless vs Optical BF - 100%	CAPEX Overhead	53%	71%	113%
	OPEX Overhead	15%	21%	52%
	TCO Overead	37%	51%	94%
Wireless vs. Optical - BF 100%	CAPEX Overhead	77%	105%	166%
	OPEX Overhead	22%	31%	76%
	TCO Overead	55%	75%	139%
Optical -Wireless vs Optical BF - 50%	CAPEX Overhead	-54%	-49%	0%
	OPEX Overhead	-14%	-10%	20%
	TCO Overead	-46%	-40%	4%
Wireless vs. Optical - BF 50%	CAPEX Overhead	-47%	-39%	24%
	OPEX Overhead	-9%	-3%	40%
	TCO Overead	-39%	-31%	28%
Optical -Wireless vs Optical GF	CAPEX Overhead	-73%	-70%	-35%
	OPEX Overhead	-31%	-28%	0%
	TCO Overead	-66%	-63%	-29%
Wireless vs. Optical - GF	CAPEX Overhead	-69%	-64%	-19%
	OPEX Overhead	-27%	-22%	16%
	TCO Overead	-62%	-57%	-13%

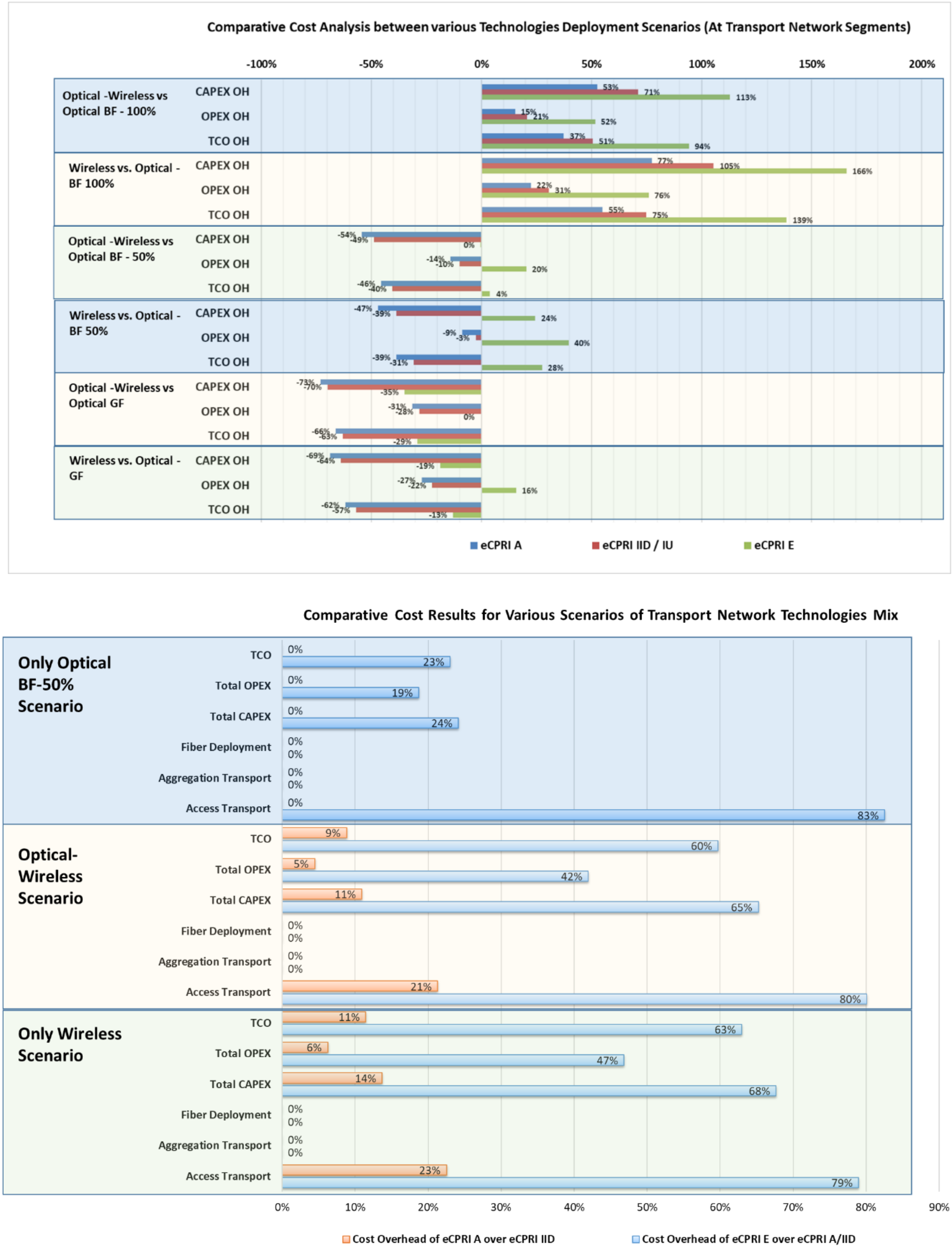


Figure 5-6 Scenarios Set 2 – Comparative Results – Cost Overheads Analysis

As indicated through the comparative analysis results, the cost of deployment is highly influenced by the selection of the transport network technologies, by the existence of fiber deployment and by the selection of the functional splitting at gNBs. In practice, in areas where fiber deployment is already existing, using wireless technologies increases the cost significantly from 50% to even 145% depending on the level of wireless technologies usage and on the FS scheme. However, considering the cases of no fiber deployment, it appears more cost efficient the usage of wireless technologies even with FS eCPRI E. In the case of partial existing fiber deployment, the scenarios shall be carefully analysed, since the cost efficiency of wireless technologies depends highly on the FS scheme.

Scenarios Set 3: Trackside vs. On-board 5G network deployment

This set of scenarios evaluate the Track-to-Train versus the on-board 5G network deployment from the techno-economic perspective. We consider FS A/B for the deployment, and complete wireless deployment to backhaul the on-board gNBs along the railway tracks. Essentially what is evaluated is the cost benefit achieved by the decrease of the number 5G access network nodes needed for the on-board deployment compared to those needed for the Trackside deployment, and the cost overheads that are incurred by the need to densify and extend the access transport deployment along the tracks for the backhauling of the on-board 5G access network nodes. In the Athens-Patras railway case, the cost of the radio access network is decreased by 76% in the case of the on-board deployment compared to the trackside one, while the cost of the access transport is almost 10 times greater in the case of the on-board deployment compared to the trackside one. Considering the total costs, CAPEX is almost doubled, and OPEX is also increase significantly in the two scenarios. However, eventually the TCO can be 'only' 1,5 times greater in the case of the pure on-board deployment compared to the trackside deployment (see Table below). Apparently the access transport cost overhead depends highly on the radio emission characteristics of the equipment and the propagation characteristics of the environment along the tracks, which are the two critical factors affecting the deployment of wireless transport equipment. Thus, in real network deployments, this analysis shall be carefully performed for the different wireless access transport equipment alternatives.

Table 5-6 Comparative Results of On-board 5G network deployment vs Trackside 5G network deployment

Cost Structure	On-board vs Trackside Deployment
Access Network	-76%
Access Transport	995%
Total CAPEX	206%
Total OPEX	60%
TCO	147%

Scenarios Set 4: FS Processing at Edge and MEC Offloading

This set of scenarios focus on the cost analysis with regard to the benefits and overheads of performing BBU processing at Edge and the offloading part of the applications traffic at Edge. In the railway scenarios we consider the edge deployment at the railway platforms as an alternative to keeping all processing centralised at a railway main premises – being located at a main/ central platform area. We consider three main offloading scenarios ranging from: (1) purely decentralised deployment where vBBU processing is performed at Edge along with the application offloading – only internet traffic is routed via a main UPF node; to (2) partially decentralised deployment where only vBBU processing is performed at Edge along while all traffic is served by a central UPF; to (3) completely centralised deployment where all vBBU processing and all application traffic is processed at a main/ central processing location. The scenarios that have been evaluated are shown in the following figure.

Table 5-7 Scenarios Set 4 - Definition

Offloading Scenarios		Functional Spliting
Decentralised	vBBU Processing at Edge: 100% Application offloading at Edge: 70%	eCPRI A
		eCPRI IID / IU
		eCPRI E
Completely Centralised	Completely Centralised Deployment (vBBUs and Application processing at Main site)	eCPRI A
		eCPRI IID / IU
		eCPRI E
Only vBBU Processing	vBBU Processing at Edge: 100% Application offloading at Edge: 0%	eCPRI A
		eCPRI IID / IU
		eCPRI E

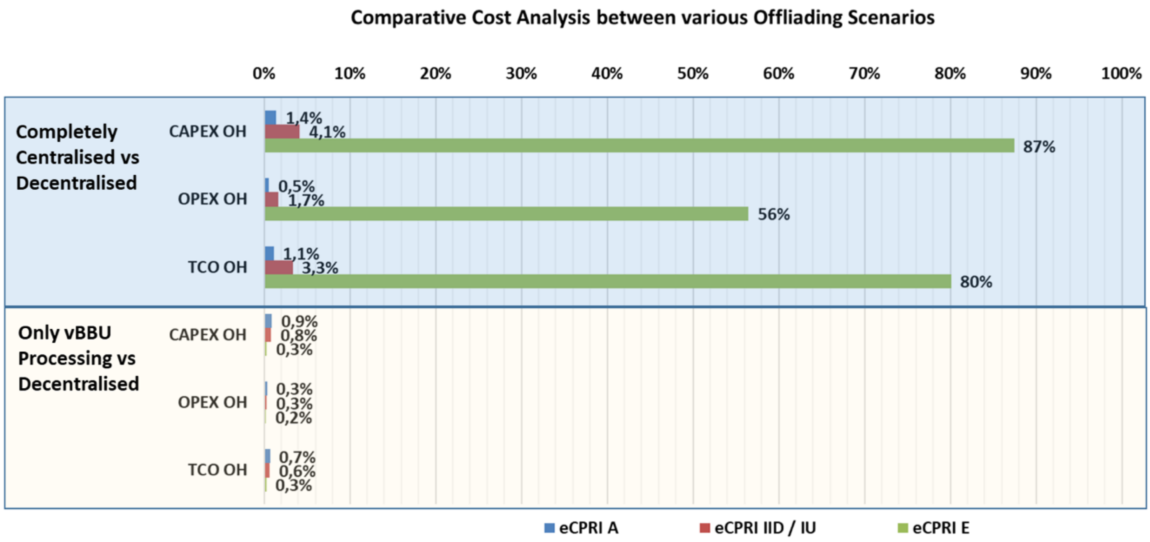
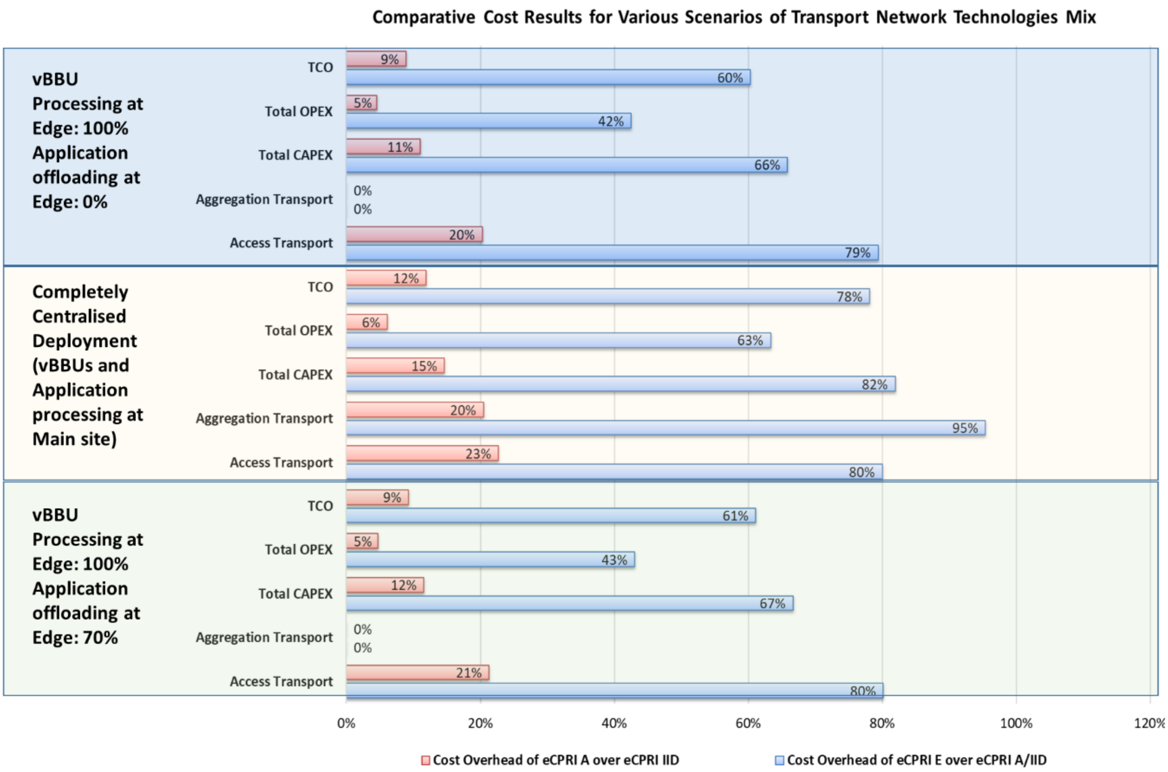


Figure 5-7 Scenarios Set 4 - Comparative Results of various Scenarios of Offloading at Edge



As indicated by the comparative analysis results, the centralized or decentralized deployment of vBBU processing have no impact on the TCO for CPRI schemes A to IID, while the TCO increases by 80% for eCPRI E when vBBU processing is centralized compared to decentralized deployment. The impact of application offloading at the edge is also marginal in terms of cost, however apparently this will depend on the estimated traffic generated by the specific applications.

To conclude, the exemplary cost analysis has evidenced some important results:

- The fiber deployment along the tracks is the biggest cost share, so that premises, owning fibre and digs, are commercially advantaged;
- The analysis confirms that wireless systems is a valid transport network alternative to optical transport in cases of lack of existing fiber deployment. Compared to deployment analysis of the past this is a significant conclusion that highlights the performance and cost efficiency increase over the years.
- The selection of eCPRI scheme shall come hand in hand with the deployment distribution and technologies selection decision.
- The analysis is highly sensitive to the cost assumptions, which are highly influenced by the Business-to-Business agreements, the target equipment volumes, the maturity level of the product.

6 Social Performance

6.1 Objective, scope, and limitations

The objective of the social dimension assessment is to determine the expected social impact of the services and applications developed and demonstrated in laboratory and testbed trials in the context of the 5G-VICTORI project. Assessing services and applications also with regard to their social performance adds a perspective of social value creation to technical and market performance-based approaches. 5G technologies and the respective services and applications have the potential to substantially affect different types of stakeholders, including business and private end-users, but also society at large. While there are risks and potential pitfalls, new information and communication technologies based on 5G also hold high potential for supporting societal goals [4]. Adding a social dimension perspective to service and application assessment is important, firstly, because potential social benefits are value propositions of new technologies and services and because this is increasingly important for reputation and accountability. Secondly, it is also of overarching normative importance, because in today's era innovations should aim at addressing social challenges and working towards the goals we have set ourselves as a society. These are formulated for example in the United Nations (UN) Sustainable Development Goals (SDGs) [1], which include, besides environmental and economic sustainability, societal sustainability. The current political guidelines as formulated by the European Commission President also characterize the need to jointly consider social and market interests under a social pillar [24].

The services and applications developed in the context of the 5G-VICTORI project may have direct as well as indirect social impacts on different groups within society or society at large, including unintended consequences, requiring a thorough and systematic assessment of the social dimension. This is all the more the case since 5G services and applications also find usage in critical infrastructure fields. As direct impacts those consequences that are part of the explicit purpose a respective service is developed for are understood, while indirect impacts depend on the actual usage, its scale in the market and society, and how the general public responds and reacts to the service. Both direct and indirect potential effects are considered to the extent possible at the current TRLs (for the definition of the different TRLs see

6.2 Technology Readiness Levels

in the appendix). The overall goal of the social dimension (level 1 goal) can be formulated as realizing socially beneficial potential to the maximally possible extent, which also includes limiting potential negative side effects.

Given that the services and applications currently have medium TRLs, they do not have the social impacts to be expected at a future state when they are commercially deployed. The current social assessment is therefore a prospective assessment, anticipating what likely social impacts can be expected under the assumption of full deployment. The transferability of insights to the phase of actual deployment depends, firstly, on whether the service is commercially deployed with the characteristics it currently has in the lab and testbed phase and, secondly, on contextual developments, i.e. how it is taken up and how its actual usage develops. This is a first limitation of the service and application assessment on the social dimension. A second limitation is the method of data collection, which will be described in more detail in the section on methodology. The assessment relies on the evaluation of experts regarding the services, however there is only a limited amount of perspectives per service and at this stage it is not possible to include perspectives of external experts, meaning the assessment is considerably shaped by experts closely involved in the 5G-VICTORI project. At a later stage of technology development, once higher TRLs are achieved, external experts as well as relevant stakeholders should be involved to a greater extent and KPIs should be updated accordingly. Nevertheless, preliminary KPIs providing a prospective assessment can provide initial evidence regarding potentials, challenges, and pitfalls, and are a good starting point further social dimension assessment can be based on [5].

When looking at socially relevant consequences of services and applications from a business perspective, this can be done using the framework of Key Value Indicators (KVIs) rather than KPIs [5]. From the perspective of social impact assessment this is less suitable here, since the social dimension is understood as a dimension in its own right, beyond the framework of business value proposition. The aim is not only to identify what values are addressed, but to establish an idea of the potential for impact, including its strength, i.e. the potential *performance* on the social dimension. Therefore, using the framework of KPIs is suitable for the social dimension. An additional reason concerning the broad assessment undertaken here is to preserve coherence across the different performance dimensions.

6.3 Methodology and metrics

As discussed in section 2.1 and 2.2, the second step after identifying the assessment dimensions is the identification of the dimension specific KPIs. They were defined by integrating two perspectives: firstly, societal challenges were examined, pain points, as well as factors considered to be of societal value and goals that society has agreed on, such as the SDGs, and investigated which of these could potentially be addressed or impacted by the services and applications developed in the 5G VICTORI project. In the second perspective the services and applications developed were analyzed, the context they are likely to be deployed in, the targeted users and stakeholders, and examined what potential impacts of social relevance are to be expected. Further, the results of business ideas developed in workshops conducted within the context of the project were analyzed, since this provides evidence regarding planned and expected developments in commercial deployment. From this, in collaboration with the partners and discussions with experts, first the main KPIs and their related goals were identified, and in a second step the KPI specific indicators were determined. For the social dimension five KPIs were identified: Employment, Health & Safety, Equality & Access, Education & Culture, Societal Acceptance, which are listed in Table 6-1. Besides a brief description, in the rightmost column the SDGs addressed by the KPI are given. In defining these KPIs the aim was to identify non-overlapping KPIs (to the extent possible), in order for the measures to yield information about separate socially relevant aspects.

