EXPERIMENTATION AND VALIDATION OPENNESS FOR LONGTERM EVOLUTION OF VERTICAL INDUSTRIES IN 5G ERA AND BEYOND

[H2020 - Grant Agreement No.101016608]

Deliverable D6.2

Technoeconomic Analysis and Stakeholders Engaging (Intermediate Report)

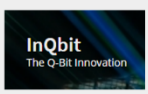
Editors Dimitris Tsolkas (FOGUS), Katerina Giannopoulou (FOGUS)

Contributors FOGUS, INF, LNV, IEA, TID, MAG, 8BELLS, QCOM, IQB, ATOS, ININ, COS, GMI, CAF, IMM, PAL, UMS

Version 1.0

Date January 31st, 2023

Distribution PUBLIC (PU)



DISCLAIMER

REVISION HISTORY

Revision	Date	Responsible	Comment
0.1	September 30, 2022	Dimitris Tsolkas (FOGUS)	Initial ToC (already refined based on Plenary meeting discussions)
0.2	October 15, 2022	Katerina Giannopoulou (FOGUS)	Finalized ToC with sub-sectioning and Inputs from FOGUS
0.3	October 31, 2022	Katerina Giannopoulou (FOGUS)	Merging initial inputs from contributing partners, revisiting content (especially COS, TID, LNV and the SME)
0.4	November 30, 2022	George Avdikos (8BELLS), John Karadimas (MAG)	Initial draft - content ready for harmonization – Key inputs from 8BELLs and additions from MAG
0.5	December 13, 2022	Dimitris Tsolkas (FOGUS),	Full draft ready
0.6	January 5, 2023	All main editors	Internal review/gaps identification
0.7	January 15, 2023	Katerina Giannopoulou (FOGUS) Dimitris Tsolkas (FOGUS)	Deliverable ready for review.
0.8	January 24, 2023	Regel Gonzalez Usach (UPV)	UPV review
0.9	January 26, 2023	Christina Skoubridou (IEA)	IEA review
1.0	January 28, 2023	Project management team	Finalization - Ready for submission

LIST OF AUTHORS

Partner	***Partner FULL NAME***	***Name & Surname***
FOGUS	*FOGUS INNOVATIONS & SERVICES*	*Dimitris Tsolkas* *Katerina Giannopoulou* *Georgios Krommydas* *Eugenios Tsitos*
IQB	*InQBit*	*Stylianou Ioannis* *Ilias Politis*
8BELLS	*Eight Bells Ltd*	*George Avdikos*
MAG	*MAGGIOLI SPA*	*Yannis Karadimas*
ZORTE	*ZORTENET P.C.*	*Andreas Oikonomakis* *Akis Kourtis* *George Xylouris*
UMS	*UM AUTONOMOUS SYSTEMS LIMITED*	*Ivano Manfredonia,* *Dominic Morris*
CAF	*CAFA Tech*	*Tanel Järvet, Märten Rannu, Shvea Järve*
COSM	*COSMOTE S.A*	*F. Setaki* *G. Lyberopoulos*
GMI	*GMI Aero SAS*	*George Kanterakis*
INF	*INFOLYSIS*	*Vaios Koumaras* *Theodore Papadopoulos* *George Theodoropoulos*
LNV	*Lenovo (Deutschland) GmbH*	*D. Dimopoulos* *A. Salkintzis*
PAL	*PAL Robotics*	*Alessandro Di Fava*
IMM	*Immersion*	*Charles Bailly*
ININ	*INTERNET INSTITUTE Ltd*	*Rudolf Sušnik* *Luka Koršič*
NCSRD	*NCSR Demokritos*	*Harilaos Koumaras*
IEA	*Impact Entrepreneurship Award*	*Maria Gabriella Anagnostopoulos* *Christina Skoubridou*
TID	*Telefónica Investigación y Desarrollo S.A.U.*	*David Artuñedo*

GLOSSARY

Abbreviations/Acronym	*Description*
3GPP	*3rd Generation Partnership Project*
4G	*4th Generation of Mobile Networks*
5G	*5th Generation of Mobile Networks*
5G PPP	*5G Infrastructure Public Private Partnership*
AI	*Artificial Intelligence*
API	*Application Programming Interface*
AR	*Augmented Reality*
ARPU	*Average Revenue per User*
BERD	*Business Enterprise R&D Expenditure*
BS	*Base Station*
CAGR	*Compound Annual Growth Rate*
CAPEX	*Capital Expenses*
CSP	*Communication Service Provider*
D2D	*Device-to-Device*
DESI	*Digital Economy and Society Index*
DWNA	*Distributed Wireless Network Architecture*
EC	*European Commission*
EU	*European Union*
FirstNet	*First Responder Network Authority*
FoF	*Factory of Future*
GDP	*Gross Domestic Product*
HAL	*Harmonized API Layer*
HetNets	*Heterogeneous Networks*
ICT	*Information and Communications Technology*
IIoT	*Industrial Internet of Things*
IT	*Information Technology*
MDAS	*Modified DAS*
MEC	*Multi-Edge Computer*
mmWave	*millimeter Wave*
MNO	*Mobile Network Operator*
ML	*Machine Learning*
MPICOC	*Modified Picocell*
Network App	*Network Application*
NEF	*Network Exposure Function*
NFV	*Network Function Virtualization*
NH	*Neutral Host*
NHN	*Neutral Host Network*
NPN	*Non-Public Network*
NPV	*Net Present Value*
NSSF	*Network Slice Selection Function*
NWDAF	*Network Data Analytics Function*
ODA	*Official Development Assistance*
Open RAN	*Open Radio Access Network*
PED	*Price Elasticity of Volume*
OPEX	*Operational Expenses*

PLMN	*Public Land Mobile Network*
PNI-NPN	*Public Network Integrated NPN*
PPE	*Personal Protective Equipment*
pysim5G	*python simulator for integrated modelling of 5G*
QoS	*Quality of Service*
RAN	*Radio Access Network*
R&D	*Research and Development*
ROI	*Return of Investment*
SA	*Sensitivity Analysis*
SDN	*Software-Defined Networking*
SIEM	*Security Information and Event Management*
SME	*Small and Medium-sized Enterprises*
SNPN	*Stand-alone NPN*
TCO	*Total Cost of Ownership*
TSN	*Time-Sensitive Networking*
UDN	*Ultra-Dense Network*
UE	*User Equipment*
UKPN	*United Kingdom Power Networks*
vApp	*Vertical Application*

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

In the framework of EVOLVED-5G project and specifically within Work Package 6 (WP6)/Task 6.3 (T6.3), an analysis has been conducted around technoeconomic aspects that emerge from the introduction of the Network Applications (Network App) ecosystem. By definition Network Apps interact with an underlay network to provide advanced services to verticals or to networks. The interaction that is created among the network and the applications, is supported by APIs than can refer to any plane, namely control, data, or management. A key concept that EVOLVED-5G investigates is the interaction at control plane, targeting the network core exposure capabilities (and thus, the related standardized APIs) for 5G NPN (Non-Public Networks) scenarios. The analysis follows a top-down approach.

The first step was to identify the current business and economic impact of 5G. Through a state-of-the art analysis that we conducted (entitled 5G viability and related investments) and a study of related market reports, useful insights were extracted, regarding the 5G NPN growth in EU and the current expectations from operators and verticals. Then, digging into the concept of Network apps for 5G NPNs, we identified four technology enablers that could pave the way towards the rise of a Network App business paradigm. Those enablers are i) the mobile network openness, which is produced through standardized APIs, ii) the concept of developing Network apps based on highly accepted patterns like the microservice programming, iii) the analytics potential that brings though the NWDAF function high potential for data collection and processing (with AI tools), and iv) the development of auxiliary platforms that facilitate business and stakeholders' interaction, such as marketplaces. Having specified the related technology enablers, an iterative methodology for technoeconomic analysis was agreed, where the following actions were included in a loop: i) business models and value networks study, ii) viability study, iii) technological impact assessment, and iv) sensitivity analysis. In this context, initial value network models were designed, and business modeling approaches were studied. Also, a mapping of the 5G stakeholders to the stakeholders of a network app was conducted, while for engaging SMEs, startups, developers and entrepreneurs cross-WP activities have started, like the EVOLVED-5G acceleration program. Towards the viability study, feedback was collected regarding the expected technology impact on the business cases that are included in the project. In addition, for a structured feedback collection an online survey was prepared and released. The survey had a major goal to reveal business and technological factors that are related to the Network app ecosystem. The results were analyzed, providing some key insights like the following ones:

- There is an optimistic view about the exploitation of the mobile openness and the concept of Network apps (impact is expected in the next 5 years).
- The use of standardized APIs is a well-perceived choice, meaning that the EVOLVED-5G approach seems to be in the right direction for long term exploitation.
- Artificial intelligence (AI) and open sourcing are key enablers for the success of the Network app ecosystem.
- To reap the benefits of Network App ecosystem, the tighter collaboration among the stakeholders and the further financial support from EC research funds, are the most critical factors.

TABLE OF CONTENTS

1 INTRODUCTION

1.1 Purpose of the document

This deliverable is the second of a series of four WP6 reports to be delivered by the project consortium during its 36-month work plan. The primary objective of this report, entitled *"Technoeconomic Analysis and Stakeholders Engaging (Intermediate Report)"*, is to outline the business and economic impact of 5G ecosystem, the key enablers which will affect the Network App market growth and the mapping of the EVOLVED-5G stakeholders.

1.2 Structure of the document

The deliverable is organized in the following manner:

- **Section 1. Introduction:** This section describes the Purpose of the Deliverable, the structure and target audience.
- **Section 2. Business and Economic impact of 5G:** This section describes the impact of 5G in EU, the deployments which have been done so far and the 5G viability in these and in the future investments. Also, it is referred to 5G NPN and in general, to the private wireless growth.
- **Section 3. Key Enablers for Network App market growth:** This section describes the identification of the four enablers that are related to the Network Applications concept within EVOLVED-5G, which are currently paving the way for a new business paradigm on top of 5G and beyond networks. These are the open APIs, microservice programming, open sourcing, and analytics.
- **Section 4. Technoeconomic aspects and business analysis:** This section describes the examination of the technoeconomic aspects of the EVOLVED-5G Ecosystem based on the Business models and Value networks identification (definition and interaction among different business roles and stakeholders), the Business case viability study (TCO model), the impact of new technologies on the business case (investigation of the impact of the innovative technology on the business case) and the sensitivity analysis (assessing the degree of uncertainty that links the model outputs to the inputs).
- **Section 5. Mapping EVOLVED-5G stakeholders to 5G ecosystem:** This section describes the set of stakeholders related to the EVOLVED-5G framework which can be extended by additional entities of the 5G ecosystem, that might develop interest for Network Apps and their development process in the future.
- **Section 6. Survey on Network App research and market potential:** This section describes the online survey which has been developed and delivered, in the context of this deliverable. It also declares the purpose and the approach of this survey, the structure and lastly the outcomes and the results.

1.3 Target audience

The scope of this deliverable is to expose to the audience the EVOLVED-5G activities around technoeconomic aspects and business modeling approaches for the 5G and the Network Applications ecosystem studied in the project. Its intention is to be accessible to a board variety of research individuals and communities.
The target audiences are described below:

- **Project Consortium**: To validate this deliverable is well documented and to provide information.
- **Industry 4.0/Industry 4.0 developers and Factories of the Future (FoF) vertical groups**: To set a common understanding of the technologies and their impact in a financial and technical way. To highlight the variety of use cases that can be deployed in the context of 5G NPN and in general of 5G ecosystems.
- **Other vertical industries and groups:** To encourage and reinforce ventures in this direction.