The services and applications developed in the context of the 5G-VICTORI use cases span diverse fields and differ greatly in terms context of usage, targeted user groups, etc. Therefore, some of the KPIs are more immediately relevant for some applications and services than for others. Nevertheless, all KPIs are examined for all services. This entails that a low scoring on a specific KPI can mean either a shortcoming regarding indicators that can and should be better addressed by the service, yet it can also mean that indicators that are not immediately affected by the service and therefore not creating the pressure to adapt the service to achieve better values on the indicator. Looking at both of these cases makes sense and in fact is a valuable contribution, because on the one side the applications and services are at an early stage of development and social performance measures of 5G technologies is not particularly widespread. On the other side looking at KPIs that seem less immediately relevant for some services can provide surprising insights. Moreover, since many solutions may be transferable to other usage contexts in the future, the scope of implications may widen and it is therefore helpful to have the explicit scoring also on dimensions that could become relevant in the future. For considering the results further this means to examine low scoring on a particular KPI for each service and determine whether or not a better performance can be expected from this service at this stage.

Table 6-1 Social Dimension Specific KPIs

Assessment Dimension: Social		
KPI	**Description/goal**	**SDGs* addressed**
Employment	The goal of the KPI employment is to increase the availability of high-quality jobs; both an increase of the quality of jobs as well as an increase in job numbers can be regarded as positive in social value terms	SDG 1, SDG 8, SDG 10
Health & Safety	The goal of the KPI health & safety is to increase the health and safety of the population, both in general and at the workplace	SDG 3
Equality & Access	The goal of the KPI equality & access is to provide equal benefits/access to diverse groups and/or extra benefits/access to disadvantaged groups	SDG 5, SDG 10
Education & Culture	The goal of the KPI education & culture is to increase the availability and spread of education and (high quality) information, both an increase in quality as well as an increase in accessibility can be regarded as positive in social value terms	SDG 4, SDG 16
Societal Acceptance	This KPI measures the how likely problems of societal acceptance are; societal acceptance can be regarded as positive in social value terms	SDG 16

*SDGs addressed include: SDG 1 no poverty; SDG 3 good health and well-being; SDG 4 quality education; SDG 5 gender equality, SDG 8 decent work and economic growth; SDG 10 reduced inequalities, SDG 16 peace, justice and strong institutions

As discussed in section 2.2 and 2.3, KPIs should be measurable quantities or derived from measurable KPI-specific indicators. This generally allows for the formulation of threshold or target values that need to be fulfilled. In the case of social dimension, the explicit quantification of KPIs for the services is not possible at their current TRL level. The assessment has to rely on qualitative evidence about the expected potentials and challenges of each service. The general target or goal of the KPI indicates the direction, i.e. whether a positive or negative impact can be expected. It was also gauged whether the expected value is low, moderate or high, meaning that the attempt was made to measure how likely the effect is and what strength is expected. Yet it is important to note that this is only a first indication regarding the strength of the impact.

The KPIs are measured using a qualitative approach. Evidence is collected from those responsible for the individual services and applications, the use case and service owners, via surveys and cross-check the plausibility of answers. Based on whether a service is likely to have a positive effect with respect to a certain KPI and the expected value of this effect each survey is assigned points. The metrics of the KPIs are derived from the metrics of the KPI-specific indicators. For each KPI-specific indicator there are 4 possible values a service can achieve: 0, 1, 2 or 3 points. 0 indicates that there is no expected positive effect, while 1 – 3 indicate that there is a positive effect with different degrees of likelihood or strength. The measures of the four KPI-specific indicators are then aggregated using linear aggregation to create the overall measure of the KPI: this can accordingly range between 0 and 12 (for a similar approach see the work by Geibler et al. [25]). The values are mainly derived from the answers collected in our survey. The online survey was implemented via the tool sosci (see Appendix, section 11.2, for the questionnaire). The respondents answer to questions in a form, from which this scaling is directly derivable. However, this is only taken as a preliminary measure. Within the survey there is additional information, regarding related expected developments as well as information on the reasoning behind the application and service owners' answers. This additional information is used to validate the measure and put it into context. This first perspective captures the perspective from the UC and service owners: this is a crucial perspective, since they know the services best and have the most informed insight on how the services and applications function and how they will be brought to the market, what costumer segment they will target etc. To this perspective, in a second step, the perspective of experts from IZT is added, who have expertise on sustainability matters. They conduct a jury review of the assessment of the UC owners, examining whether the perspective from the UC owners needs to be complemented and modified with regard to certain aspects. Added together, these two perspectives give a comprehensive assessment of the services' social potential.

6.3.1 KPI Employment

The general goal of the KPI employment is to increase the availability of high-quality jobs. This means that both an increase of the quality of existing jobs as well as an increase in job numbers are regarded as positive. If the two factors go in different directions, e.g. a lot of new jobs are created but these tend to be of very bad quality, an attempt has to be made to weigh the two factors against one another to estimate the net effect.

The four KPI specific indicators that were identified are listed in Table 6-2. They include an indicator for expected creation of new jobs, as well as indicators assessing the quality of existing and new jobs (for work place related indicators in a similar field cf. Grandi et al. [26]). Job quality is defined as comprising non-economic and not immediately health related aspects of jobs, including the satisfaction with nature and content of the work performed, working-time arrangements, workplace relationships and general job satisfaction.[2] Furthermore, it is also considered whether the expected income profile of newly created jobs is high.

Table 6-2 Specific Indicators for the KPI Employment

KPI Employment		
KPI specific indicator	**Description/goal**	**Measurement/values**
Quality of existing jobs	Increase the quality of existing jobs	0 – 3 points
Number of jobs	Increase the number of jobs	0 – 3 points

[2] This is similar to part of the OECD job quality definition, see OECD https://www.oecd.org/statistics/job-quality.htm

Quality of new jobs	Create new jobs that are of a high quality	0 – 3 points
Income profile new jobs	Create new jobs that have a high income	0 – 3 points
		∑ 0 -12 points

6.3.2 KPI Health and Safety

The general goal of this KPI is to increase the health and safety of the population. Besides affecting the population in general, the services and applications developed in the context of the 5G-VICTORI project are partly targeted at or will primarily affect people at the workplace. Accordingly, firstly, health and safety effects on the general population are looked at and, secondly, health and safety at the workplace and of employees (for work place related indicators in a similar field cf. Grandi et al. [26]).

The four KPI specific indicators are listed in Table 6-3. One important aspect of safety is the reduction of accidents, therefore there is one indicator for accidents concerning the general population as well as an indicator for accidents or the need to work in unsafe environments at the workplace. The indicator measuring accidents concerning the general population also covers other unsafe situations, such as crime. The other two indicators gauge the reduction of stress and the potential for other positive health effects, one for the general population and the other for employees at the workplace.

Table 6-3 Specific Indicators for the KPI Health & Safety

KPI Health & Safety		
KPI specific indicator	**Description/goal**	**Measurement/values**
Reduction of accidents	Reduce accidents or other unsafe situations for end users/general public	0 – 3 points
Reduction of accidents at the workplace	Reduce accidents at the workplace or the need to work in dangerous environments	0 – 3 points
Reduction of stress	Reduce stress and/or have other positive health effects for end users or general population	0 – 3 points
Reduction of stress at the workplace	Reduce stress and/or have other positive health effects at the workplace/for employees	0 – 3 points
		∑ 0 -12 points

6.3.3 KPI Equality and Access

The general goal of the KPI Equality and Access is to promote equal access and benefits to diverse individuals and groups. This means either providing equal access or benefits to these groups or providing additional benefits or avenues of access to disadvantaged groups. Some of the services and applications are likely to have direct effects on equality by providing access to disadvantaged groups. With regard to this KPI, the opposite effects, i.e. the danger of unintended negative effects on equality and access, need, to be considered explicitly as well. As the literature on digital inequalities has pointed out there is a risk of ICT reinforcing existing inequalities or creating novel inequalities [27].This is due to inequalities in access, but also inequalities regarding digital skills and usage and the ability to derive benefits from the services and applications.

For this KPI identified five KPI specific indicators were identified (see Table 6-4). The first three indicators measure different aspects of access: affordability (for private end users, but also for business users, such as SMEs), hard- and software requirements and digital literacy that is required to use the service. The other two KPIs look at benefits for disadvantaged groups. The first of these indicators is a generic indicator for whether the service or application provides benefits to any disadvantaged group. The latter focuses on rural users and measures whether access and benefits are as good or better as they are for the urban population. Putting special focus on rural users as a disadvantaged group is important, since there is evidence that in terms of digital inequalities related to ICT services, including 5G services, the urban/rural divide is salient [28]. Therefore, a separate indicator for this group is included. Since it can be considered as one among multiple potentially affected disadvantaged groups, the values of the two indicators are considered together, however, so that the sum of the two adds up to 3 points.

Table 6-4 Specific Indicators for the KPI Equality & Access

KPI Equality & Access		
KPI specific indicator	**Description/goal**	**Measurement/values**
Affordability of service	Affordability of service for low income users or small business users	0 – 3 points
Hard-/software requirements	Usability/accessibility of service accessibility without needing to acquire extensive hard-/software	0 – 3 points
Digital literacy	Usability without requiring extensive digital literacy/ease of usage	0 – 3 points
Benefits for disadvantaged groups	Provide benefits for disadvantaged groups	0 – 1.5 points
Benefits for rural population	Provide approximately equal or more access/benefits for rural population compared to urban population	0 – 1.5 points
		∑ 0 -12 points

6.3.4 KPI Education and Culture

The general goal of the KPI Education and Culture is to increase the availability and spread of education and (high quality) information. Since access to high quality education or any education is not universal, both an increase in quality as well as an increase in accessibility can be considered to be of high social value. This is the first part of this KPI. The other aspect is cultural knowledge and education beyond formal education and training and means of communication and accessing information.

The four KPI specific indicators that were identified are listed in Table 6-5. The first two indicators focus on the availability and accessibility of education and its quality. The third indicator examines cultural knowledge and civic education. The aim is to capture the potential of services to promote, for example, knowledge about arts, historical topics, political processes and similar fields. The fourth indicator gauges the effect on communication and information, for example through promoting easier news provision, real-time translation services, etc.

Table 6-5 Specific Indicators for the KPI Education & Culture

KPI Education & Culture		
KPI specific indicator	**Description/goal**	**Measurement/values**
Availability of education	Increase the availability and accessibility of education and training	0 – 3 points
Quality of education	Increase the quality of education and training	0 – 3 points
Cultural knowledge and civic education	Further cultural knowledge and/or civic education (e.g. through promoting knowledge about arts, history, political processes)	0 – 3 points
Communication and information	Further communication and information (e.g. by promoting easier quality news provision, real-time translation services)	0 – 3 points
		∑ 0 -12 points

6.3.5 KPI Societal Acceptance

Societal acceptance is a basis for the marketability of services and applications aimed at commercial users, and it is, though to a lesser extent and more indirectly, also important for services targeted at business users. Part of the overall goal related the KPI societal acceptance is thus to increase societal acceptance. In terms of goal formulation, it is however somewhat more fitting to state that the goal is to address the fears of the public well. This can include both providing information and taking action to diminish fears that are due to misconceptions, as well as taking counter measures to actual risks the public wants addressed. The societal acceptance measure in this paper addresses whether there are aspects that could encounter problems of societal acceptance and how likely this is, not whether they are well addressed. The latter should be done in a second step. This KPI is to some extent related to the other social dimension KPIs, since social acceptance is likely to also depend on the overall performance of a service regarding social sustainability. However, at this stage, where *potentials* for social sustainability that are considered, it makes sense to look at the expected societal acceptance and potential factors engendering opposition separately. This can help identify problem pressures and issues that need to be addressed early on.

The four KPI specific indicators that were identified are listed in Table 6-6The first concerns data protection and privacy concerns. This is a widely perceived problematic topic in the context of ICT use since the 1990s, when the monitoring of personal information started to become ubiquitous [29], [30], [31]. Typical concerns address the collection, unauthorized use of and improper access to personal data, which is characterized by the European Commission as “any information that relates to an identified or identifiable living individual. Different pieces of information, which collected together can lead to the identification of a particular person, also constitute personal data.” [32]include for example name and surname, email address, location data (for example the location data function on a mobile phone), Internet Protocol (IP) address or a cookie ID. The second concerns radiation. Independently of scientific evidence, as with previous cellular network generations, fears and narratives around radiation and 5G are present in parts of the population. In Germany, for example, a third of the population states that there is too much radiation exposure [33]; 43% oppose the installation of further antennae and state that they would protest planned antennae close to their home [34]. Since the onset of the COVID-19 pandemic, despite lacking any scientific evidence, rumors around relations between the virus and 5G have circulated in parts of the population [35]. Accordingly, there is a potential for fears around this affecting societal acceptance. The third indicator concerns automation and job loss. Technological developments are regarded as having the potential to replace human labor (both in the scientific community as well as by the general public [36]), this may affect societal acceptance of 5G based services. The fourth indicator captures environmental concerns: there are multiple aspects with regard to which 5G based services may be scrutinized for their sustainability, such as energy consumption through the production and use of e.g. infrastructures, sensors and end user devices and the resources needed for their manufacturing. The topic of consequences contributing to climate change of today’s energy consumption as a whole and by ICT specifically is nowadays not only addressed by social stakeholders like nongovernmental organizations e.g. Greenpeace, international movements e.g. Fridays for Future, Parents for Future or Scientists for Future, but also found its way into governmental resolutions e.g. the European Green Deal implemented by the European Commission in 2019, which states that net greenhouse gas emissions shall be reduced to zero in 2050. Therefore, the energy efficiency of IC technologies is expected to raise even more interest [37]. The manufacturing of IT components (semi-conductors, circuit boards) requires a lot of raw and often rare materials. The conditions of mining these materials are frequently criticized by civil society groups e.g. Catapa, Bits&Bäume and Greenpeace regarding the adverse effects on the natural environments of the extraction and manufacturing areas, as well as harmful social impacts [38], [39]. Since higher frequencies are used in 5G technologies for e.g. multiple antennas and beamforming, even more efficient semi-conductors will be required in the future [4], which is expected to lead to even more opposition regarding resource intense ICT products, e.g. short-living end user equipment, regardless of the correctness of the assignment to the problem.

Note that the scoring with respect to this KPI is inverse: the questions ask whether societal opposition is expected, if the answer is no the scoring is 3 points, if the answer is yes 1 – 3 points are subtracted, depending on the expected strength of the opposition.

Table 6-6 Specific Indicators for the KPI Societal Acceptance

KPI Societal Acceptance		
KPI specific indicator	**Description/goal**	**Measurement/values**
Data protection and privacy	Decrease acceptance hindering aspects/strengthen societal acceptance	0 – 3 points

Radiation	Decrease acceptance hindering aspects/strengthen societal acceptance	0 – 3 points
Automation and job loss	Decrease acceptance hindering aspects/strengthen societal acceptance	0 – 3 points
Environmental concerns	Decrease acceptance hindering aspects/strengthen societal acceptance	0 – 3 points
		∑ 0 -12 points

6.4 Results by KPI

KPI Employment

The scores achieved on the overall KPI Employment are spread widely, ranging from 1 to 10, with most services scoring between 3 and 8. Disaggregating the KPI specific indicators, many services are expected to increase the quality of existing jobs, this is a main contributor to high overall KPI values. To the extent that services are seen to have the potential to create new jobs, these jobs are generally expected to also be of high quality and medium to high income. The expectations concerning job creation are less strong: for most services for which job creation is expected the potential is seen as small or medium, and rather in the long run. These scores are the combined results of the survey conducted among the UC owners and the expert judgements collected in the jury approach. Looking at the divergence of these scores shows that the jury scores are somewhat lower for about half of the services. The most frequent divergence is regarding quality of existing or new jobs.

KPI Health and Safety

The scores achieved on the overall KPI Health and Safety are somewhat polarized: while there are several services that are not expected to affect Health and Safety at all or only very weakly, substantial numbers of other services score between 8 and 11. This means that several services score high on all KPI specific indicators. Here slight divides can be made out between services scoring high on safety compared to stress and other health benefits and between services affecting the public compared to affecting employees. Yet it is notable that often all four indicators score similarly. Examining the divergence between UC owner scorings and the jury scoring, there is a difference in about half of the services. The majority is scored lower by the jury, but several services are scored higher. The indicators where most divergences occur are the job quality indicators.

KPI Equality and Access

Most services score low to moderate on the overall level of KPI Equality and Access. Only few services score above 8. Disaggregating the KPI specific indicators, most services are expected to provide at least some level of accessibility in terms of financial, hard-/software, and digital literacy requirements. Among these different criteria for access digital literacy is the one that seems to provide the most challenges (although this criterion is likely to be less relevant for services targeting qualified personnel). Few services are expected to benefit disadvantaged groups. There is little divergence between the UC owner scores and the jury scores. Interestingly, the three services where there is divergence are scored higher by the jury. This suggests that UC owners tend to underestimate the potential of the services to positively affect equality and access.

KPI Education and Culture

The scores achieved on the overall KPI Education and Culture are polarized: most services score low, between 0 and 4. Several services, however, score high, between 9 and 11. Those services that score low to medium tend to have positive scores on either the KPI specific indicators covering education (availability and quality) or civic education and communication/information. The indicator that achieves the highest score in sum is communication and information. There is not much divergence between the UC owner and the jury scores. Where there is divergence the jury scoring is mostly lower. The KPI specific indicators where divergence occurs are those on education and training and cultural knowledge.

KPI Societal acceptance

All services score relatively high on societal acceptance; many achieve a score of 11, the lowest score is 8. Disaggregating across KPI specific indicators shows that the expectations differ across areas: where opposition is expected it is mostly opposition based on radiation and automation concerns, while little opposition is expected based on environmental or data privacy concerns. Concerning divergence between UC owners and the jury scoring, this is the KPI where there is by far the most divergence. Divergence occurs in almost all services. Concerning UC owners' scorings, many UC owners do not expect any societal opposition. The jury scoring is lower. Concerning radiation concerns, a potential for some societal opposition is seen for all services. While the specific consequences for services may differ based on how visible it is that they are based on 5G, the 5G infrastructure in general is likely to be the most important target of opposition and this has the potential to affect all services, although to different degrees. Further, the jury identifies potential for opposition based on automation and job loss concerns for several more services than those whose self-assessment also indicates this. The same holds for expected opposition based on data privacy concerns and concerns related to environmental sustainability.

6.5 General results

A notable overall result is that there is divergence between the self-assessment by the UC owners and the jury. This increases confidence in this methodology, since it confirms the importance of having both a perspective informed by technical and business considerations as well as a perspective focused on social sustainability.

With respect to some KPIs the UC owners overestimate the expected potential of the services relative to the jury assessment, this is most clearly the case for the KPI employment. Here the jury perspective can help pointing out issues where further effort may be required if initially identified potentials are to be realized. For other KPIs, most clearly on average for equality and access, UC owners appear to underestimate the potential performance. Here additional potentials not spotted by UC owners may be contributed from the jury perspective.

The most consistent divergence between the self-assessment and the jury perspective is for the KPI societal acceptance: UC owners appear quite complacent regarding potential concerns from the public, compared to the perspective of the jury. Concerning societal acceptance, actual societal acceptance is highly dependent on how a service and application is brought to the market, i.e. its final design and framing etc., but it is also dependent on how the potentials captured by the other social KPIs are realized. An important factor for whether a service will be fully and easily accepted or face opposition is increasingly dependent on whether it can be perceived as benefitting society at large, which is related to its social and environmental sustainability.

A further general observation is that the services differ greatly in the relative scoring on the different social dimension KPIs and KPI specific indicators. This is to be expected, since the services developed in the 5G-VICTORI context also differ substantially with respect to factors that are relevant for the social dimension. These relevant categories include targeting predominantly businesses, the public sector, or private end users (including different groups, such as travels and students). Some services focus on optimizing or extending existing systems (such as rail signalling), while others aim to provide novel services (such as smart factory services or remote teaching).