- **Scientific audience, general public, and the funding EC Organisation**: To document the work performed by the project and justify the effort reported for all relevant activities. The scientific audience can also get an insight into the technical and economic approach of this deliverable.

2 BUSINESS AND ECONOMIC IMPACT OF 5G

2.1 5G IMPACT IN EUROPEAN UNION

Currently, in Europe the ICT sector [1] represents 4.1% of the total value added, 2.7% of total employment, 15.2% of total BERD (Business enterprise R&D expenditure), and 18.1% and 20.4% of the R&D personnel and researchers in the EU28, respectively. As the PWC study reports [2], at global level 5G will add US$1.3tn to global GDP by 2030. Towards this, 5G, as a key ICT technology will be a major contributor. In the specific use case that the EVOLVED-5G project targets at, i.e., the manufacturing industry, it becomes apparent that, 5G can:

- Free up machinery from being tethered to a particular location by replacing cables with wireless connectivity, giving manufacturers a far greater degree of flexibility.
    - Note that compared to other wireless technologies that can theoretically offer this flexibility in a factory (e.g., WiFi 6), 5G is much faster, includes a unified control system/network core (i.e., it is not just the wireless interface), has better coverage and reliability, and it can be incorporated to a public 5G network.
- Meet specific requirements at higher quality, scale and speed, and at lower cost by providing more adaptable and responsive production lines that can be reconfigured faster and with less effort
- Accelerate the development of connected and self-orchestrating intelligent ecosystems that can quickly anticipate and address issues and opportunities.

In total 5G applications in manufacturing are expected to add US$134bn to global GDP by 2030.

The 5G is currently at the dawn of commercial usage and exploitation for service provisioning widely. EVOLVED-5G targets the exploitation of 5G capabilities towards the so-called Network App ecosystem. Thus, prior an assessment of the business and economic impact that is expected from the Network App ecosystem, the current proliferation of 5G deployments and technologies is summarized, based on the official EC report Digital Economy and Society Index (DESI) 2021 [3].

On the one hand, the **5G readiness** indicator in the DESI shows the portion of spectrum assigned for 5G purposes in each Member State in the 5G pioneer bands. The percentage score of the 5G readiness indicator is based on the amount of spectrum assigned in a specific Member State and ready for 5G use by the end of 2020 within the 5G pioneer bands identified in Europe. This score is calculated based on the portion of spectrum assigned in each 5G pioneer band in comparison with the maximum feasible amounts, which are as follows:

- 700 MHz band: 60 MHz (703-733 & 758-788 MHz),
- 3.6 GHz band: 400 MHz (3,400-3,800 MHz),
- 26 GHz band: 1000 MHz within 24,250-27,500 MHz

All three spectrum bands have an equal weight, so having the maximum feasible amount assigned – and ready for 5G use – in the range of one of these bands will result in a score of 33.3%, i.e., one third of the total maximum score.

As depicted in Figure 1 by the end of August in 2021, 25 of the 27 Member States had assigned spectrum in the 5G pioneer bands, compared to 16 a year earlier. Germany, Croatia, Denmark, Greece, Finland and Slovenia assigned more than 90% of spectrum. On the other hand, Estonia and Poland have not yet assigned any 5G spectrum (according to the above conditions).

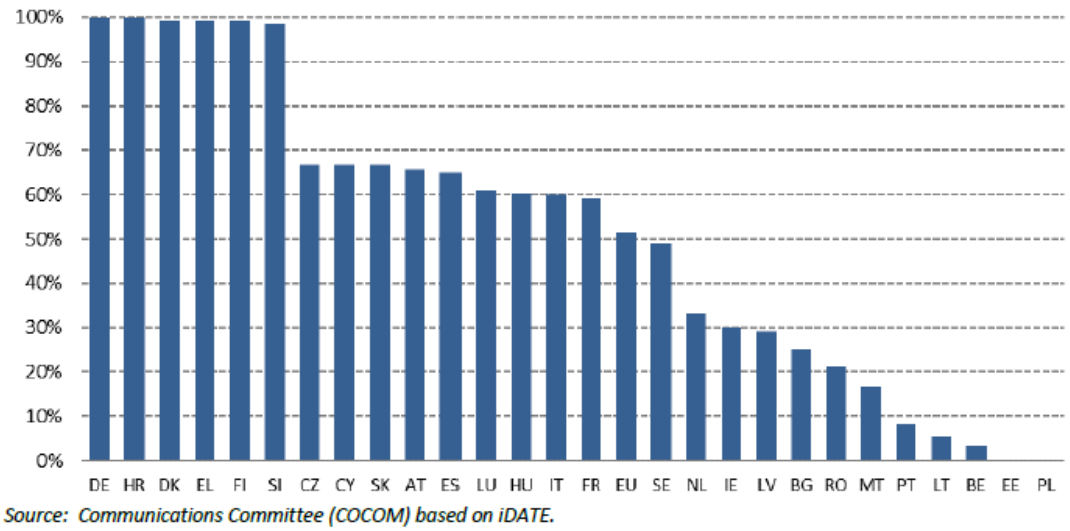


Figure 1. Assignment of 5G spectrum as % of total harmonized 5G spectrum per Member State

On the other hand, regarding the **5G coverage**, 13 Member States started commercial 5G network deployments by mid-2020. Highest coverage levels were recorded in the Netherlands and Denmark (80% of populated areas each), followed by Austria (50%), Ireland (30%) and Germany (18%). The coverage results for urban and rural areas in EU countries are depicted in Figure 2.