Despite these considerable differences, some broad tendencies can be identified. Regarding employment, where there is a potential for new jobs, this is mostly jobs in the realm of data analysis and system maintenance and generally in the IT sector. With respect to health and safety, several services have substantial potential. Especially regarding non-safety potentials, such as for example decreased stress, the likely impact is quite uncertain due to potentially countervailing effects: for example, an increase in perceived security through CCTV services may lower stress levels, yet qualms concerning data privacy may increase stress. Concerning equality and access, several services score quite well, with low hurdles in terms of soft- and hardware or literacy requirements. Beyond this some have the potential to benefit disadvantaged groups: while this was is not an explicit aim of 5G-VICTORI, this potential should be further strengthened and possibly addressed more explicitly. Several services also score quite high on education and culture. One potential here is to provide, via digital replicas of systems, the opportunity for employees to gain training in a system without facing critical or dangerous environments. This also holds the further potential of increasing safety. This may also be applicable to other similar services.

Further results from the social assessment at the service level are documented in the performance profiles (see section 8). An overview over the scoring results across all services is given in the Appendix (see section 11.3).

7 User Performance

7.1 Objective and scope

The objective of the user dimension is to determine the perceived usability and corresponding user-acceptability of the services and applications developed and demonstrated in the laboratory and testbed trials in the context of the 5G-VICTORI project. It is further to collect from the teams working on the different services and applications insights into to what they see as challenges and potentials regarding the user perspective. Assessing services and applications also with regard to what experience users have when in the process of using, clearly provides essential information on the expected adoption. The goal with respect to this dimension is to provide a service that supplies a continuously easy and pleasant usage experience and thus will be used. The services and applications developed in the 5G-VICTORI use cases target different user groups: while some target private end-users, such as train passengers, other target business users. The perspective taken in this section is that of the person who uses the service in the sense of interacting with it. This also encompasses business users, but does not look at the company level, instead looking at the perspective of individual employees interacting with (parts of) the service. The metrics used here are based on established usability questionnaires [40], [41], the Net Promoter Score (NPS) [42] and a question on user satisfaction. In addition, user acceptance is also included, in order to capture potential hesitations based on concerns around 5G technologies in general. This is related to the societal acceptance dimension addressed by the social performance perspective, since it has the potential to affect adoption of individual services it also needs to be considered in the assessment of the user experiences. The insights from the societal performance provided in this deliverable may guide the concrete formulation of the user acceptance item. As discussed in section 2, the scope of the user perspective in this deliverable is limited to a preliminary methodology formulation and pre-tests by pseudo-users. This is due to the stage of development of most services and applications developed in the context of the 5G-VICTORI project. The goal of this section thus consists on defining the methodology and constructing a questionnaire to be used at a later stage of development for specific services and applications, once they are ready to be released. The questionnaire suggested will need to be tailored to individual services and applications.

7.2 Methodology and metrics

As described in sections 2.1 and 2.2, the second step after identifying the dimensions of assessment is identifying the dimension specific KPIs. In the process of literature reviews and WG discussions the following KPIs were defined as being the important ones to be evaluated here: likelihood of recommendation, service usability, customer satisfaction, and user acceptance (see Table 7-1).

Based on these four KPIs we constructed a questionnaire (see Appendix, section 11.4). As the level of 5G-VICTORI development is still preliminary (lab tests), we decided to run this evaluation activity on a preliminary level and to make use of several ‘pseudo users’, who are defined as people using the services as if they were working in a real-world environment. The use case owners were instructed to recruit people, possibly working in the same company or institute, but not directly involved in the work on the particular service. With these ‘pseudo users’ a test-usage was conducted (using the service to the extent possible for this particular service’s stage of development). The questionnaire answers of these pseudo users serve as a pre-run of the questionnaire, which was done for several services, to provide first evidence on whether this is a suitable method to be run at a later stage. The results from these questionnaires are to be regarded as very preliminary: firstly, because they stem from pseudo users not using the fully developed service and secondly because the questionnaire was only provided to single or several pseudo users by service. For assessing the user performance of the fully developed service answers by many more users should be collected.

In addition to the (pseudo-)user questionnaire, the use case leaders were asked to add their perspective on the current stage of user dimension activities as well as perceived challenges. The aim here is to provide a first idea what potential advantages and also challenges the services inherit, especially in the areas of usability, acceptance and customer satisfaction. A summary of the main points raised by the UC owners of 5G-VICTORI UCs is compiled in the results section.

Table 7-1 User Dimension Specific KPIs

Assessment Dimension: User Perspective	
KPI	**Goal**
Likelihood of Recommendation	To maximise the rate of recommendation by users, i.e. the NPS. The goal of this KPI is to measure the loyalty of users based on their own experience with this tool or service.
Service Usability	To maximise the service usability. The goal is to assess the experience of the users while interacting with the product with the goal to provide a continuously easy and pleasant experience.
Customer Satisfaction	To maximise user/customer satisfaction. This KPI aims to find out how positive the overall experience with the tool or service is seen.
User Acceptance	To understand potential challenges to the acceptance of the service.

KPI Likelihood of Recommendation

For the KPI Likelihood of Recommendation a question based on the net promoter score (NPS) was chosen as the single indicator [42]. The NPS consists of a question regarding likelihood of recommendation, with the answer options ranging from 0 (not at all likely) – 10 (very likely). The question wording is: *How likely is it that you would recommend this service to others?* Those who score 9 or 10 can be counted as promoters, scores of 7 or 8 are counted as passives, while scores below 7 are seen as not recommending [42].

KPI Service Usability

The questions for measuring KPI Service Usability are based on the System Usability Scale (SUS) [40], [41]. The SUS includes 10 different questions, the KPI specific indicators, inquiring about different aspects of usability and including differently framed questions to make the scale more reliable. The scoring system uses a five-point Likert scale, meaning the answers range from 1 (strongly disagree) to 5 (strongly agree). The indicators are displayed in Table 7-2. The overall KPI score is calculated by summing up the scores of the positively framed questions (on light orange background in the table) and inverting the scores of the negatively framed questions (on darker orange background in the table) before also summing these up and adding the two sums. In standard usage of SUS the algorithm for calculating the overall score is somewhat different – since this is somewhat less intuitive it was not implemented for the pseudo user analysis. In order to compare it with other SUS scores it may be desirable to also score future results in this way, therefore the algorithm is given in the following: for positive (light orange) items subtract one from the user response, for negative (darker orange) items subtract the user responses from 5 (this results in values from 0 to 4, with four being the most positive response). These responses are added up and multiplied by 2.4, resulting in a range of possible values between 0 and 100.

Table 7-2 Service Usability KPI Specific Indicators

Assessment Dimension: User Perspective		
KPI	**KPI Specific Indicators**	**Scoring System**
Service Usability	*I think that I would use this service frequently*	1 (strongly disagree) – 5 (strongly agree)
	I found the service unnecessarily complex	1 – 5
	I thought the service was easy to use	1 – 5
	I think that I would need the support of a technical person/support material to be able to use this service	1 – 5
	I found the various functions in this service were very well integrated	1 – 5
	I thought there was too much inconsistency in this service	1 – 5
	I would imagine that most people would learn to use this service very quickly	1 – 5
	I found the service very cumbersome to use	1 – 5
	I felt very confident using the service	1 – 5
	I needed to learn a lot of things before I could get going with this service	1 – 5

KPI User Satisfaction

In order to track how satisfied the users are overall with the experience, a single question on general satisfaction was included. The wording is: *How would you rate your overall satisfaction with the service you just received? I am…* The answer options ranged from 1 (very unsatisfied) to 5 (very satisfied). The users were additionally asked to briefly describe their reasons for the response.

KPI User Acceptance

For gaining insights regarding potential challenges to acceptance of the services, the users were asked whether aspects that would make them hesitate exist. The answer options consisted of yes/no, if yes was selected they were asked to describe these aspects. Given that potential challenges to acceptance may be based on hesitation towards using 5G based services (this is discussed in more detail in section 6, on social performance), this context was made explicit. The complete wording reads: *The service, including for example the delivery of data, is based on 5G technologies. Are there aspects that would make you hesitate to use the service?* Results from this item are analysed by extracting and evaluating keywords.

7.3 Preliminary results and insights

For about half of the services and applications in the 5G-VICTORI project it was possible to recruit pseudo users and collect questionnaire results. The number of pseudo users by service is 1 to 3. Table 7-3shows the average scores of the KPIs (except user acceptance) across all services (a table with more detailed results can be found in the Appendix, see section 11.5). What is notable is that overall the results are very positive. Variance is not high, the lowest score on the KPI likelihood of recommendation is 8 out of 10, on the KPI service usability it is 3 out of 5 (of the converted score), and on the KPI customer satisfaction it is 4 out of 5. This quite positive scoring is likely to be partly due to the fact that pseudo users were recruited from the environment of the use case owners, so they are likely to have relatively similar backgrounds. What can be further seen in the overall results is that the KPI that scores lowest is service usability. Given the current state of development this is to be expected. This is further interesting, because the indicators for this KPI allow for the clearest disaggregation of what drives user satisfaction, thus allowing for the most specific insights regarding challenges and potentials.

Table 7-3 Preliminary User Perspective Assessment Results

Results User Perspective Assessment			
KPI	**KPI Specific Indicators**	**Scoring System**	**Score**
Likelihood of recommendation	*How likely is it that you would recommend this service to others?*	1 (not at all likely) – 10 (very likely)	8.8
Service usability	Average over all KPI specific indicators	1 – 5, converted as described in text	4.0
Customer satisfaction	*How would you rate your overall satisfaction with the service you just received? I am…*	1 (very unsatisfied) – 5 (very satisfied)	4.2
The included services are: RDIu, RDFu, RDFg, RCTg, EDHv, EDSv, EDCv, MCDv, MCBg, ESCv			

Regarding the KPI user acceptance, most pseudo users stated that there were no aspects that would make them hesitate to use the service. Those questionnaire respondents who did mention aspects came mostly from the business end-user services. The aspects they mentioned were requirements for sensitive data and control signals and the doubt that 5G based services can fulfill these requirements at a cost as low as wireline communications or previous generation wireless communications (EDHv and EDSv). A further aspect that was mentioned was the need to familiarize oneself and receive training in order to use services (EDSv and EDCv). One pseudo user also stated that while they do not expect to use the service frequently, it is expected to be very helpful in emergency situations. This should be considered when analyzing results from actual users later on. It indicates that the sub-question from the SUS asking for frequency of usage maybe may need to be adapted to fit some types of services developed in 5G-VICTORI.

Besides gaining preliminary insights from pseudo users, the UC owners were also consulted regarding challenges and potentials of the user perspective. They provided both quite general insights, which will be discussed in the following, as well as service specific insights which constitute part of the service profiles in the following section. One observation repeatedly emerging from the answers is that for many services in the context of 5G-VICTORI, part of the main goal is an enhanced user experience, through improving a similar, existing service by basing it on 5G technologies (e.g. RCTg, RCSg, MCBg, MCDv) or through adding more user-friendly visualizations (EDHv, EDSv). It also emerges that while in the case of many services questions regarding the form of the concrete user experience are already being discussed, they cannot yet be fully addressed given the status of the applications/services. Besides designing a user experience that conforms to criteria such as captured by the indicators defined above, several services face specific challenges. These include, among other things, graphical user interfaces (GUIs) that work in harsh, outdoor conditions, or 3D GUIs. Several use case owners note, that in particular with respect to services that target business users, the service requires training before being able to use it effectively.

Overall, the general insights from the user perspective assessment are the following: the questionnaire constructed for future distribution among users worked reasonably well in pretesting it with pseudo users. Comments in the questionnaire as well as insights from the UC owners regarding specific challenges of services underline the necessity to adapt this basic questionnaire to fully fit a particular service.

8 Social and User Performance Profiles by Service

This section documents results from the social and user dimension, i.e. those dimensions that can be assessed at service level, which can be directly related to the level of individual services and applications. Service profiles are constructed, providing a concise overview of a particular service's performance with respect to social and user aspects, outlining its strengths and its challenges. While the social dimension is available for each service, notes regarding the user dimension are only added where use case owners named service specific aspects above and beyond what is mentioned in section 7.3. The service profiles are clustered by vertical.

8.1 Performance profiles of Rail Transportation Services

8.1.1 UC #1.1 Enhanced Mobile Broadband under High Speed Mobility – Service: "Rail Enhanced MBB Patras rail operation non-critical" (RENv)

Service description: This service targets train operators (offboard control center). The goal of the infrastructure service is to implement a CCTV capturing the rail track state live to monitor the track quality and provision maintenance for the tracks when needed. The cameras will be mounted on the front and rear part of the train capturing video images that will be forwarded in real time over the 5G network to the operations center of the railway operator (TRAINOSE) which is co-located at the 5G-VINNI cloud. The camera's application will prepare the camera preview video for streaming on the onboard network before. The cameras and the cameras' application part (generating and sending the CCTV monitoring frames) are essentially the two components of this non-critical service. The onboard train network will be based on a fibre ring network technology. This will interconnect all Access Points (Onboard 5G NR and/or Wi-Fi AP) and the rooftop antennas via Software Defined Networking (SDN)-enabled switch, together with edge computing elements. This predictive maintenance service imposes loose performance requirements.

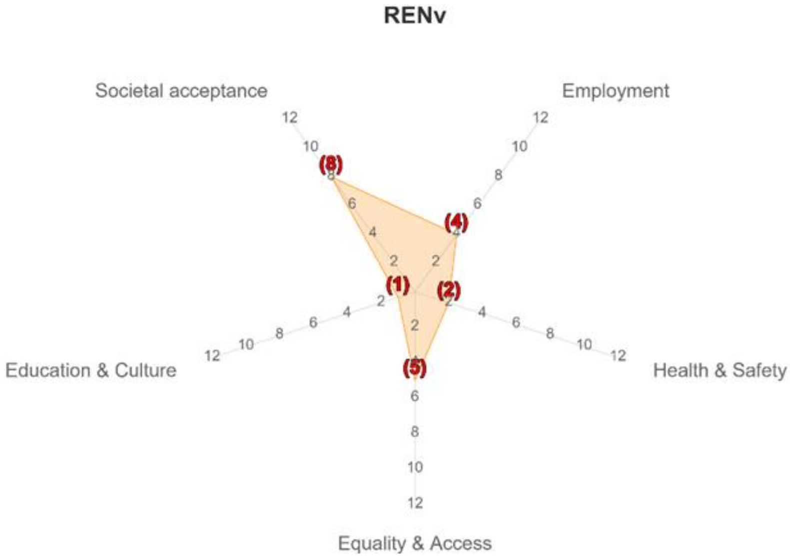


Figure 8-1 Performance RENv on all Social Dimension KPIs

Performance profile: In terms of the social assessment dimension, this service holds the potential to enhance the quality of the railway tracks through making monitoring easier and timely maintenance possible. It can thus have a positive effect on the quality of jobs and stress at the workplace. More indirectly it may also affect passengers positively through ensuring a well-maintained reliable train system. In terms of equality and access the indirect effects should benefit all passengers equally. Given that the 5G Network covers the railways there are no major obstacles for railway companies to make use of this service. Given the focus on the functioning of railway systems the service is not expected to score high on the education and culture KPI. There exists a potential for some opposition due to radiation, automation, or environmental concerns.

8.1.2 UC #1.1 Enhanced Mobile Broadband under High Speed Mobility – Service: "Rail Enhanced MBB Patras - Business services for Passengers" (REPv)

Service description: This service targets (rail) passengers. Its main goal is to demonstrate seamless service provisioning of infotainment and live TV streaming services (via COSMOTE TV) to passengers as the train moves along the tracks. These eMBB services are characterized by low criticality, but are susceptible to high error rates. The demonstrated solutions hold the potential to lower error rates and provide a seamless service. The system uses a Web-RTC-based Mobile TV streaming application - available over common web browsers at the client side. Regarding the network deployment, it is the same as for the complete bundle of the services of the UC. It consists of a heterogeneous transmission network deployment, interconnecting the on-board network components of TRAINOSE train with the 5G-VINNI core network and the public network (internet and public COSMOTE TV retransmission server). On-board the train, passenger connectivity is provided over the onboard gNB.

Performance profile: In terms of the social assessment dimension, this service holds the potential to require and produce medium to high income jobs that are likely to be of good quality, due to the challenging technological aspects required for streaming media services in trains. Since the service is likely to be available to all passengers it scores medium high on equality and access. The service further creates the opportunity to stream educational and civic knowledge related media content. The service has no health and safety related aspects, therefore no direct impact is expected. There exists a potential for some opposition due to radiation or environmental concerns.

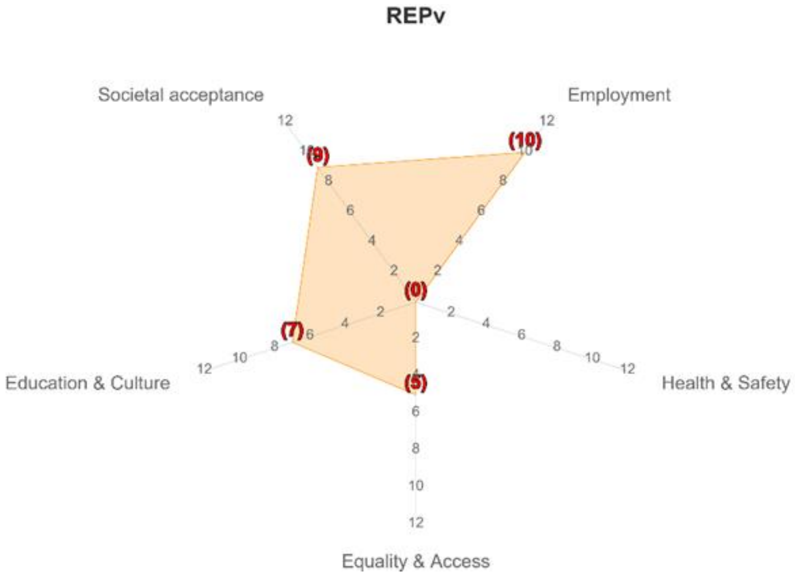


Figure 8-2 Performance REPv on all Social Dimension KPIs

8.1.3 UC #1.1 Enhanced Mobile Broadband under High Speed Mobility – Service: "Rail Enhanced MBB Patras - Rail operation Critical Services" (RECv)

Service description: This service targets train operators (onboard and offboard). The goal of the subservices is to cover mission-critical (MC) communication and safety related aspects of railway systems. Information generated in this type of services must be shared between different stakeholders, e.g. an infrastructure operator and several railway operators. The service provides telephony (bi-directional voice critical Push-to-Talk voice MCPTT; single session call and group call) and data (MCX data) for the train operator. These rail critical services are provided between the offboard office (here at University of Patras) and onboard the train. On the train a set of mobile and fixed terminals will be running the relevant applications. Voice and data sessions will be established between these terminals. The PTT session is established between an onboard end-point (denoted as caller A e.g. driver's UE) and a responsible controller at the control center (caller B). PTT can be initiated by the driver or controller. A MCX Data session transfers mission critical data with high integrity and reliability and with low delay to the necessary parties.