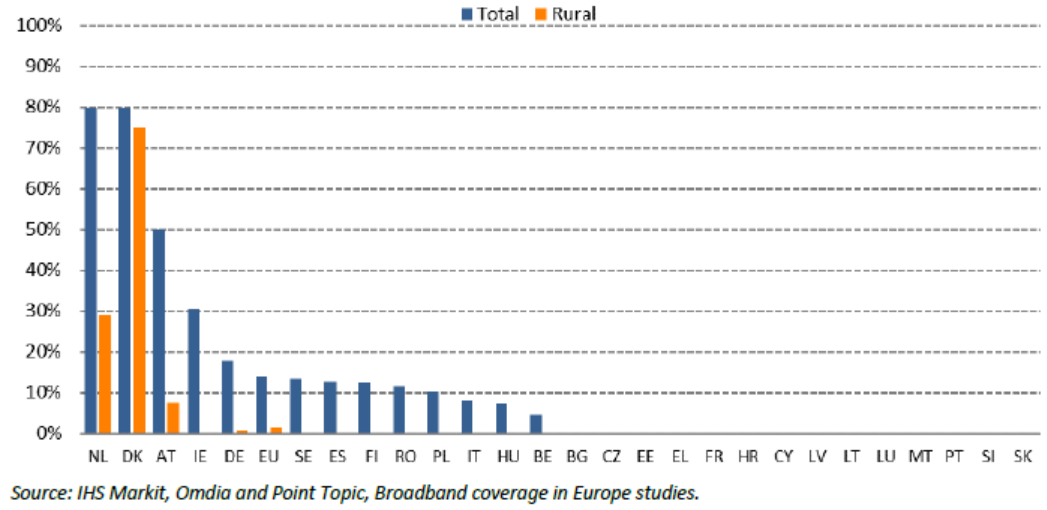


Figure 2. 5G mobile coverage as % of populated areas

According to the report in [4] on the Impact of 5G on the European Economy, the European economy will grow while the 5G technology is going to unlock new high bandwidth, IoT and ultra-low latency products, improve productivity and service quality. Particularly, from 2021 to 2025 it is estimated that 5G will drive up to 2 trillion euros in new economic outputs. As a result, the GDP will reach 1 trillion euros and up to 20 million full, part time, or even temporary jobs can be created and transformed properly as in Figure 3 are presented. Figure 4, depicts the fields which are going to rise with the transition to 5G technology. In particular, the need of data scientists, engineers and automation professionals will increase. Also, new types of jobs will be created, for example in agriculture industry, where drone operators will be useful to work alongside traditional farmers.

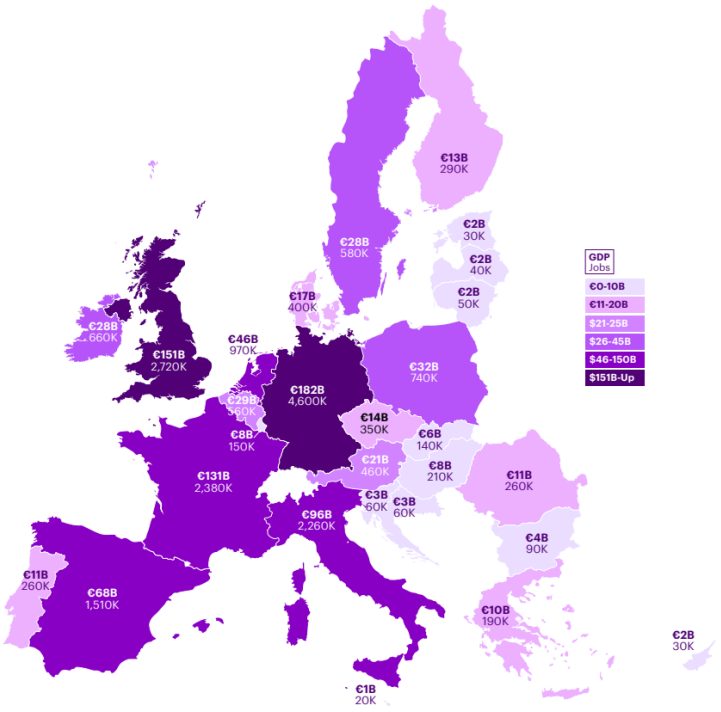


Figure 3. 5G impact on GDP and jobs by country

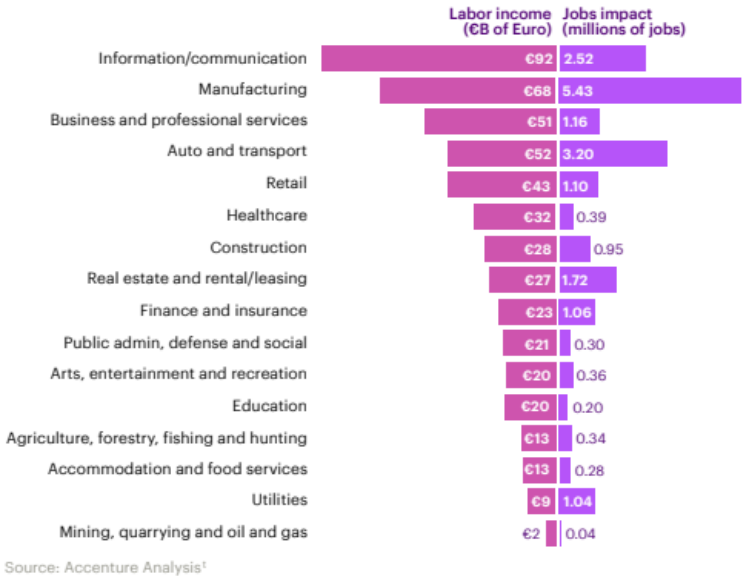


Figure 4. Jobs and labor income

2.1.1 Deployment delays and concerns

Back in September 2016, the Commission launched a plan, namely the 5G Action Plan [5], to reinforce the efforts for the deployment of 5G infrastructures and services across Europe. Based on this plan, the Member States should follow the guidelines such as making spectrum bands available for 5G bands, promoting early deployment in major urban areas and aligning roadmaps and priorities for a coordinated 5G deployment. However, a difficulty has been noticed from the Member States to fill the gaps in the digital skills, to transform SMEs in a digital way and in general to roll out of 5G networks. As a result, there are some delays and concerns about achieving the definite goals.