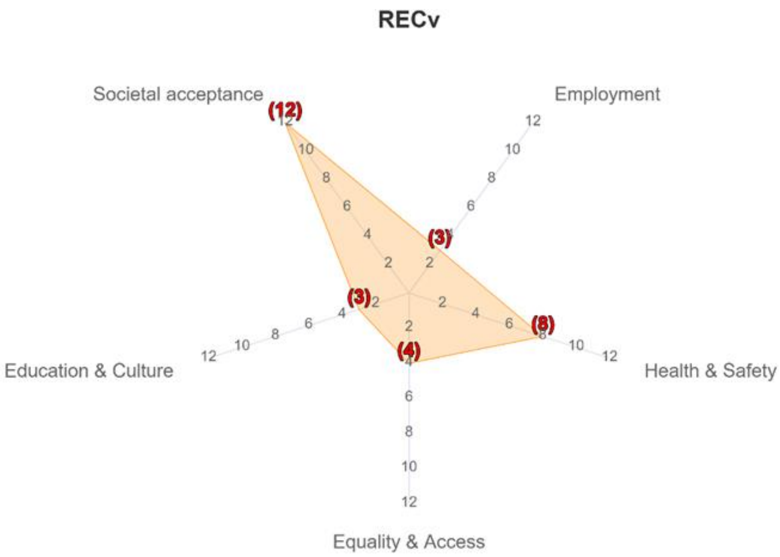


Figure 8-3 Performance RECv on all Social Dimension KPIs

Performance profile: With respect to the social assessment dimension, the clearest potential of this service lies in improving the safety and the security of rail operation. This positively affects both the health and safety of rail employees and the general public (passengers), as well as increasing the work quality of employees. Given the focus on the functioning of railway systems the service is not expected to score high on the education and culture KPI. There exists a potential for some opposition due to radiation or environmental concerns.

8.1.4 UC #1.2 Digital Mobility Transportation and Media – Service: "Digital mobility Bristol App1 Immersive Media" (RDIu)

Service description: this service targets (rail) passengers and travellers more generally. The goal is to provide immersive media and VR services to travellers in their journey through the city after arriving at a train station. When the passengers get off the train and move towards the city, the service should be preserved: A synchronous 360° tour guide at specific geolocations will be given to a group of users with 5G connectivity. The seamless service virtual tour guide is provided while passengers pass the route planned through the city. The service relies on video streaming and synchronization, both are designed as a two-part application, one running in the backend and one on the edge nodes. In order to support mobility and seamless connectivity when moving from one edge to another, the synchronization edge and streaming server services need to move as well, staying as close to the users as possible. The service aims to achieve low latency and high bitrates for multiple devices running to provide an immersive media and VR tour guide experience.

Performance profile: On the social assessment dimension this service will require both support personnel as well as specialized personnel to update the content and maintain the application itself. This is likely to imply good quality employment with medium to high income.

The service is meant to be available for all travellers, thus it should benefit all groups who travel equally. It is likely to provide information not previously (easily) available, and also holds the potential to provide educational content. The service has little health and safety relevant aspects. There exists a potential for some opposition due to privacy or radiation concerns, and the potential for considerable opposition due to environmental concerns.

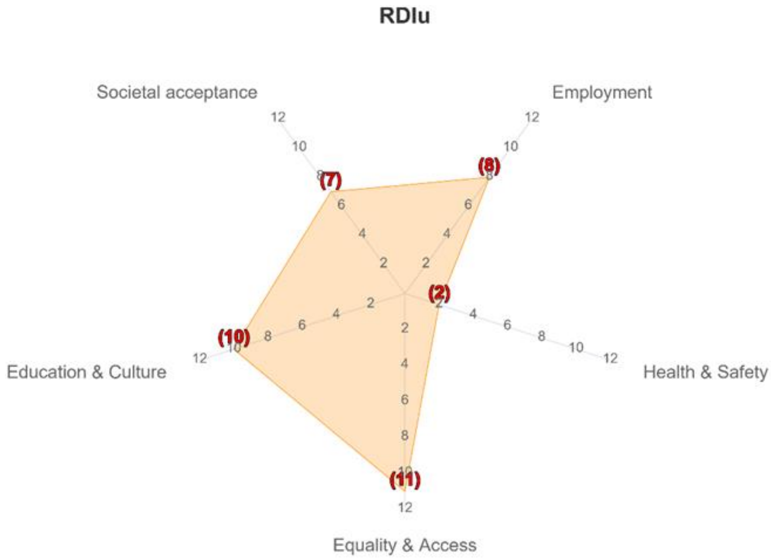


Figure 8-4 Performance RDIu on all Social Dimension KPIs

8.1.5 UC #1.2 Digital Mobility Transportation and Media – Service: "Digital mobility Bristol App2 VR Live" (RDLu)

Service description: this service targets students. The goal is to provide a remote training class using 360° VR multi-camera live streaming. The focus is on enabling large user connectivity and reaching a high number of users. A remote training class will take place at the University of Bristol and users can attend via 360° VR in real-time from anywhere in Bristol with access to the 5G UK network. The system consists of three 360º cameras, which will stream to the MATI HTML5 multi-camera player. Each camera sends a high bandwidth stream (up to 50 Mbps) to the backend streaming server. The backend streaming server in turn re-encodes the stream to multiple qualities and segments it to support HTTP live streaming.

Performance profile: On the social assessment dimension this service will require both support personnel as well as specialized personnel to update the content and maintain the application itself. This is likely to imply good quality employment with medium to high income. It is likely to provide information not previously (easily) available, and also holds the potential to make providing high quality educational content easier. This also means making it possible for remote students and other groups who at the moment may not have access to this content. The ability to provide educational content to large numbers of students may lead to a homogenisation of content and teaching style, which can have both adverse or beneficial effects. There are no health and safety relevant aspects. There exists potential for some opposition due to radiation or environmental concerns.

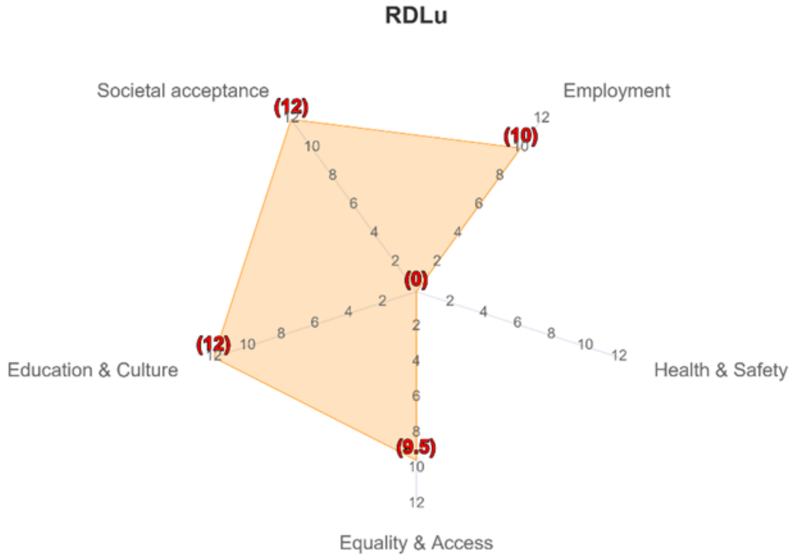


Figure 8-5 Performance RDLu on all Social Dimension KPIs

8.1.6 UC #1.2 Digital Mobility Transportation and Media – Service: “Digital Mobility - Bristol App3 Future Mobility” (RDFu) & Service: “Digital Mobility Berlin App3 Future Mobility” (RDFg)

Service description: Note: these services are so closely related that they are considered together. These services targets (rail) passengers and travellers more generally. The goal is, firstly, to provide and improved passenger’s guidance service with multi-modal transport journey planning and, secondly, to collect and analyse information from passengers and travellers (location, mobility, movement). The applications provide passengers with specific location guidance and multi-modal transport journey planning beyond the starting location using AI techniques. They build towards live spatial scanning of indoor transport hubs to achieve situational awareness that outperforms any other mapping and routing service available for multi-modal long-distance travellers. The spatial data is collated with transport operators’ live data streams (arrival times, cancellations, etc.). The arising solution is offered as a service to passengers via 5G connected smartphones. The collected data, which includes passengers’ location and mobility, provides a basis for Insurtech UCs and insurer verticals. Moreover, in emergency situations the applications can create and manage network slices. The service has a front-end, a smart phone app, and a back-end, a data collation and analytics and route planning service. The Insurtech layer will operate from the back-end and sync with the insurers through an API.

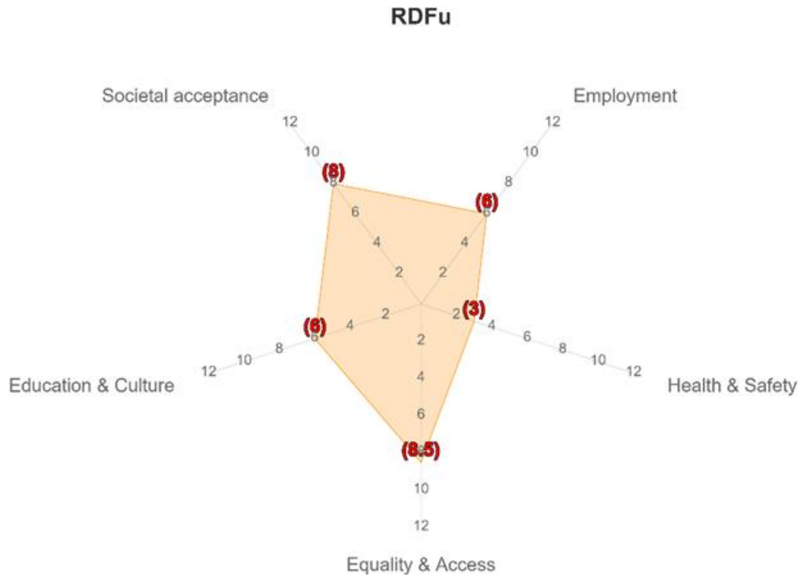


Figure 8-6 Performance RDFu on all Social Dimension KPIs

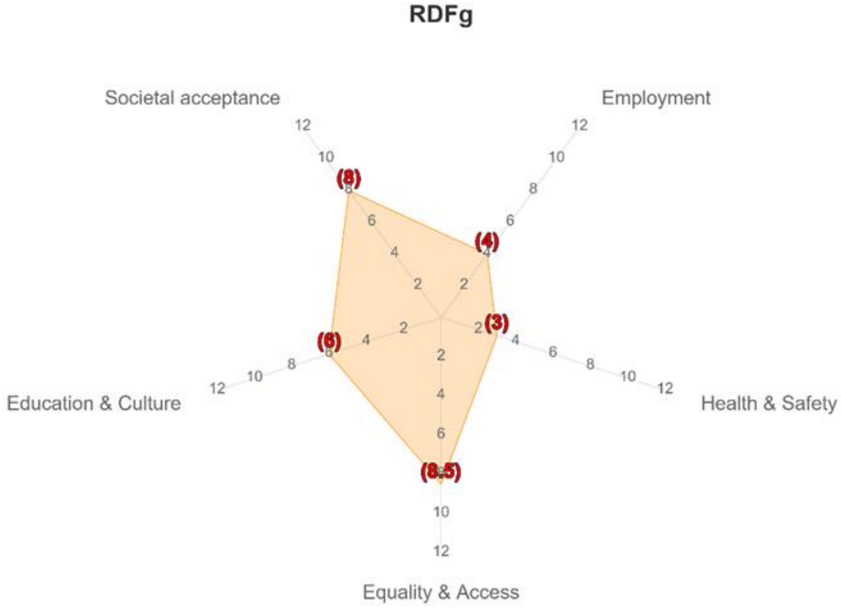


Figure 8-7 Performance RDFg on all Social Dimension KPIs

Performance profile: These services have the potential to provide data driven insights for different areas and make it possible query data in an easy to use way. While the main focus at the moment is travel planning other fields of application are already under consideration, some of which would specifically target disadvantaged groups or educational and cultural aspects. These services therefore score on all indicators, with the strength of the potential depending on which planned application areas is pursued further. There exists a potential for some opposition due to privacy, radiation or environmental concerns. From the user perspective, for both services considered here GUIs are at the stage of being refined. The aim is to design frameworks that can be adapted to different specific usages, such as the planned fields of application mentioned above. The aim is further to align the 2D and 3D GUI. Overall, the services are quite advanced in analysing and addressing issues related to the end user experience.

8.1.7 UC #1.3 Rail Critical Services – Service: "Rail Critical services Berlin Rail Telephony" (RCTg)

Service description: This service targets rail operators. The goal is to provide essential services for safe railway operation including firstly mission critical (MC) Railway Telephony (including operational voice, private and group communication, emergency group communication) and MC Railway Data Services (including alerts in case of a railway emergency, enhanced location railway service and operational messaging). The system consists of mobile, onboard terminals and fixed terminals running rail applications for MC voice, data and video communication.

Performance profile: This service is likely to positively impact the safety and the security of rail operations through improving pre-existing voice services. It also makes it possible to provide additional information (e.g. by including rich messaging or video or file download). Most other indicators do not apply to this service, since it does not provide a new functionality but mainly enhances an existing service. There exists a potential for some opposition due to radiation or environmental concerns. Concerning the user perspective, a strength of this service is its GUI on mobile phones. A challenge that needs to be addressed is making the GUI suitable for harsh outdoor conditions. A further challenge is to establish the usage in the user community, the new functions need to be explained to the users and specific trainings to highlight usage are probably required.

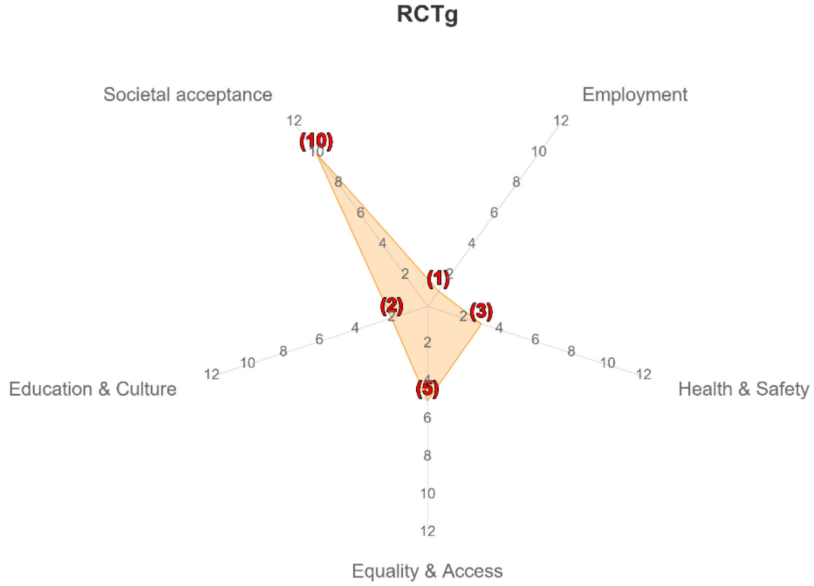


Figure 8-8 Performance RCTg on all Social Dimension KPIs

8.1.8 UC #1.3 Rail Critical Services – Service: "Rail Critical services Berlin Rail Signaling" (RCSg)

Service description: This service targets rail operators. Its goal is to demonstrate that Rail Signaling is conveyed over 5G with the required characteristics, regardless of other services and background traffic. Further, the goal is to show the usage of different 5G QoS and Network Slices for Rail Signaling compared with other services. Generic rail signalling is emulated using a traffic generator. The system includes access to a web-browser for logging in to the Hawkeye Server, which is used for configuring traffic between endpoints, getting results and reports, etc. The hardware box IxProbe can be used on the train for generating and terminating traffic. In this way no other computer is needed to host an endpoint on the train, the IxProbe is sufficient.

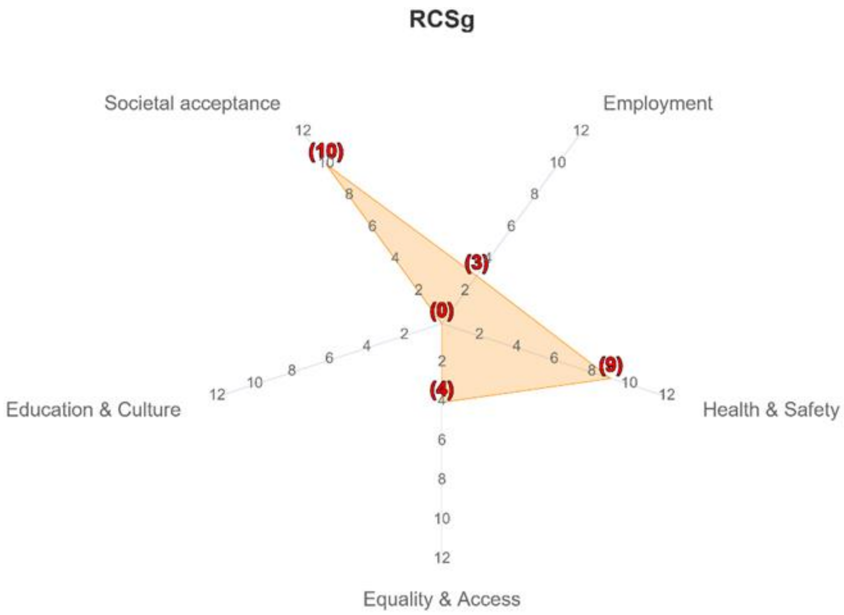


Figure 8-9 Performance RCSg on all Social Dimension KPIs

Performance profile: This service is likely to positively impact the safety of rail operations through improving previous rail signalling systems with a higher capacity system. Most other indicators do not apply to this service, since it does not provide a new functionality but mainly enhances an existing service that has a very specific usage area. There exists a potential for some opposition due to radiation or environmental concerns.

8.1.9 UC #1.3 Rail Critical Services – Service: "Rail Critical services in Berlin - CCTV streaming" (RCCg)

Service description: this service targets railway operators/security staff. The goal is to demonstrate that onboard CCTV moving pictures can be streamed to an office with good quality, undisturbed, and with good-enough short latency. Making it possible to stream pictures in real time from CCTV cameras is a strong trend on trains. A first onboard CCTV camera is located in the driver's cab, pointing forward, looking towards track and signals. A second onboard CCTV camera is located in the driver's cab, looking towards the dashboard, showing train instruments like train speed. This creates possibilities for real time remote supervision/maintenance. The CCTV network camera sends video over ethernet. A web-browser is used for monitoring pictures from the network camera.

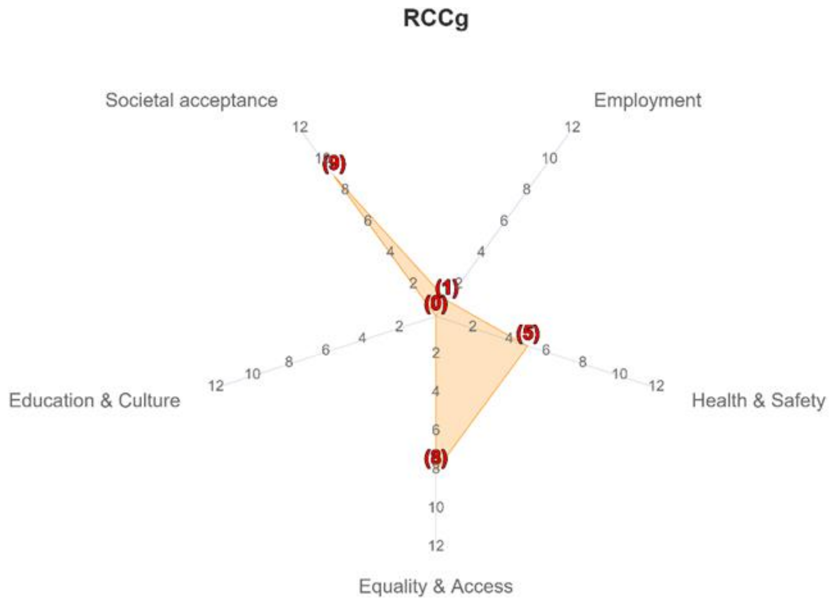


Figure 8-10 Performance RCCg on all Social Dimension KPIs

Performance profile: This service has the potential to positively impact safety and security, both in railway operations and on trains. It is likely to be accessible in terms of cost, hardware, and digital literacy requirements. There exists a potential for some opposition due to privacy, radiation, or environmental concerns. On the other KPIs no clear potentials are currently discernible.