The main reason for 5G deployment delays is the lack of clarity on the expected quality of service (QoS) of 5G networks. So far, only Germany and Greece, from all the Member States, have defined the minimum speed and the maximum latency of the performance of 5G services[1]. It is necessary the quality of 5G services in the EU to be defined, so all the citizens can have access with the same QoS to 5G network. Ensuring these, it won't be a "digital division" among the Member States and they can have a common base to be developed in economic and technology way [6].

From the aspect of a Member State, the government should support the roll out of 5G. First of all, it should exist a trade-off between spectrum fees and incentives for operators who desire to deploy networks more widely. Secondly, there are some obstacles about passive infrastructure and backhaul which can be overcome with the help of Connectivity Infrastructure Act by EC. Lastly, the market structure has to expand and more mobile operators join the 5G deployment which can lead to an overall improvement of the quality of infrastructure [7].

The pandemic of COVID-19 caused a negative impact on the telecom's revenue. Even though, this sector is quite resilient to economic unstableness, it has been noticed a decrement in 2020 and 2021 revenue based on Figure 5. The reason is that investment programs by industries and business customers have been paused or cancelled and there is a delay in payments among customers and business customers [8].

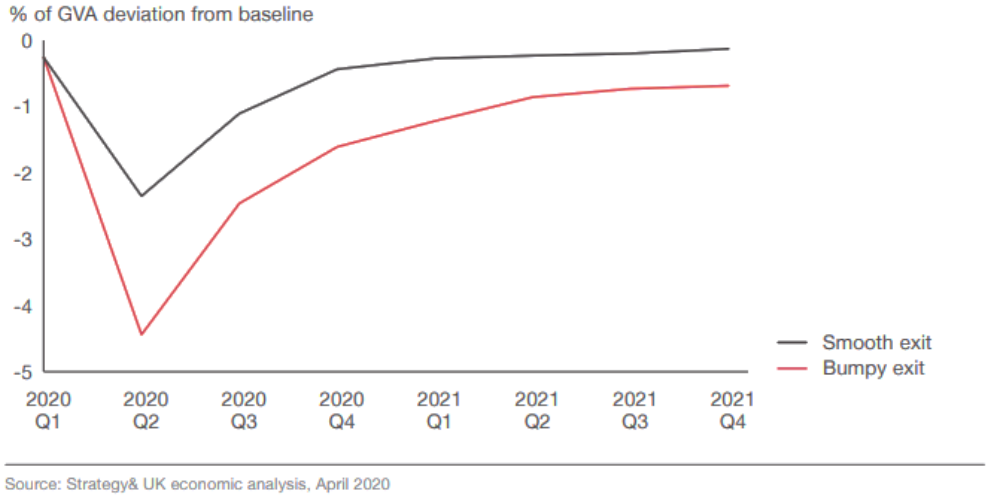


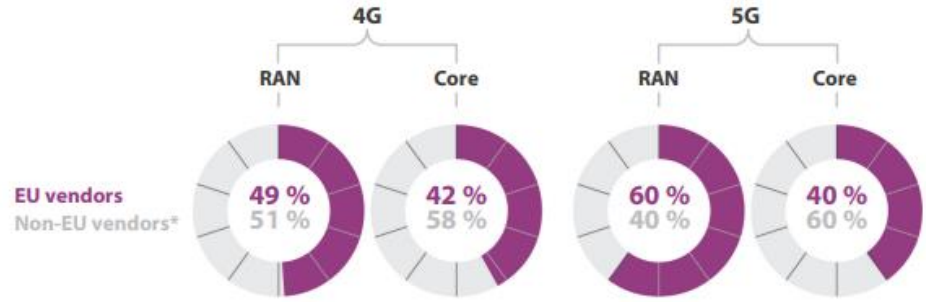
Figure 5. Impact of COVID-19 on telecoms revenue

Also, during the pandemic, the chip storage hit while the demand for chips was higher than the supply. More specifically, the demand for electronics, which have semiconductor chips, was rising because almost all the parts of human's daily life became digital. The educational system had to operate in a digital way, most of the employees were asked to work from home, and many other daily activities were carried out using Internet infrastructure. So, the need for electronic devices rapidly grown and it became a crucial matter for the technology sector [9]. However, the most important and pivotal sector of chip storage was the car industry which was seriously affected considering that in 2021 the production was decreased by one third. Even though, the demand for cars didn't cut back, the production couldn't continue at the same rate because of the lack of microchips which are used in modern automobiles, slashing security systems and computerized panels. Last but not least, the transportation issue contributed to this crisis. The reason was the restrictions caused by the pandemic, such as the closed ports, lead to massive number of packets, including microchips, waiting to be delivered, for months.

[1] https://5gobservatory.eu/wp-content/uploads/2021/07/90013-5G-Observatory-Quarterly-report-12_v1.0.pdf

The value of the technological dependency made the EU bring chip manufacturing to Europe and some companies as Intel committed to contribute to this effort [10]. The Commission proposed the European Chips Act which will ensure that EU has all the necessary tools and technological capabilities to design, create and package advanced chips and for this reason, it will mobilize more than 43 billion euros of public and private investments. The goal is to double its current market share to 20% in 2030 [11].

The delay of 5G deployment, the deadlines of achieving predefined goals by EC and the barriers which have to be exceeded in practical way, create many concerns about the alertness of EU in the context of adoption of 5G networks and 5G rollout. From the hardware aspect, many European markets have banned Chinese network equipment -even though it is cost-efficient, for security reasons [12]. That leads to the growth of European vendors and smaller players who have expressed their concerns about EU support. In 2021, five of the leading European telecommunications companies (Deutsche Telekom, Orange, Telecom Italia (TIM), Telefónica and Vodafone) published a common report [13] about the necessity of an Open Radio Access Network (Open RAN). It is an advanced RAN, more effective, open, intelligent and virtualized which can extend 5G to more users in a secure and cost-beneficial way and help the spreading of innovation to industries. This will lead Europe to successfully achieve the goal of 5G by 2030 and avoid the risk of being left out and behind in the development of next generation networks. Also, the Open RAN players in Europe will be increased considering that there are only 13 unlike the 57 in the rest of the world. There are some requirements that European Union has to engage to, such as a high-level of political support for Open RAN, the creation of a European Alliance on Next Generation Communication infrastructures, policy makers to provide funding and tax incentives to operators, the standardization based on the global standards and the collaboration with international partners [14].



* *non-EU includes North America, Asian and Australian vendors.*

Source: ECA, based on BEREC. Internal Report concerning the EU 5G Cybersecurity Toolbox Strategic Measures 5 and 6 (Diversification of suppliers and strengthening national resilience). BoR (20) 227.

Figure 6. 4G and 5G equipment in the EU by EU and non-EU vendors

However, according to EU's report on cybersecurity of Open RAN [15], it is proven that Open RAN will increase the network's complexity and create several security risks such as surface attacks, more entry points for malicious actors and misconfiguration of networks. There are many recommendations of actions based on EU 5G Toolbox, which can minimize those risks and allow this new architecture to evolve properly.

Moreover, concerns about data protection are expressed, in the case of vendors who operate within the framework of a non-EU legislation and the software control centers are outside the EU. As it is shown in Figure 6, more than 50% of the equipment of 4G and 5G, comes from a non-EU vendor. The Commission has addressed these concerns highlighting that any business which provides services to EU citizens should respect the European rules and values. Even though, the Member States have different restrictions on the high-risk vendors. For example, the Swedish national regulatory telecom authority (PTS) has set requirements about the auction of 5G spectrum such as new implementations of central functions for the radio use in the frequency bands must not use products from China and in the case of existing infrastructure from those

vendors must be replaced as soon as possible. On the other hand, Hungary has not restricted any vendor and has declined to be part of the international 5G Clean Network Program which is promoted by the USA [6].

2.2 5G VIABILITY AND RELATED INVESTMENTS

Here we summarize surveys and reports which have as goal 5G viability and related investments. Trying to capture the state-of-the-art in the area we target at the technoeconomic aspects of those reports. The common denominator of all the selected reports is the fact that they target to find out the most cost- and energy-efficient solution which covers all the requirements of the scenarios that they target at. At the end of the section, we provide some useful insights from the state-of-the-art analysis.

- **Small cells for Micro-Operators-Deployment Framework [16]**. It is an indoor deployment framework of a micro-operator in a campus which is incorporating network slicing, network sharing and small cells. Femtocells are low-cost, low-power and plug-and-play devices and they can be deployed with Wi-Fi. They can also replace Wi-Fi access points and use the existing network cabling, local servers, switches and existing internet backbone. The goal of this paper is to examine different scenarios for a campus network (in-building wireless access), having as criterial not only technical such as performance, coverage and spectrum utilization but economical ones, including the Total Cost of Ownership (TCO), Capital Expenses (CAPEX) – site acquisition, equipment, planning, commissioning and deployment costs- and operational expenses (OPEX) – annual site lease, power usage, operational costs. The result of this techno-economic analysis shows that the cost of femtocells and Wi-Fi access points are almost comparable. Even though, femtocells have higher OPEX (the CAPEX is close to Wi-Fi cost) they present advantages in latency, reliability, performance and they cover totally the needs of the initial scenario. On the other hand, for the same amount of capacity, it requires less femtocells than Wi-Fi access points which leads to lower TCO. According to the above results, it is proven that small cell network deployment can be cheaper and more beneficial than an exclusive Wi-Fi deployment, even though small cells are more expensive than Wi-Fi access points on a unit basis.
- **Techno-Economic Analysis for Programmable Networks [17]**. It compares a programmable with a traditional techno-economic model. The programmable network has mainly virtual parts and its architecture is based on SDN (Software-Defined Networking) and NFV (Network Function Virtualization). The traditional model refers to the existing networks which are currently being used for mobile communication and they are based on hardware resources without having any virtualization parts. The comparison between these models is performed in a techno-economic way and it has to do with base station (BS) cost, power consumption cost, OPEX, CAPEX and TCO cost. More specifically, the BS costs affect both models but it is noticed that traditional model has higher BS cost, and especially when the amount of BS is increased. This observation is not the same for the SDN networks while the cost of cells is lower and as result the BS cost is not affected much. In this sense, it should be noted that power consumption is so important for environmental reasons as for economical ones. In particular, the traditional network needs four times the cost of the SDN network which means that the second one is significantly more cost efficient. The OPEX costs have not a severe economic impact on the overall pricing model, making the SDN option a viable solution for operators and providers. The CAPEX cost is high, which is affected by oVS, OFController and other parameters, and it is the main concern of adopters. The analysis shows that the benefits of this technology, the financial profits and the low OPEX cost will contribute to the adoption and integration.
- **A Techno-Economic Framework for 5G Transport Networks [18]**. It focuses on wireless heterogeneous networks (HetNets), which provides high capacity to end users in the future 5G communication systems in a cost and energy-efficient way. It is noticed that the transport part of a RAN has a high cost and it has an impact on the revenues of mobile network operators (MNO). Based on this study, two different scenarios can be examined for the transport network, with microwave and fiber having as a base a homogeneous and a HetNet deployment respectively. The metrics that have been used for the

technoeconomic evaluation are the TCO (backhaul and RAN expenses), CAPEX and OPEX costs. The first one is higher in the homogeneous scenario even though the backhaul cost of HetNet is more than double than the other case. Also, for a homogenous wireless deployment, when a microwave backhaul is used the OPEX is a significant part of total cost. On the other hand, when a fiber-based backhaul is used the OPEX is a small part of total cost but the CAPEX is increased while the fiber infrastructure is more expensive. In the heterogeneous deployments, the choice of backhaul technology is very important to maintain the cost savings and the benefits of this deployment. For this reason, fiber technology seems to be the most cost-efficient and profitable option in areas with high density of users. As a result, the leasing of fiber connectivity and the reuse of the available fiber infrastructure is the lower-cost alternative.