8.1.10 UC #1.3 Rail Critical Services – Service: "Rail Critical services Berlin Sensor Data" (RCDg)

Service description: This service targets rail operators. Its goal is to demonstrate mission critical reliable sensor data transfer between communication endpoints (MCX/FRMCS application). The Rail Critical Sensor Data test cases are performed between Berlin office and onboard the train using a set of on-train, mobile and fixed terminals running sensor data application, which are communicating with each other by rail critical/performance/business data sessions.

Performance profile: This service has the potential to positively impact safety in railway operations through making it possible to react earlier to avoid critical situations and maintaining equipment more effectively. There exists a potential for some opposition due to radiation, automation, or environmental concerns. On the other KPIs no other clear potentials are currently discernible.

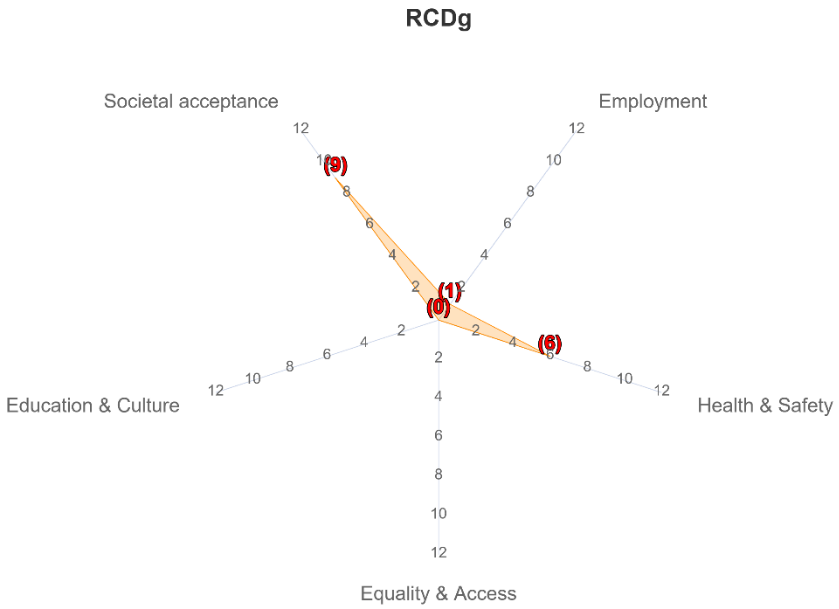


Figure 8-11 Performance RCDg on all Social Dimension KPIs

8.2 Assessment of Media Services

8.2.1 UC #1.2 Digital Mobility - Public safety and security – Service “Infotainment/ Video Services in Dense, Static and Mobile Environment” (MDIe)

Service description: This service targets passengers travelling in local busses. It provides various 5G based infotainment components (media streaming, social networks access, email access, online shopping, municipality public services access for tourists and citizens) within the vehicles while on the move or in the stations. The infotainment component is carried out through a captive portal, in which the municipality frequently carries out surveys on issues of general interest. A captive portal is a powerful and flexible solution that allows real-time communication with users on the captive portal by displaying information considered by the city administration as important and public interest: surveys, alerts, tourist information. In order to gain access to the infotainment services the traveller connects their UE to SSID Wi-Fi on the bus and is redirected to the porta. For free internet access an authentication procedure based on Mobile Station International Subscriber Directory Number (MSISDN) is performed, the traveler inputs the number on the captive portal, receives a code by SMS, which can be used in the portal for gaining free internet access.

Performance profile: Through providing infotainment on public buses, including information such alerts or tourist information the service may reduce stress during the bus journey. In terms of equality and access the service provides good accessibility in terms of cost and hardware and further is likely to benefit disadvantaged groups who tend to rely on public buses; lower income users can benefit, through example, by not needing to use limited data rates they privately purchased. The service also provides a means to for accessing information and communicating. There is a potential for some opposition due to privacy, radiation, and environmental concerns.

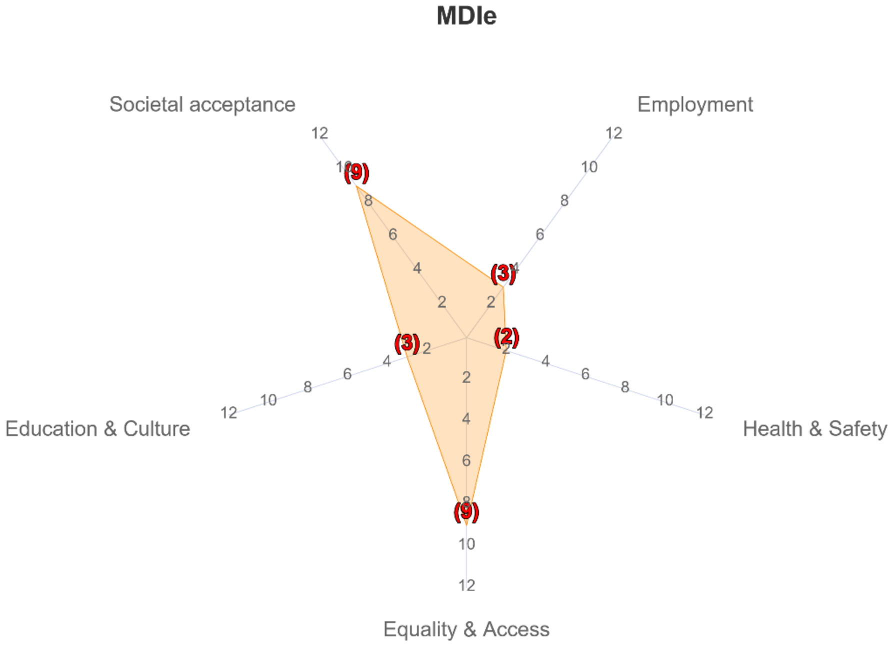


Figure 8-12 Performance MDIe on all Social Dimension KPIs

8.2.2 UC #1.2 Digital Mobility - Public safety and security – Service "Prioritized Communication to Command and Control Center" (MDCe)

Service description: this service targets passengers travelling in local busses and transportation safety staff/first responders. The goal is to have a system that usually provides infotainment to passengers (see service "Infotainment/ Video Services in Dense, Static and Mobile Environment" - MDIe), but simultaneously monitors different factors within the bus to identify potential emergency situations. In an emergency case the critical services need to be prioritized over the infotainment services. When a threat or a potential emergency situation is identified by the system, the infotainment resources are backlogged and a high-quality live stream is established to the public safety critical service. For this the vehicle is equipped with surveillance cameras linked to a Municipality Command & Control Centre (CCC). Once the threat alarm is triggered, the CCC operator needs to access camera images from the bus to decide what further emergency measures need to be taken. Thus the system needs to fulfil the QoS of the slices with guaranteed bandwidth and low latency must be fulfilled. The availability and stability of the service needs to be guaranteed.

Performance profile: Through providing means for immediate prioritized notification and communication in case of emergencies, this service positively affects the health and safety of the public, thereby also potentially reducing stress and positively affecting transportation staff/first responders. Regarding equality and access the service is accessible to all passengers, and is likely to benefit disadvantaged groups who tend to rely on public buses. The service also provides a means to for information and communication, albeit emergency information (thus scoring on education and culture). There is a potential for some opposition due to radiation, and environmental concerns. There is further the possibility of moderate opposition due to privacy concerns.

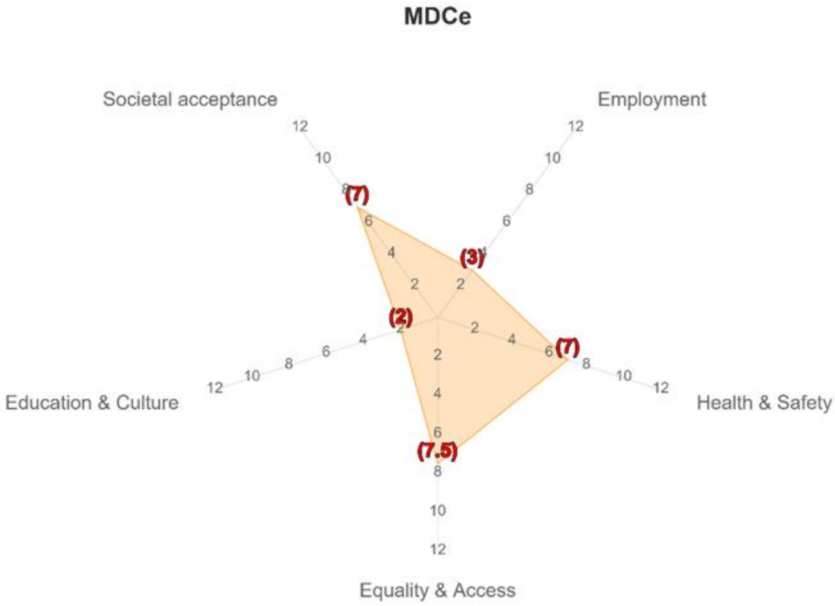


Figure 8-13 Performance MDCe on all Social Dimension KPIs

8.2.3 UC #1.2 Digital Mobility - Public safety and security – Service “Artificial Intelligence Recognition and Identification of Emergency Situation” (MDAe)

Service description: this service targets passengers travelling in local busses and transportation safety staff/first responders. The goal is to monitor multiple factors within the bus and detect potential emergency situations using AI recognition and identification mechanisms. One factor monitored is emergency breaks, its causes and possible consequences, using an accelerometer, two cameras within the bus and a third camera at the front of the bus. A second factor is indicators of violence, for this the mobility of the skeletons of passengers is analysed, unusually fast movement of the legs or the arms is detected. A third factor is potential health issues of passengers: if the traveler’s head drops under a specific height and the velocity is above the threshold, then is considered as a fall. If the system does not detect that the passenger manages to get up quickly again the incident is classified as serious. The system further associate objects (bags, trollies, coats) with passengers, identifying cases where a passenger leaves without their object.

Performance profile: Through providing means recognize emergency situations, this service positively affects the health and safety of the public, thereby also potentially reducing stress and positively affecting transportation staff/first responders. Regarding equality and access the service is accessible to all passengers, and is likely to benefit disadvantaged groups who tend to rely on public buses. Further, the AI recognition and identification mechanisms could be geared towards risks specific disadvantaged groups face, such as elderly people or people with special needs. The service also provides a means to for information and communication, albeit emergency information (thus scoring on education and culture). There is a potential for some opposition due to radiation, and environmental concerns. There is further the possibility of moderate opposition due to privacy concerns.

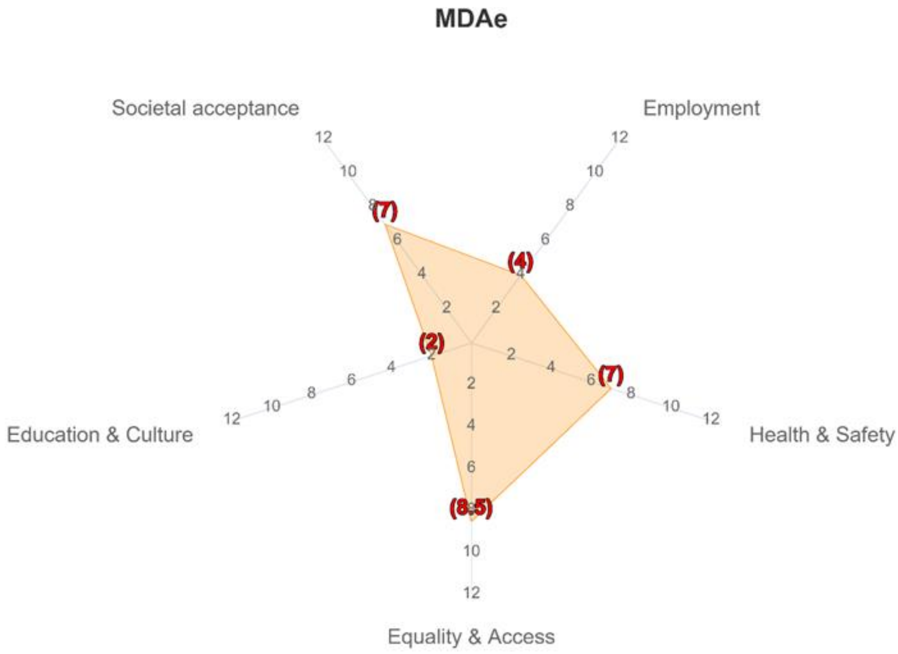


Figure 8-14 Performance MDAe on all Social Dimension KPIs

8.2.4 UC #3 CDN services in dense, static and mobile environment – Service "CDN Services Berlin" (MCBg)

Service description: This service targets (rail) passengers and provides them with a reliable, interruption-free media experience while travelling on trains. Passengers connect their personal devices to the train's on-board Wi-Fi network and open the rbb steaming and VoD app "rbb Mediathek" they usually use. They select the video content they want to watch, press play and enjoy the TV program without interruptions due to lack of mobile internet availability. They also avoid high use of data volumes and any possible related costs. This service is made possible by implementing the data shower approach developed in 5G-VICTORI. This extends streaming content delivery networks (CDN) services to trains, by equipping them with caches filled with content via wireless data links. The data shower utilizes mmWave connectivity, which allows large amounts of media data to be transferred between caches within a very short time period. This allows for a transfer of media content from the train station's CDN cache to the train's cache at data rates of up to 2.5 Gbit/s or even higher. Following the data shower concept, Video-on-Demand (VoD) content will be preloaded on a train's content cache, which acts as an edge server of the content providers' CDN. These caches hold copies of content in order to optimize media delivery for end users. In this use case, the data shower approach is used to fill the cache in the train during a train stop at the station. It is assumed that viewers use their personal mobile devices, such as smartphones, tablets, laptops, to consume media streams. The personal devices are connected to the trains' on-board Wi-Fi network

Performance profile: This service requires skilled jobs in the areas of hardware installation and configuration, programming and content distribution, accordingly it has the potential to create quality and medium to high income jobs. It further aims to provide uninterrupted access to high quality media services during train journeys, thus potentially making train travel a positive, stress reduced experience. The service is likely to be accessible in terms of cost, hardware, and digital literacy requirements. It will be available free for all travellers, benefitting, for example, lower income users (if they have access to train travel) by not requiring them to use limited data rates they privately purchased. The service provides the means to deliver content, which may include cultural knowledge or civic education content. There exists a potential for some opposition due to radiation or environmental concerns.

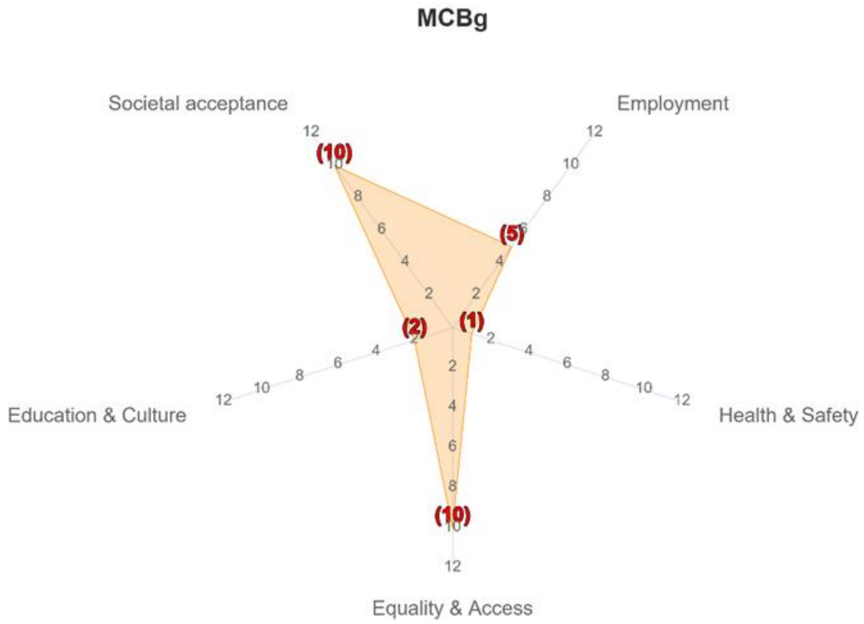


Figure 8-15 Performance MCBg on all Social Dimension KPIs

8.2.5 UC #3 CDN services in dense, static and mobile environment – Service "CDN Services Patras" (MCDv)

Service description: This service targets (rail) passengers. The main objective is to provide continuous TV and VoD content to railway passengers as they move between train stations, without full 5G coverage along the tracks. For this purpose, a CDN platform is used which can alleviate delays and content gaps occurring when content is delivered directly from the existing content origins. The target CDN platform comprises 3 stages/ 3 application components: the Central CDN Server serving as a point of connection to various Content Origins of TV/ VoD providers etc., the Main CDN Server serving as the main caching point (deployed at 5G network edge (e.g. at the train station or in premises close to it)), and the Edge CDN Server providing the last mile caching server (deployed on-board the train). Connectivity between the Main CDN Server and the Edge CDN server is achieved over the 5G network gNBs deployed at a train station. The media content to be watched by passengers can be either of VoD type (e.g. pre-stored content) or of streaming TV. The continuous service provisioning in lack of 5G coverage achieved by using a data shower approach. The data shower approach assumes three main elements: the data source, the data transmission system and the data sink. In this case the data source is the Central CDN and the Main CDN servers which preloads the relevant media (TV channel) content from the content providers' Content Origin. This is performed before the train enters the station. Then this content is downloaded to the Edge CDN server (cache) from the Main CDN server once the train approaches a train station; i.e. when 5G Network connectivity is available to the Edge CDN server. Then the content is available to be viewed by the end-users on board the train over an on-board WiFi network. In the passenger's mobile equipment, it is installed the CDN application, which the passenger uses in order to watch media content of preference.

Performance profile: This service is expected to create job opportunities in several areas such as media content production addressing commuters, CDN design and deployment, mobile network design and deployment addressing railway environments, accordingly it has the potential to create quality and medium to high income jobs. It further aims to provide uninterrupted access to high quality media services during train journeys, thus potentially making train travel a positive, stress reduced experience. The service is likely to be accessible in terms of cost, hardware, and digital literacy requirements. The service provides the means to deliver content, which may include cultural knowledge or civic education content. There exists a potential for some opposition due to radiation or environmental concerns.

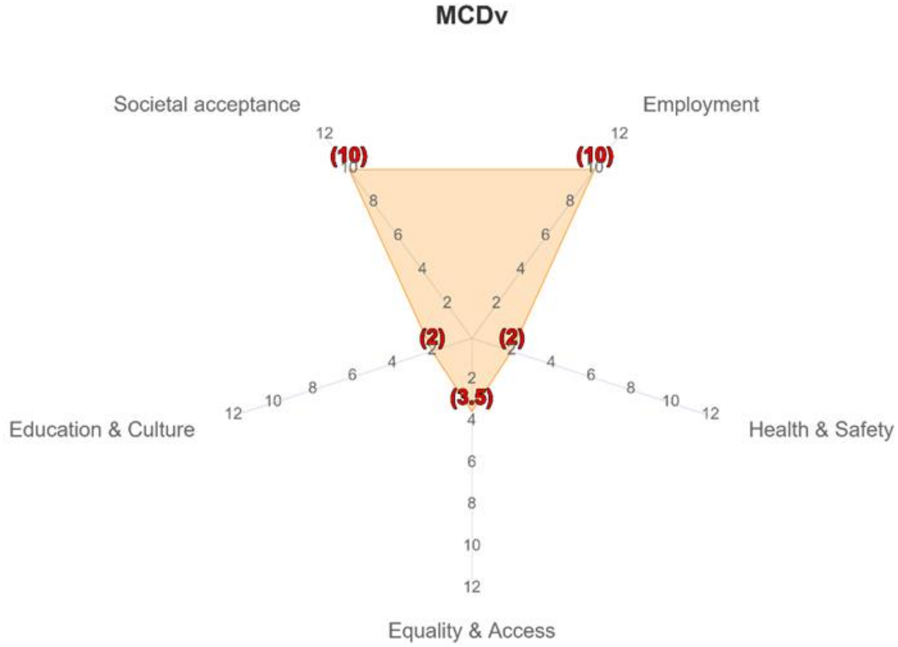


Figure 8-16 Performance MCDv on all Social Dimension KPIs

8.2.6 UC #3 CDN services in dense, static and mobile environment – Service "CDN Services Patras" (MCSv)

Service description: This service targets (train station) service operators/security staff. The goal of the service is to provide a system that allows the operator to monitor a train station from a remote operations center via VR/360º cameras deployed on site. When the field-of-view (FoV) is stable, the security footage should be received in high-quality with ultra-low latency. While the operator rotates the FoV, they need to receive smooth camera footage, without motion sickness, until the angle is stable again (they stop rotating). The system consists of a 360° Camera: the equipment used for capturing the situation at the train station area at all times; a 360° Camera Server: the component which is responsible for streams processing; and a 360° Camera Client: the receiver of the camera streams, which renders the video footage to the train station's security staff.

Performance profile: This service holds some potential to increase job quality through remote monitoring. It also is likely to improve safety conditions in stations and on platforms and thus decrease stress of passengers and employees. The service is likely to be accessible in terms of cost, hardware, and digital literacy requirements. No potentials regarding education and culture are currently discernible. There exists a potential for some opposition due to privacy, radiation, or automation concerns, and a moderate potential for opposition due to environmental concerns.

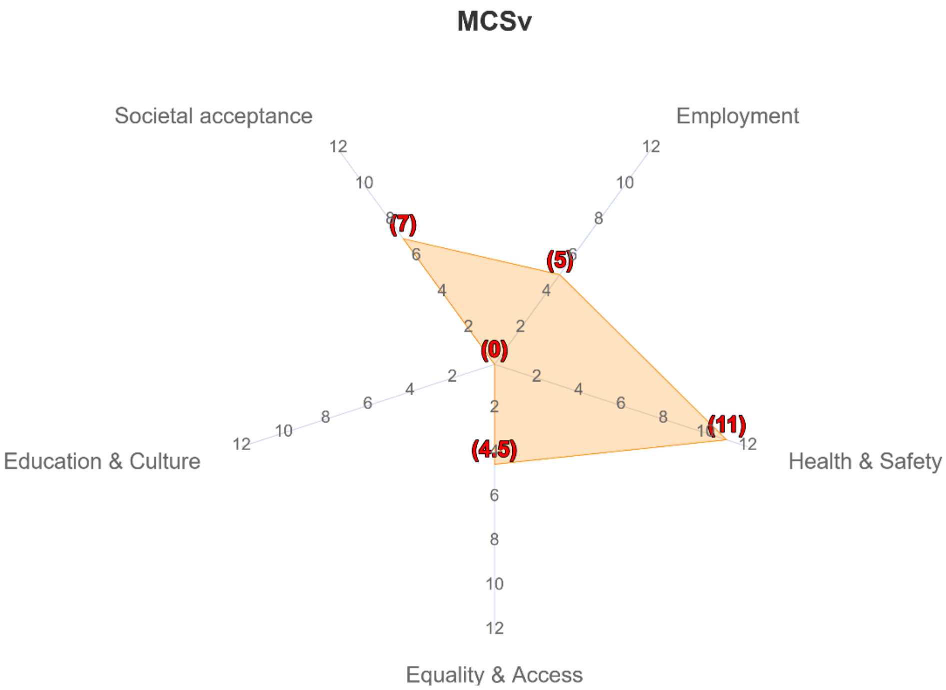


Figure 8-17 Performance MCSv on all Social Dimension KPIs

8.3 Assessment of Energy and Factories of the Future Services

8.3.1 UC #2 Digitization of Power Plants – Service "Digitization of Power Plants – Patras – Sensor data collection" (EDSv)

Service description: this maintenance service targets factory supervisors. It presents an end-to-end vertical application customized for preventive maintenance activities in a factory of the future: a great number of low-cost sensors will be installed to cover every inch of legacy industrial facilities (here the legacy ADMIE site located at Rio). By their integration into the facilites' private network, a highly connected smart factory infrastructure is created. The deployment of a smart network of energy efficient sensors and the corresponding management system will enable preventive maintenance techniques by achieving real-time / remote monitoring and inspection of the equipment via a visualization tool. This concept is directly related to the massive IoT (mMTC) concept, where small and infrequent data packets are transmitted from numerous standalone devices. The system consists of sensors supporting 5G NR connectivity technologies and an advanced data management platform integrated at a MEC server at the edge of the network at the site. Sensor data is collected and processed locally at the MEC server, while filtered data will be sent to the cloud (here University of Patras Cloud) for storage and to enable smart applications, through an extension of the 5G-VINNI infrastructure via a mmWave link from the cloud to the facility. This service is characterized by the emission of small measurement data packets in a periodic fashion; thus, it does not require low network latency but high bandwidth and computing resources, which is of course proportional to the number of industrial sensors installed at the site.

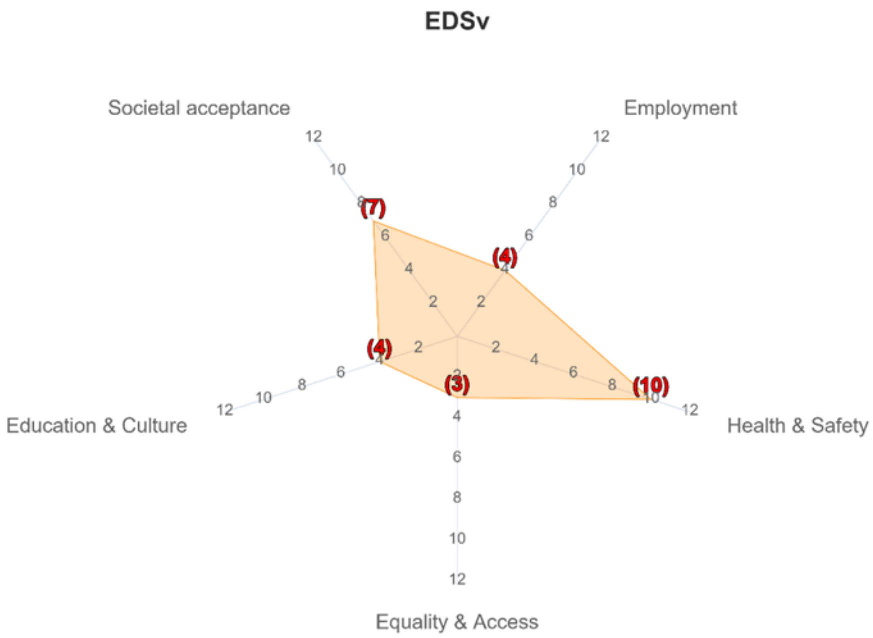


Figure 8-18 Performance EDSv on all Social Dimension KPIs

Performance profile: This service is expected to create some job opportunities in areas such as maintenance and big data analysts and IT support, which are expected to be high quality and medium to high income jobs. It further positively affects health and safety at the workplace, via efficient monitoring of infrastructure in remote, hard to reach, and dangerous areas, reducing the risks of accidents. Through positively affecting maintenance of an electricity provisioning system this also positively affects the safety and health of the public to some extent. The equipment needed requires considerable investment, therefore using this service may not be easily feasible for some SMEs. The service also provides opportunities for education and training: through a digital replica of the system workers can be trained to work with the system before they work at the field. There exists a potential for some opposition due to radiation concerns, and a potential for moderate opposition due to automation, or environmental concerns. Concerning the user perspective, this service offers live presentation of monitoring data on a user-friendly dashboard. This also includes automatic alarms and background analytics which can be used by without necessitating special training courses.

8.3.2 UC #2 Digitization of Power Plants – Service "Digitization of Power Plants – Patras – Real-time monitoring of HV power cable" (EDHv)

Service description: This operation service targets factory supervisors. It is a HV submarine cable status monitoring application (here: submarine cable between ADMIE sites in Rio and Antirio which are separated by sea and electrically connected via a submarine cable). The service emphasizes real-time measurement collection and processing. The service must achieve specific latency regardless of the background traffic in the industrial facility. EDH refers to small amounts of data with high priority, while EDS refers to the handling of a large number of infrequent packets of data, originating from different sensors. The goal of the application is to improve quality and reduce cost / time of maintenance activities. The service system consists of the IoT platform, the legacy industrial sensors producing numerous different real-time measurements each minute, the 5G network slice that will be used for the time-critical measurements collection and the additional equipment needed for the provision of 5G connectivity to the legacy sensors. This unified monitoring system is able to process data from the facility sites and generate alerts or auto trip signals in case of major problems: the application identifies possible abnormal operation conditions in real-time, informs the operator and provides input to future local controllers. This service is responsible for the emission of low latency alarm signals to a real-time controller; thus, it is characterized by low computational and network latency and high reliability requirements.

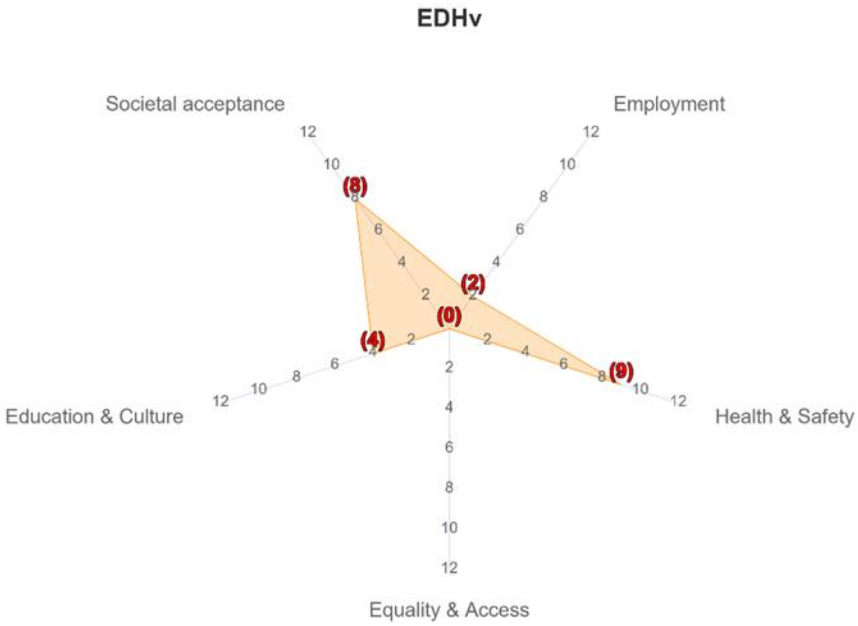


Figure 8-19 Performance EDHv on all Social Dimension KPIs

Performance profile: This service allows for real-time monitoring of physical assets with automated tools reacting to sudden events, thus constituting a powerful tool for workers, possibly affecting work quality positively. Real-time monitoring makes it possible to detect possible problems early on and remotely, thus increasing safety at the workplace and reducing stress. Through positively affecting maintenance of an electricity provisioning system this also positively affects the safety and health of the public to some extent. The equipment needed requires considerable investment, therefore using this service may not be easily feasible for some SMEs. The service also provides opportunities for education and training: through a digital replica of the system workers can be trained to work with the system before they work at the field. There exists a potential for some opposition due to radiation or automation concerns, and a potential for moderate opposition due to environmental concerns. From the user perspective the service simplifies tasks by providing live measurements to a dashboard or input to a real-time controller. In the former case the interactive dashboard is designed to be user friendly, in the latter case automated real-time control signals are provided without human interaction.

8.3.3 UC #2 Digitization of Power Plants – Service "Digitization of Power Plants – Patras – Facility CCTV monitoring" (EDCv)

Service description: This security service targets power transmission operators. The system consists of one UHD CCTV installed in a control room and a mobile surveillance robot with 5G-enabled connectivity, which is patrolling outdoors, both capturing images from the industrial infrastructure to be monitored as well as computational and 5G network resources. The goal is to forward the processed data as alarm signals to power transmission operators to ensure the safety of and in the power plant. Industrial infrastructures must be monitored, not only for the security of the facilities themselves but also for the technical personnel to ensure their physical wellbeing and protect them from multiple safety hazards. A power utility is a harsh environment where not only a high safety risk exists, but it is also a critical infrastructure. To this end, CCTV monitoring of facilities over 5G will provide a solution to this problem by providing live video feed when technical personnel is present or an event occurs, while not compromising other Industry 4.0 applications running in the background. The cameras capture images from the interior of the control room and the outdoor facilities respectively and forward them to the MEC server for preprocessing. In case an event is detected (e.g. technical personnel in the room or intruder at the facilities), the video feed will be forwarded towards the cloud (here University of Patras Cloud). From there, an alarm will be raised in order to notify the responsible security supervisor of the power transmission operator.

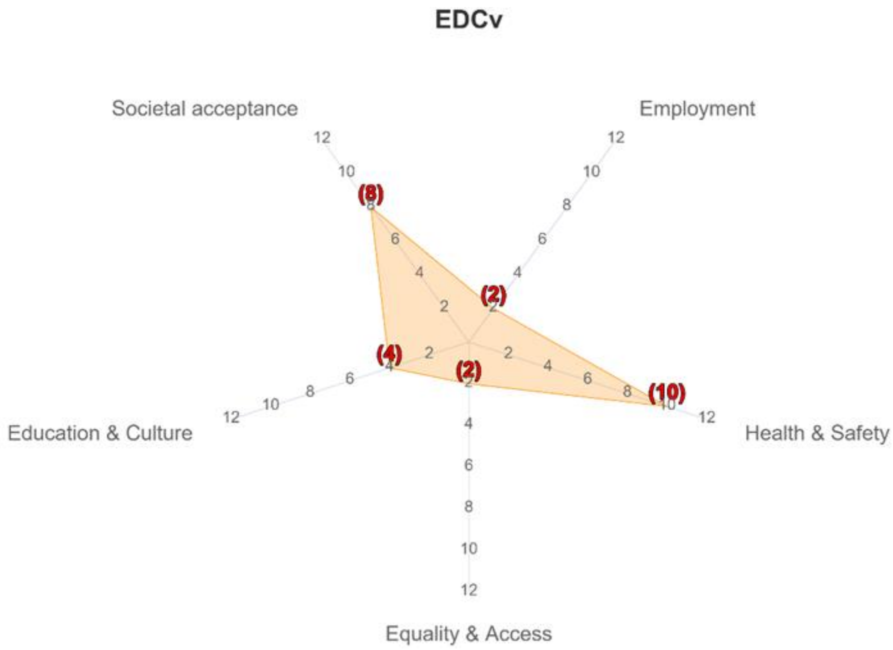


Figure 8-20 Performance EDCv on all Social Dimension KPIs

Performance profile: This service has some potential to create high quality jobs, specifically IT specialists. The remote monitoring system makes it possible to identify infrastructure faults in a timely manner, thus preventing working accidents and decreasing work time spent in hazardous working environments, positively affecting health, safety, and stress levels. The equipment needed requires considerable investment, therefore using this service may not be easily feasible for some SMEs. Using the service requires a strong IT background, therefore no usage with low digital literacy is possible. No potentials regarding education and culture are currently discernible. There exists a potential for some opposition due to radiation or automation concerns, and a potential for moderate opposition due to environmental concerns. From the user perspective, one challenge is that some training is needed for navigating the remotely controlled surveillance robot. The CCTV in application is relatively simple to use and does not require much effort from the user.

8.3.4 UC #4 Smart Energy Metering– Service "Smart Energy Metering – Patras – Real-time power consumption" (ESCv)

Service description: This service targets railway operators on the one side and power transmission system operators on the other side. The goal of this real time service is gathering the energy consumption and load data (recovery of energy fed back during braking) in the Remote Metering Solution (RMS) and Energy Management System (EMS) platforms. The former aims to assist infrastructure managers and railway operators to select optimal strategies and resources in a cost-effective and energy-efficient manner (i.e. by synchronising decelerating and accelerating rolling stock). The goal of the latter is to assist substation operators to perform smart energy techniques such as demand-respond, peak management, substation stress avoidance, load balancing, efficient HV grid interaction and cost savings in the EMS platform. The power demand profile of a traction system exhibits various changes while running, accelerating and decelerating a high-speed train, with constant power surges that stress the traction power network, and consequently the power grid. Thus, it is necessary for railway operators to mitigate these intense power surges, as this way they are not only able to secure the wellbeing of their equipment, but they can also release the stress of the power network and/or provide auxiliary service to the power grid transmission operator. In this way, by monitoring the power flows in these subsystems, the railway and power utility operators will be able to identify voltage fluctuations and develop specific energy profiles in order to mitigate them. Moreover, by leveraging the information regarding the current status and profile of the railway system, the power utility operator will be able to perform more accurate predictions of the energy demand (energy forecasting) or even use the railway system as flexible load. The service is compatible with both FRMCS and smart grid standards. A set of live data is gathered from the railing stocks and transmitted through the communication network to a data management platform even when the train travels with high-speed. The 5G facility needs to support simultaneously multiple tenants and multiple services, with various QoS, requirements, etc., over a single infrastructure. Both management systems (EMS and RMS), owned by different departments are hosted at the same cloud infrastructure as isolated vertical applications. Data privacy is validated as each operator has access only at his own Management System.