- **An Open-Source Techno-Economic Assessment Framework for 5G Deployment [19].** It introduces an integrated techno-economic assessment approach for evaluating the capacity and the cost of 5G deployment according to a python simulator for integrated modelling of 5G (pysim5G). Pysim simulator has an open-source codebase with documentation and it is available in an online repository, ready for use by engineers, business analysts or researchers. It includes statistical analysis for radio interference to assess the system-level performance of 4G and 5G band coexisting and to quantify the costs of ultra-dense 5G networks. Due to Python's popularity and the benefits of using open-source software, users can really take advantage of pysim5G or utilize other software packages. The network planning tools are very important for 5G adoption, to calculate the cost and the application of this framework helps out with the evaluation of different infrastructure sharing strategies. The results focus on capacity, coverage and cost for 4G and 5G co-existing spectrum bands. More specifically, the passive site sharing, and the passive backhaul sharing strategies can reduce the total cost by 30%. The best cost reduction of 50% is presented by multi-operator RAN in comparison to a baseline of a single dedicated network.
- **Techno-economic Analysis and Prediction for the Deployment of 5G Mobile Network [20].** A techno-economic analysis for the deployment of 5G technology over the existing 4G mobile network, took place in Shanghai/China with duration of 6 years. The main goal of this analysis is the benefits and the cost-effectiveness of adoption 5G technology. In order to be performed this model, several parameters have to be defined, such as the predicted number of users, the churn rate that focuses on its impact on revenue of 5G network, the pricing strategy analysis and the evolution of CAPEX and OPEX for a variety of Base Stations classes and different indoor scenarios. Apart from the price and cost, the coverage and the capacity are under consideration. The outcomes show that a good analysis of Price Elasticity of Volume (PED), (I.e., a measure of sensitivity of realized volume to changes in unit price) provides an important margin of benefit. Also, for the current mobile broadband demand of the different scenarios, the microcells are the most cost-efficient solution. The network investment model, reveals that the deployment of a large amount of new sites is expensive, although this cost can be decreased by the reuse of existing sites or using the carrier aggregation functionality of LTE-A RAT. Finally, it is ascertained a lack of the capacity limited by the macro sites and in general a limited coverage with small cell solutions such as femtocells, picocells deployed with 5G mmW system and Wi-Fi. To overcome the lack of these, operators should investigate the cooperative layouts of macro sites with femtocells, 5G mmW PBS or Wi-Fi and achieve the trade-offs among capacity, cost and coverage.
- **Techno-Economic Analysis of 5G Non-Public Network Architectures [21].** The NPN networks are an attractive solution for verticals, operators and stakeholders while they present a boost in the revenue, a cost reduction and speed up the Return of Investment (ROI). The transition to this type of networks, demands a costly infrastructure update which requires understanding of the complexity of 5G NPN. The study in [21] focuses on cost savings in support of ROI that depends on NFV and Neutral Host (NH) deployment, the trade-off between enterprise goals and the trends of 5G NPN adoption globally. The analysis of different scenarios shows that the infrastructure influences the CAPEX cost the most. Also, a greater cost saving in CAPEX elements, which includes the equipment and the installation, is noticed in the case of NVF and Neutral Host are implemented. In particular, the equipment holds the most cost-savings, over than 68% for NPN with shared RAN and Control plane and in case of NPN with shared RAN this percentage is coming up to 33%. A factor that contributes to the reduction of cost for infrastructure is in NPN Shared RAN and Control plane. On the other hand, if a SNPN is going to be used, then the

reduction of infrastructure cost will be lower. Moving on to the installation cost, the greater reduction is noticed at the SNPN deployment and the lower at NPN shared RAN and Control plane. The OPEX outcomes show that energy consumption is the most important factor in cost savings. For an NPN shared RAN the cost reduction is going to be 22%, for a NPN shared RAN and Control plane 77% which is due to NFV use. From the aspect of TCO, the greater cost reduction is presented at NPN Shared RAN and Control plane by 53%. According to the above results, the NPN Shared Ran and Control plane is the deployment with the most cost reduction. In general, the cost saving strategies and the type of deployment are going to define the commercial deployment and ensure the achievement of enterprise goals.