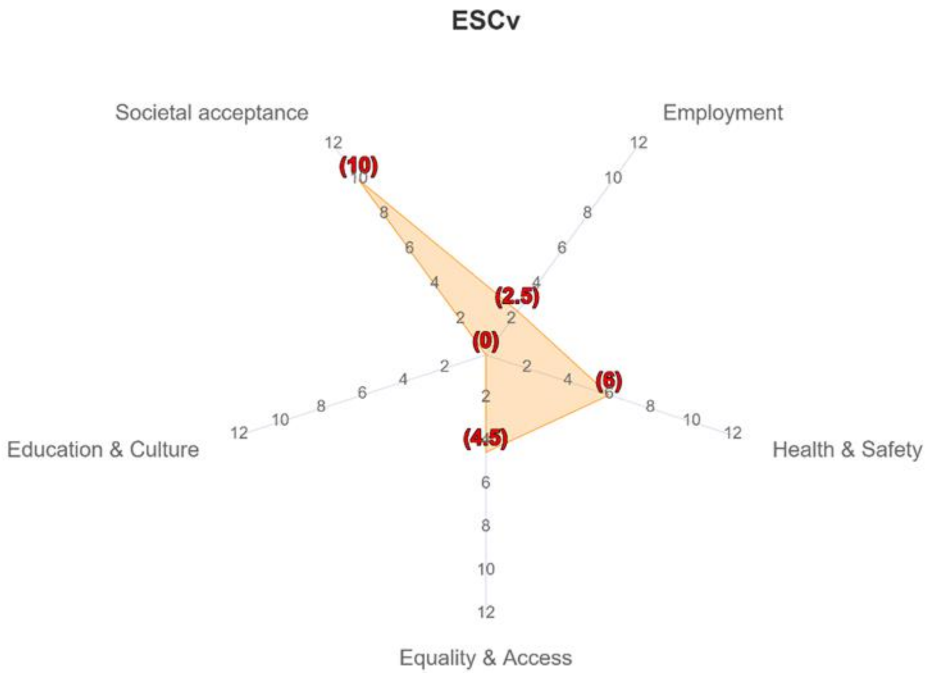


Figure 8-21 Performance ECSv on all Social Dimension KPIs

Performance profile: This service has some potential to create high quality jobs, specifically IT specialists. This service will ease the collection and analysis of power measurements, without the need of being physically at the facilities or complex interactions between actors. Therefore, the effort of workers and their exposure to hazards will be reduced, positively affecting health and safety. The equipment needed requires considerable investment, therefore using this service may not be easily feasible for some SMEs. Substantial digital literacy is required for usage. No potentials regarding education and culture are currently discernible. There exists a potential for some opposition due to radiation or automation concerns. Regarding the user perspective, the use of the service is relatively simple. The professional user is able to acquire power consumption data in real-time with relative ease, thus enabling the development of smart decision support systems.

8.3.5 UC #4 Smart Energy Metering– Service “Smart Energy Metering – Alba Iulia – Real-time LV energy metering services functionality” (ESMe)

Service description: This service targets energy managers and energy consumers. The goal is to provide energy metering services for three public buildings and street lighting scattered across Alba Iulia Smart City environment in Romania: Low cost/ low energy consuming devices are installed across the city that will operate through LTE-M / 5G-NR access layers. The service is realized by the interconnection of energy metering devices/ infrastructure with the data control and management platform through a multi-tenant and resource sharing slice infrastructure providing the required intelligence for smart grid operations. The application is deployed in the cloud infrastructure and configured for the collection of the measurements over LTE-M. The telemetry platform comprises the whole set of energetic dispatcher functions including monitoring the consumption for measured circuits, the import and export energies, the production of electrical energy, the behavior of consumers and producers and the quality of the energy produced or consumed. Collected measurements will be transferred to, stored and processed in the cloud. The results will be fed into the telemetry platform, which will also be used by the service “Smart Energy Metering Alba Iulia Energy Analytics” (ESAe), where advanced analytics will be used for operational performance follow-up and consumption monitoring.

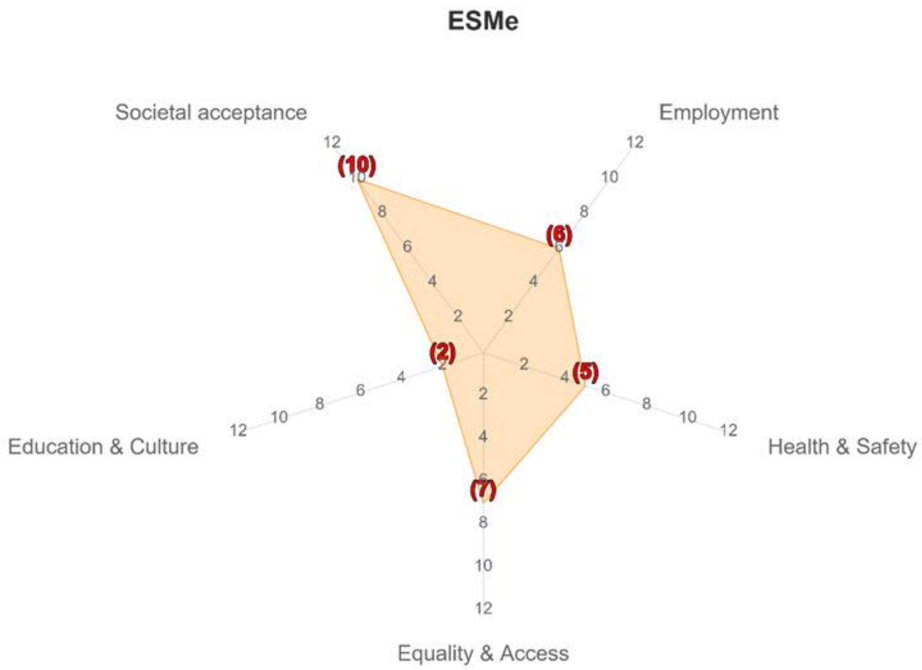


Figure 8-22 Performance ESMe on all Social Dimension KPIs

Performance profile: This service necessitates data analysts as well as maintenance and installation personnel, it thus has some potential to create jobs, which are likely to be of medium to high income and quality. Given its current focus on public buildings and public services the possibilities for other usage areas the service scores medium on equality and access. The service provides a new means of information with respect to energy consumption and efficiency. There is a possibility of some opposition because of privacy and radiation concerns. Given the beneficial results with respect to environmental sustainability concerns and opposition for environmental reasons is unlikely.

8.3.6 UC #4 Smart Energy Metering– Service "Smart Energy Metering Alba Iulia Energy Analytics" (ESAe)

Service description: This service targets energy managers and energy consumers. Building up on the service "Smart Energy Metering – Alba Iulia – Real-time LV energy metering services functionality" (ESMe), the second component of the telemetry platform is the advanced analytics, which is used for operational performance follow-up and consumption monitoring. The goal of the telemetry analytics component is to implement real-time and historical reports for energy consumption and QoS, carbon footprint and energy cost, on spot audit and historical checks, and circuits virtual clustering. Also, real time alerts for device status or parameter deviation, based on measured parameters and predefined threshold are available.

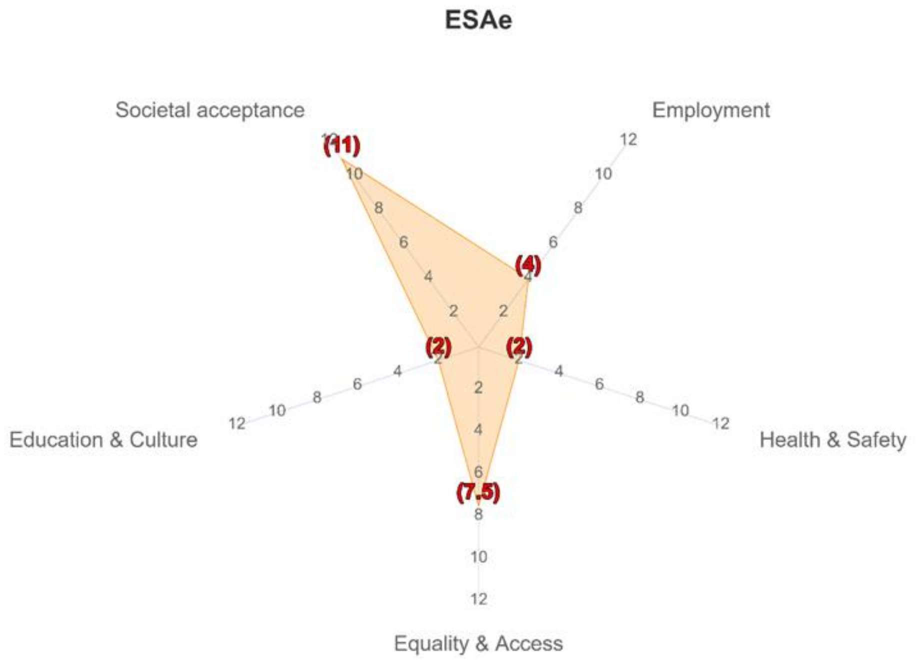


Figure 8-23 Performance ESAe on all Social Dimension KPIs

Performance profile: This service necessitates data analyst, it thus has some potential to create jobs, which are likely to be of medium to high income and quality. Given its current focus on public buildings and public services and the possibilities for other usage areas the service scores medium on equality and access. The service provides a new means of information with respect to energy consumption and efficiency. There is a possibility of some opposition because of privacy and radiation concerns. Given the beneficial results with respect to environmental sustainability concerns and opposition for environmental reasons is unlikely.

9 Conclusion

A main aim of 5G-VICTORI is providing advanced integrated 5G infrastructures and conducting large scale trials for advanced UC verification. Digital technologies applied in a broad range of sectors have the potential to contribute to societal and economic objectives, such as economically, socially and ecologically sustainable development. Telecommunications networks are crucial in making such technologies utilizable and 5G solutions have the potential to address the diverse requirements networks need to fulfil to enable new technologies. With this broad aim in mind, this deliverable provides an assessment of the current deployment, UC, and service developments within 5G-VICTORI. It discusses performance on five dimensions: the **technical, environmental, economic, social** and **user dimension**.

Taking this comprehensive perspective is essential to monitor whether the developments are on track to realize the potential 5G holds and to identifying challenges early on. Including sustainability perspectives if of considerable importance, because while technical and user performance constitute an essential condition for the success of infrastructures, services and applications, their performance with respect to social, environmental, and economic sustainability is crucial for their ultimate success in terms of societal acceptance, market potential, and scaling. It also is decisive for the overall expected impact – the assessment discussed in this document accordingly will provide a base for the impact assessment, which is part of WP5 activities.

The document first discussed some general features across all assessment dimensions. The main methodological takeaway is the importance of choosing the right assessment target or reference level for each dimension. This is particularly important in a broad assessment including quite different dimensions, especially of a project that has such a broad scope of use cases and services and applications as 5G-VICTORI. Rather than trying to establish one homogenous reference level, it needs to be defined early on which dimension can be best measured and which level at the current stage of development: for some dimensions this is the deployment level, while the performance on other dimensions can be examined at service and application level. The objectives and approach of the different dimensions considered are summarized below:

The technical assessment aimed at providing performance results of a 5G network dimensioned to support the use cases and applications in scope. This dimensioning exercise takes into consideration both HW and SW requirements.

The environmental assessment performance focused on a power consumption related evaluation for the 5G-VICTORI solution when deployed in a realistic context and scale for the use cases in scope. This evaluation includes dimensioning and operating the 5G-VICTORI platform with realistic service demands and deriving the overall platform power consumption levels based on real (experimentally measured) power consumption data for the 5G technologies deployed by the 5G-VICTORI platform.

The economic dimension, concentrated on the economic evaluation of large-scale network deployments with the aim to minimise the overall deployment cost and to investigate various technological aspects as well as critical parameters at early deployment stages. The ultimate goal is to identify economically viable and sustainable deployment options as an underlying network layer supporting the vertical/user services.

To assess **social** performance, UC and service owners as well as a jury were surveyed to capture the expected effects of the different services with regard to a range of societally important factors. Individual performance profiles by service were generated, capturing the current perspective on social performance and providing the basis for further shaping the services. Despite the (expected) considerable differences in performance between the services, some broad tendencies were identified.

Regarding the **user** dimension the goal was to construct a user questionnaire to be adapted for use by specific services and applications at later development stages. This questionnaire was successfully pretested. Beyond this, current challenges some services face regarding the user perspective were collected and documented.

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11 Appendix I

11.1 Technology Readiness Levels

Table 11-1 Technology Readiness Levels (TRL)[3]

TRL level	Description
TRL 1	Basic principles observed
TRL 2	Technology concept formulated
TRL 3	Experimental proof of concept (beginning of the 5G-VICTORI-project)
TRL 4	Technology validated in lab
TRL 5	Technology validated in relevant environment (industrially relevant environment in the case of key enabling technologies)
TRL 6	Technology demonstrated in relevant environment (industrially relevant environment in the case of key enabling technologies)
TRL 7	System prototype demonstration in operational environment (end of the 5G-VICTORI project)
TRL 8	System complete and qualified
TRL 9	Actual system proven in operational environment (competitive manufacturing in the case of key enabling technologies; or in space)

3 https://ec.europa.eu/research/participants/data/ref/h2020/wp/2014_2015/annexes/h2020-wp1415-annex-g-trl_en.pdf

11.2 Social assessment questionnaire

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5G-VICTORI → base

Page 01

Dear 5G-VICTORI project partners,

thank you for participating in this survey! One part of the Use Case Assessment (T3.4) is assessing the services developed in the project with regard to **social sustainability**. Accordingly, we need your perspective on several aspects related to the social dimension of the services and UCs. When filling in the survey, please take the **hypothetical perspective** of the service being commercially **implemented**.

We realize that some dimensions are much more relevant to some UCs/services than to others - nevertheless we need your answers to all questions. At the end of our five question sections, each referring to one of our social dimension KPIs, you will be able to leave a comment if you have thoughts on how the questions apply to your service or anything similar. Our five KPIs are employment, health & safety, equality & access, education & culture, and societal acceptance.

It will take you approximately **10 - 20 minutes** to go through the questionnaire for each service that you are responsible for and complete it. If you are filling out the questionnaire for more than one service, **please fill it out separately for each service**.

We would kindly ask you to fill in the questionnaire **until August 10th**, so that we can work with your answers well before finalizing D3.7 which is due in September.

Which service are you answering for? In case you are the person responsible for answering more than one service, please only indicate one service here and fill in the survey separately for the individual services.

- ○ UC 1.1 Enhanced Mobile Broadband under High Speed Mobility – Service: "Rail Enhanced MBB Patras rail operation non-critical" (RENv)
- ○ UC 1.1 Enhanced Mobile Broadband under High Speed Mobility – Service: "Rail Enhanced MBB Patras – Business services for Passengers" (REPv)
- ○ UC 1.1 Enhanced Mobile Broadband under High Speed Mobility – Service: "Rail Enhanced MBB Patras – Rail operation Critical Services" (RECv)
- ○ UC 1.2 Digital Mobility Transportation and Media – Service: "Digital mobility Bristol App1 Immersive Media" (RDIu)
- ○ UC 1.2 Digital Mobility Transportation and Media – Service: "Digital mobility Bristol App2 VR Live" (RDLu)
- ○ UC 1.2 Digital Mobility Transportation and Media – Service: "Digital Mobility – Bristol App3 Future Mobility" (RDFu)
- ○ UC 1.2 Digital Mobility Transportation and Media – Service: "Digital Mobility Berlin App3 Future Mobility" (RDFg)
- ○ UC 1.2 Digital Mobility – Public safety and security – Service "Infotainment/ Video Services in Dense, Static and Mobile Environment" (MDIe)
- ○ UC 1.2 Digital Mobility – Public safety and security – Service "Prioritized Communication to Command and Control Center" (MDCe)
- ○ UC 1.2 Digital Mobility – Public safety and security – Service "Artificial Intelligence Recognition and Identification of Emergency Situation" (MDAe)
- ○ UC 1.3 Rail Critical Services – Service: "Rail Critical services Berlin Rail Telephony" (RCTg)
- ○ UC 1.3 Rail Critical Services – Service: "Rail Critical services Berlin Rail Signaling" (RCSg)
- ○ UC 1.3 Rail Critical Services – Service: "Rail Critical services in Berlin – CCTV streaming" (RCCg)
- ○ UC 1.3 Rail Critical Services – Service: "Rail Critical services Berlin Sensor Data" (RCDg)
- ○ UC 2 Digitization of Power Plants – Service "Digitization of Power Plants – Patras – Sensor data collection" (EDSv)
- ○ UC 2 Digitization of Power Plants – Service "Digitization of Power Plants – Patras – Real-time monitoring of HV power cable" (EDHv)
- ○ UC 2 Digitization of Power Plants – Service "Digitization of Power Plants – Patras – Facility CCTV monitoring" (EDCv)
- ○ UC 3 CDN services in dense, static and mobile environment – Service "CDN Services Berlin" (MCBg)
- ○ UC 3 CDN services in dense, static and mobile environment – Service "CDN Services Patras" (MCDv)

○ UC 3 CDN services in dense, static and mobile environment – Service “CDN Services Patras” (MCSv)

○ UC 4 Smart Energy Metering– Service “Smart Energy Metering – Patras – Real-time power consumption” (ESCv)

○ UC 4 Smart Energy Metering– Service “Smart Energy Metering – Alba Iulia – Real-time LV energy metering services functionality” (ESMe)

○ UC 4 Smart Energy Metering– Service “Smart Energy Metering – Alba Iulia Energy Analytics” (ESAe)

○ Other

Page 03

KPI 1 - Employment

In the following section we pose several questions regarding **KPI 1 - employment**. We are particularly interested in the potential of job creation and job quality. Please remember: you are answering for the **hypothetical scenario** of the service being commercially **implemented**.

1. Does the service increase the quality of existing jobs?

- (x) Yes
- ( ) No

How much does the service increase the quality of existing jobs?

- ( ) A little
- ( ) Moderately
- ( ) A lot

2. Is the service likely to create new jobs?

- (x) Yes
- ( ) No

How large do you expect the potential to create new jobs to be?

- ( ) Small
- ( ) Moderate
- ( ) Large

3. Do you see a potential of the service to create new jobs in the short-run or in the long-run?

- (x) Already in the short-run
- ( ) Rather in the long-run
- ( ) No clear potential

4. To the extent that the service creates new jobs, are these likely to be jobs with a high job quality?

- (x) Yes
- ( ) No
- ( ) Not applicable

On average, how likely is it that the new jobs are of high job quality?

- ○ Somewhat likely
- ○ Rather likely
- ○ Very likely

5. To the extent that the service creates new jobs, are these likely to be jobs with a medium or high income?

- ◉ Yes
- ○ No, not very likely
- ○ Not applicable

How likely is it that the new jobs are, on average, with medium or high income?

- ○ Somewhat likely
- ○ Rather likely
- ○ Very likely

Please give reasons for your answers to our KPI 1 (Employment) questions in the space below. You can also use the space to add further comments, explanations, or specifications.

Page 04

KPI 2 - Health & Safety

In the following section we pose several questions regarding **KPI 2 - Health & Safety**. We are particularly interested in potential impacts on safety and health aspects, both for the general public and for employees (i.e. at the workplace). Please remember: you are answering for the **hypothetical scenario** of the service being commercially **implemented**.

6. Does the service reduce the likelihood of accidents (e.g. in the transport sector) or other unsafe situations (e.g. crime), affecting end users (e.g. passengers) or the general public?

- (•) Yes
- ( ) No

How much do you expect the service to reduce the likelihood of accidents or other unsafe situations for end users or the general public?

- ( ) A little
- ( ) Moderately
- ( ) A lot

7. Does the service reduce the likelihood of accidents at the workplace and/or the need to work in dangerous environments?

- (•) Yes
- ( ) No

How much do you expect the service to reduce the likelihood of accidents at the workplace and/or the need to work in dangerous environments?

- ( ) A little
- ( ) Moderately
- ( ) A lot

8. Does the service reduce stress or have other positive effects on the health of end users, e.g. passengers, or the general public?

- (•) Yes
- ( ) No

How much do you expect the service to reduce stress and have positive health effects for end users or the general public?

- ○ A little
- ○ Moderately
- ○ A lot

9. Does the service reduce stress of employees or have other positive effects on health at the workplace?

- ◉ Yes
- ○ No

How much do you expect the service to reduce stress and have positive health effects on employees?

- ○ A little
- ○ Moderately
- ○ A lot

Please give reasons for your answers to our KPI 2 (Health & Safety) questions in the space below. You can also use the space to add further comments, explanations, or specifications.

Page 05

KPI 3 - Equality & Access

In the following section we pose several questions regarding **KPI 3 - Equality & Access**. We are particularly interested in the expected accessibility for different groups. Please remember: you are answering for the **hypothetical scenario** of the service being commercially **implemented**.

10. Is the service affordable for low income end users or small business users (such as SMEs)?

- (x) Yes
- ( ) No
- ( ) Not applicable

How affordable is the service for low income end users or small business consumers?

- ( ) Easily affordable
- ( ) Barely affordable
- ( ) Affordable

Do you plan to have a specific pricing structure (e.g. freemium)?

Do you plan to target a specific segment of costumers?

11. Can the service be used with established hardware/software by private end users or business users?

- (x) Yes
- ( ) No
- ( ) Not applicable

To what extent is the established hardware-equipment/software sufficient for applying the service?

Established hardware/software is

- ◯ Fully sufficient
- ◯ Mostly sufficient
- ◯ Barely sufficient

12. Can the service be used with low digital literacy?

- ◉ Yes
- ◯ No

How much digital literacy is required to use the service?

- ◯ No digital literacy required
- ◯ A little digital literacy required
- ◯ Substantial digital literacy required

13. Does the service provide benefits to disadvantaged groups?

- ◉ Yes
- ◯ No

Does the service provide benefits to one or more of the following groups?

Yes to

- ☐ Lower income people
- ☐ People with disabilities/special needs
- ☐ Elderly people
- ☐ Foreigners/tourists
- ☐ Women
- ☐ Children
- ☐ Other ________________

14. Is the service approximately equally available and/or does it provide equal benefits to rural and urban users or populations?

- ◉ Yes
- ◯ No

How good is the availability and/or are benefits for rural compared to urban users or populations?

- ◯ About equal
- ◯ Somewhat worse
- ◯ Distinctly worse

Please give reasons for your answers to our KPI 3 (Equality & Access) questions in the space below. You can also use the space to add further comments, explanations, or specifications.

Page 06

KPI 4 - Education & Culture

In the following section we pose several questions regarding **KPI 4 - Education & Culture.** We are particularly interested in the potential for promoting access to and the quality of education, as well as cultural knowledge. Please remember: you are answering for the **hypothetical scenario** of the service being commercially **implemented**.

15. Does the service increase the availability and accessibility of education and training?

- (●) Yes
- ( ) No

How large do you expect the increase of the availability and accessibility of education and training to be?

- ( ) Small
- ( ) Moderate
- ( ) Large

16. Does the service increase the quality of education and training?

- (●) Yes
- ( ) No

How large do you expect the increase of the quality of education and training to be?

- ( ) Small
- ( ) Moderate
- ( ) Large

17. Does the service further cultural knowledge and/or civic and cultural education?

- (●) Yes
- ( ) No

How much do you expect the service to further cultural knowledge and/or civic and cultural education?

- ( ) A little
- ( ) Moderately
- ( ) A lot

18. Does the service further communication and information?

- (selected) Yes
- No

How much do you expect the service to further communication and information?

- A little
- Moderately
- A lot

Please give reasons for your answers to our KPI 4 (Education & Culture) questions in the space below. You can also use the space to add further comments, explanations, or specifications.

KPI 5 - Societal Acceptance

In the following section we pose several questions regarding **KPI 5 - Societal Acceptance**. We are particularly interested in your expectations regarding opposition from the public due to different types of concerns.

19. Does the service include aspects that could encounter opposition from the public because of data protection and privacy concerns?

- (•) Yes
- ( ) No

How much opposition do you expect from the public because of data protection and privacy concerns?

- ( ) A lot of opposition
- ( ) Moderate opposition
- ( ) Only some opposition

20. Is the service likely to encounter opposition due to fears of radiation?

- (•) Yes
- ( ) No

How much opposition do you expect because of fears around radiation?

- ( ) A lot of opposition
- ( ) Moderate opposition
- ( ) Only some opposition

21. Is the service likely to encounter opposition due to fears of automation and job loss?

- (•) Yes
- ( ) No

How much opposition do you expect because of fears of automation and job loss?

- ( ) A lot of opposition
- ( ) Moderate opposition
- ( ) Only some opposition

22. Is the service likely to encounter opposition due to environmental concerns?

- (●) Yes
- ( ) No

How much opposition do you expect because of environmental concerns?

- ( ) A lot of opposition
- ( ) Moderate opposition
- ( ) Only some opposition

Please give reasons for your answers to our KPI 5 (Societal Acceptance) questions in the space below. You can also use the space to add further comments, explanations, or specifications. Please remember: you are answering for the hypothetical scenario of the service being commercially implemented.

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You have almost reached the end of the questionnaire. Before finishing, please enter your email address and telephone number, so that we can get in touch in case of need for clarification regarding your answers:

Last Page

Thank you for completing this questionnaire!

We would like to thank you very much for helping us.

Your answers were transmitted, you may close the browser window or tab now.

If you are filling out the questionnaire for more than one service, please fill it out separately for the next service. You can copy this link to re-enter the survey:

https://projekte.izt.de/sosci/5G-VICTORI/

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11.3 Social assessment detailed results per service

Service ID	Employment					Health & Safety					Equality & Access						Education & Culture					Societal Acceptance				
	increase quality of existing jobs (3)	Likelihood to create new jobs (3)	new jobs to have high quality (3)	new jobs to have medium / high income (3)	**Employment total (12)**	reduce unsafe situations for private users / the public (3)	reduce unsafe working situations for employees (3)	stress reduction / positve effect on private user / the public (3)	stress reduction / positve effect on employees (3)	**Health & Safety total (12)**	affordable for low income / SMEs (3)	useable with establihed hardware / software (3)	usable with low digital literacy (3)	benefitting disadvantaged groups (1,5)	equally available / bene-fitting to rural and urban users / population (1,5)	**Equality & Access total (12)**	increase availability / accessability of education / training (3)	increase quality of education and training (3)	further cultural knowledge and/or civic and cultural education (3)	further communication and information (3)	**Education & Culture total (12)**	expected opposition due to data security / privacy concerns (3)	expected opposition due to fears of radiation (3)	expected opposition due to fears of rautomation and job loss (3)	expected opposition due to environmental concerns (3)	**Societal Acceptance total (12)**
RENv	1	1	1	1	**4**	0	0	1	1	**2**	2	2	0	1	0	**5**	0	0	0	1	**1**	3	2	2	1	**8**
REPv	2	2	3	3	**10**	0	0	0	0	**0**	2	2	0	1	0	**5**	1	1	2	3	**7**	3	2	3	1	**9**
RECv	3	0	n.a.	n.a.	**3**	2	2	1	2	**7**	2	2	0	0	0	**4**	0	0	0	2	**2**	3	2	3	2	**10**
RDIu	2	1	3	2	**8**	0	0	2	0	**2**	3	2	2	1,5	1,5	**10**	2	2	3	3	**10**	2	2	3	0	**7**
RDLu	2	0	3	3	**8**	0	0	0	0	**0**	3	2	2	1	1.5	**9.5**	3	3	2	3	**11**	3	2	3	1	**9**
RDFu	2	1	2	1	**6**	1	0	1	1	**3**	3	2	2	1.5	0	**8.5**	1	1	1	3	**6**	2	2	3	1	**8**
RDFg	2	1	n.a.	1	**4**	1	1	0	1	**3**	3	2	2	1.5	0	**8.5**	1	1	1	3	**6**	2	2	3	1	**8**
RCTg	1	0	n.a.	n.a.	**1**	1	0	1	1	**3**	n.a.	2	3	0	0	**5**	0	0	0	2	**2**	3	2	3	2	**10**
RCSg	1	1	1	0	**3**	3	2	2	2	**9**	3	1	0	0	0	**4**	0	0	0	0	**0**	3	2	3	2	**10**
RCCg	0	0	1	n.a.	**1**	2	0	2	1	**5**	3	2	3	0	0	**8**	0	0	0	0	**0**	2	2	3	2	**9**
RCDg	1	0	n.a.	n.a.	**1**	2	2	0	2	**6**	n.a.	n.a.	0	0	0	**0**	0	0	0	0	**0**	3	2	2	2	**9**
MDIe	1	0	1	1	**3**	0	0	1	1	**2**	2	3	2	1	1	**9**	0	0	1	2	**3**	2	2	3	2	**9**
MDCe	1	0	1	1	**3**	3	1	2	1	**7**	2	1	2	1.5	1	**7.5**	0	0	0	2	**2**	1	2	3	1	**7**
MDAe	2	0	1	1	**4**	3	1	2	1	**7**	2	2	2	1.5	1	**8.5**	0	0	0	2	**2**	1	2	3	1	**7**
MCBg	0	1	2	2	**5**	0	0	1	0	**1**	3	3	2	0.5	1.5	**8**	0	0	1	1	**2**	3	2	3	2	**10**
MCDv	3	1	3	3	**10**	0	0	2	0	**2**	n.a.	n.a.	2	0	1.5	**3.5**	0	0	0	2	**2**	3	2	3	2	**10**
MCSv	3	0	2	n.a.	**5**	3	3	2	3	**11**	n.a.	3	0	0	1.5	**4.5**	0	0	0	0	**0**	2	2	2	1	**7**
EDSv	2	0	2	n.a.	**4**	2	3	2	3	**10**	1	2	0	0	0	**3**	2	2	0	0	**4**	3	2	1	1	**7**
EDHv	2	0	n.a.	n.a.	**2**	2	2	2	3	**9**	0	0	0	0	0	**0**	2	2	0	0	**4**	3	2	2	1	**8**
EDCv	1	0	1	n.a.	**2**	2	3	2	3	**10**	1	1	0	0	0	**2**	0	0	0	0	**0**	3	2	2	1	**8**
ESCv	1	0	1.5	n.a.	**2.5**	1	2	1	2	**6**	2	1.5	1	0	0	**4.5**	0	0	0	0	**0**	3	2	2	3	**10**
ESMe	2	1	2	1	**6**	2	1	1	1	**5**	2	3	2	0	0	**7**	0	0	2	0	**2**	2	2	3	3	**10**
ESAe	1	1	1	1	**4**	0	1	0	1	**2**	2	2	2	0.5	1	**7.5**	0	0	0	2	**2**	3	2	3	3	**11**

n.a. = not applicable

11.4 User assessment questionnaire

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0% completed

Thank you for participating in this survey! You have used a service from the 5G-VICTORI project. We are interested in **your experience with the service**. Accordingly, this brief survey contains some questions regarding your experience and your satisfaction with the service.

Note: the service is not yet in at a commercial stage. Please indicate your experience with the service at it is now, in its **current state of development**.

It will take **5 minutes** to go through the questionnaire.

Please fill in the questionnaire as soon as possible after you use the service. The latest date possible is **the 2nd of September.**

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17% completed

1. Which service did you use? In case you are not sure about the exact name please ask the person assessiting you in the usage of the service or the person who recruited you for this task.

- ○ UC 1.1 Enhanced Mobile Broadband under High Speed Mobility – Service: "Rail Enhanced MBB Patras rail operation non-critical" (RENv)
- ○ UC 1.1 Enhanced Mobile Broadband under High Speed Mobility – Service: "Rail Enhanced MBB Patras – Business services for Passengers" (REPv)
- ○ UC 1.1 Enhanced Mobile Broadband under High Speed Mobility – Service: "Rail Enhanced MBB Patras – Rail operation Critical Services" (RECv)
- ○ UC 1.2 Digital Mobility Transportation and Media – Service: "Digital mobility Bristol App1 Immersive Media" (RDIu)
- ○ UC 1.2 Digital Mobility Transportation and Media – Service: "Digital mobility Bristol App2 VR Live" (RDLu)
- ○ UC 1.2 Digital Mobility Transportation and Media – Service: "Digital Mobility – Bristol App3 Future Mobility" (RDFu)
- ○ UC 1.2 Digital Mobility Transportation and Media – Service: "Digital Mobility Berlin App3 Future Mobility" (RDFg)
- ○ UC 1.2 Digital Mobility – Public safety and security – Service "Infotainment/ Video Services in Dense, Static and Mobile Environment" (MDIe)
- ○ UC 1.2 Digital Mobility – Public safety and security – Service "Prioritized Communication to Command and Control Center" (MDCe)
- ○ UC 1.2 Digital Mobility – Public safety and security – Service "Artificial Intelligence Recognition and Identification of Emergency Situation" (MDAe)
- ○ UC 1.3 Rail Critical Services – Service: "Rail Critical services Berlin Rail Telephony" (RCTg)
- ○ UC 1.3 Rail Critical Services – Service: "Rail Critical services Berlin Rail Signaling" (RCSg)
- ○ UC 1.3 Rail Critical Services – Service: "Rail Critical services in Berlin – CCTV streaming" (RCCg)
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- ○ UC 2 Digitization of Power Plants – Service "Energy and factories – Digitization of Power Plants – Patras – Real-time monitoring of HV power cable" (EDHv)
- ○ UC 2 Digitization of Power Plants – Service "Energy and factories – Digitization of Power Plants – Patras – Facility CCTV monitoring" (EDCv)
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- ○ UC 3 CDN services in dense, static and mobile environment – Service "CDN Servics Patras" (MCDv)
- ○ UC 3 CDN services in dense, static and mobile environment – Service "CDN Servics Patras" (MCSv)
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- ○ UC 4 Smart Energy Metering– Service "Energy and factories – Smart Energy Metering – Alba Iulia – Real-time LV energy metering services functionality" (ESMe)
- ○ UC 4 Smart Energy Metering– Service "Energy and factories Smart Energy Metering Alba Iulia Energy Analytics" (ESAe)

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33% completed

2. How likely is it that you would recommend this service to others?

	not at all likely									extremely likely
It is...	○	○	○	○	○	○	○	○	○	○

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50% completed

3. Please rate your experiences with the service by answering the following questions.

	stronlgy disagree	disagree	neither agree nor disagree	agree	strongly agree
I think that I would like to use this service frequently.	○	○	○	○	○
I found the service unnecessarily complex.	○	○	○	○	○
I thought the service was easy to use.	○	○	○	○	○
I think that I would need the support of a technical person/support material to be able to use this service.	○	○	○	○	○
I found the various functions in this service were very well integrated.	○	○	○	○	○
I thought there was too much inconsistency in this service.	○	○	○	○	○
I would imagine that most people would learn to use this service very quickly.	○	○	○	○	○
I found the service very cumbersome to use.	○	○	○	○	○
I felt very confident using the service.	○	○	○	○	○
I needed to learn a lot of things before I could get going with this service.	○	○	○	○	○

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67% completed

4. How would you rate your overall satisfaction with the service you just received?

I am...

very unsatisfied	unsatisfied	neutral	satisfied	very satisfied

5. Please give some reasons/feedback for why you chose this level of satisfaction

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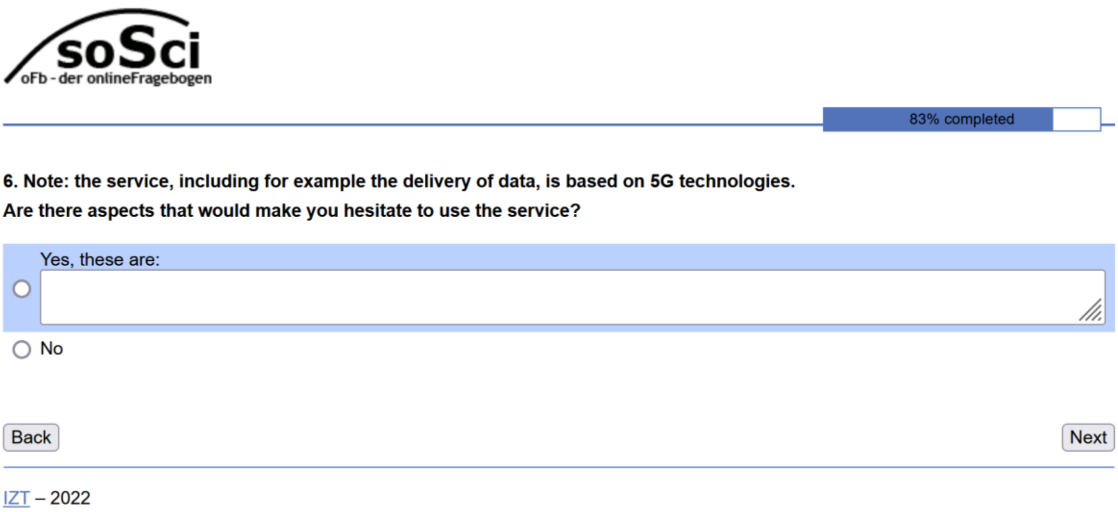

soSci oFb - der onlineFragebogen

83% completed

6. Note: the service, including for example the delivery of data, is based on 5G technologies.
Are there aspects that would make you hesitate to use the service?

- Yes, these are:
- No

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Thank you for completing this questionnaire!

We would like to thank you very much for helping us.

Your answers were transmitted, you may close the browser window or tab now.

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11.5 User assessment detailed results per service

Service ID	Pseudo user	Likelihood of recommendation (10)	Service usability: I think that I would use this service frequently (5)	I found the service unnecessarily complex * (5)	I thought the service was easy to use (5)	… need support of tech. person / support material to use service * (5)	I found the various functions in this service were very well integrated (5)	I thought there was too much inconsistency in this service * (5)	… imagine that most people would learn to use service very quickly (5)	I found the service very cumbersome to use * (5)	I felt very confident using the service (5)	I needed to learn a lot of things before I could get going with this service * (5)	**average (5)**	Customer satisfaction (5)	User acceptance: Yes / No	User acceptance: comment
RDIu	A	**8**	4	4	4	3	2	4	4	5	4	4	**3.8**	**4**	N	
RDFu	A	**9**	4	3	4	4	4	3	5	5	4	5	**4.1**	**4**	N	
RDFg	A	**9**	4	4	4	4	4	4	4	4	4	4	**4**	**5**	N	
RCTg	A	**9**	5	5	5	5	5	4	5	5	5	5	**4.9**	**5**	N	
	B	**9**	5	5	4	5	5	5	5	4	5	5	**4.8**	**5**	N	
	C	**10**	5	4	4	2	4	5	5	4	4	3	**4**	**4**	N	
MCBg	A	**8**	4	4	5	4	3	4	5	5	5	4	**4.2**	**4**	N	
MCDv	A	**10**	5	4	4	5	5	5	5	5	5	5	**4.8**	**5**	N	
EDSv	A	**10**	5	2	4	3	4	4	5	5	4	4	**4**	**4**	Y	So far reliance on wireline, hesitation because of cost and personell (training needed)
	B	**8**	4	4	4	3	4	4	4	4	4	4	**3.9**	**4**	N	
EDHv	A	**8**	3	5	5	3	3	3	4	5	4	3	**3.8**	**4**	Y	So far wireline preferred, 5G technology needs to guarantee same reliability and low latency at same or lower cost
	B	**8**	4	4	4	4	4	3	4	4	4	4	**3.9**	**4**	N	
EDCv	A	**9**	3	4	4	1	3	4	3	3	3	3	**3.1**	**4**	N	
	B	**8**	4	4	4	3	4	4	4	4	4	3	**3.8**	**4**	N	
ESCv	A	**8**	4	3	4	3	4	4	4	4	4	3	**3.7**	**4**	N	

* Answers of negatively formulated questions were inverted to calculate the average. The inversion linked the most positive rating to the highest numerical value (value 1 inverted to 5, value 2 inverted to 4 and vice versa).