- **Techno-Economic Analysis of 5G Immersive Media Services in Cloud Enabled Small Cell Networks: The Neutral Host Business Model [22]**. Edge computing and 5G can be a beneficial and interesting combination for vertical industries to develop unconventional services. The study in [22] aims to examine a cloud-enabled Small Cell network, that belongs to a NH, which is going to support Immersive Media Services in Crowded Events. A potential investment in a 5G infrastructure, has to be reviewed and a planning model to be created to predict the required computing, storage and radio resources. Also, some economic indices have to be taken into consideration such as net present value, internal rate of return and in general the Price evolution. More specifically, this analysis concentrates on the IT and radio infrastructure, deployed by NH, for sport stadiums or concert halls where a lot of attendees are and immersive video services must be provided. A Cloud Enabled Small Cell network can be a profitable and viable solution in this case, as it has been proven by three funded research projects. Based on the SESAME project for the planning model, the IST-TONIC and CELTIC-ECOSYS for the economic part, this investment can reach a break point at 6.5 years and it can be considered fruitful having in the mind that the effective functional period of telecom infrastructures is 15 to 20 years.
- **Techno-Economic Analysis of 5G Deployment Scenarios involving Massive MIMO HetNets over mmWave: A Case Study on the US State of Texas [23]**. The fifth generation of mobile communication systems contribute to efficient spectrum utilization, higher throughput per unit cost, lower consumption to deliver improved user experience and cost savings for operators. These benefits are owed to new air interfaces (Massive MIMO) and multi access schemes (millimeter wave) which can operate in high-frequency spectrum bands. The study in [23] focuses on a heterogenous network which uses Massive MIMO, for high spectral efficiency, and operates at millimeter-wave frequencies (28 GHz), for higher bandwidth availability. Also, it takes place in the State of Texas and it has as a goal to approach the potential financial returns, the TCO and in general to address the concerns of operators. Having done a technoeconomic analysis, a Revenue Modelling and calculate the annual OPEX and CAPEX, and the TCO, the report ends up that the 5G HetNet deployment's OPEX, CAPEX and TCO are near to one-third of an LTE-A configuration, which operates at 700 MHz frequency. Additionally, the profit probability of 5G deployment is higher than LTE-A and it is about 70%. The Net Present Value (NPV), a profitability parameter, is $482.14 million, which means the operators will have high positive returns. For both deployment scenarios, 5G and LTE-A, some parameters should be taken under consideration, such as the acquisition of spectrum, pricing of services based on Average Revenue per User (ARPU) and the carrier frequency that influences the cell coverage and as result the coverage.
- **Techno-Economic Study of 5G Network Slicing to Improve Rural Connectivity in India [24]**. It is an analysis of 5G slicing neutral host network (NHN) for macro-cells and small cells that points out rural areas. This study [24] targets India villages, but it is using a generic model for the techno-economic analysis, and it could be applied for different rural areas with some parameterization. Moreover, some parameters including the relationship between coverage, demand, the cost and time of investment, and the amount of subscribers, are going to be checked. This techno-economic analysis concludes that 5G slicing with NHN is feasible solution and it can be applied in rural areas and villages of India. In particular, an end-to-end 5G network slicing can reduce network cost at least 50% than a traditional one which is already used in these regions. The analysis in the term of 10 years, this type of network is sustainable and shows a customer growth of 7% even for an area where there are at least 100 subscribers. As the number of subscribers increases the network can be established in a shorter investment time and the ARPU can be lower. The crucial parts of this deployment are the demand, which is connected to population, the take-up rate and

the ARPU. However, this study has proven that a network like the above is a possible and viable solution for the low population regions and for the operators who are going to invest.

- **Low Latency 5G Distributed Wireless Network Architecture: A Techno-Economic Comparison [25]**. It refers to a modification of an existing 4G network to a distributed wireless network architecture (DWNA) in which the picocell and the distributed antenna have been set to support a multi-edge computer (MEC), an ultra-dense network (UDN), Network Functions Virtualization (NFV) and device-to-device (D2D) communication in terms of lower cost of ownership, better capacity and coverage. The initial proposal, a 5G long-term evolution DWNAS will be tested and designed in two different ways. The first way is with modified picocell (MPICOC) and the second with modified DAS (MDAS) using small cells. Also, a sensitivity analysis (SA) is performed to evaluate the CAPEX, OPEX and TCO for the MPICOC and MDAS when an MNO owns the tower infrastructure and when the tower infrastructure belongs to a third company. In the case of, MNO rents the tower infrastructure, it is noticed a reduction in CAPEX by 22%, the average saving in the TCO is 15.4% but the operational cost is constant. As a result, it is more cost-efficient for an MNO to share a tower infrastructure than to own it. From the architecture perspective, the SA showed that the operational cost of the MPICOC is 69.6% higher that MDAS. Also, the OPEX costs are increasing for both technologies when the number of antennas is increased too.
- **Techno-Economic Assessment of 5G Infrastructure Sharing Business Models in Rural Areas [26].** It provides a technoeconomic assessment of 5G infrastructure sharing business models in rural areas. More specifically, four different business model options have been studied such as the No Sharing, Passive Sharing, Active Sharing, and 5G NHN. These models were tested under the same conditions (for a generic rural region and ten years duration) and the main metric was the TCO. The findings revealed that the case of a No Sharing model, in which the operator deploys its own network, is an appropriate option when the revenue potential is high for incumbent MNO services. When the demand for services is at a medium level and there is a healthy competition among the operators, then the Passive Sharing model is suitable. In this case, the operators can share specific passive assets (for example the site and backhaul) and reduce the cost. This can be possible because in Passive Sharing model the operators share non-electronic elements like towers and site compounds. In the Active Sharing choice, operators share all passive and electronic components but not the spectrum bands, nor the network core. It can be applied when the demand for connectivity is low, and operators want to complement each other's services. Furthermore, operators have to collaborate when the user roaming process has to be provisioned, or in some areas it is hard to serve, and the multiple infrastructures cannot be helpful. Last but not least, is the 5G NHN option, in which operators share all passive and active components. It is the most cost-efficient and viable solution in areas with few subscribers but at the same time a full range of 5G applications is needed. In 5G NHN, the operators are leasing resources from the incumbent MNO. With this option, the overall cost can be reduced by 10 to 50% compared to other options and in general a sharing model can increase the viability by 30 to 90%. Lastly, this implementation, cannot happen in isolation and it needs balance between prudent technology and policy choices.

Given the above-mentioned studies, we sum up the outcomes which can contribute to achieve the goals of EVOLVED-5G project and to be a source of inspiration and a reference point for other innovative projects. As Plato said, *"necessity is the mother of invention"*, and as the world is constantly and rapidly changing, the needs, and especially the technological ones, are increasing making the adoption of 5G networks vital. This technology will allow more end users and devices to be connected everywhere at any time, businesses to grow and cities to get smarter.

Studies have shown that the transition from 4G to 5G can be smooth, without a high initial investment, by reusing the pre-existing infrastructure. With this way, the cost and the time which are needed for the adoption of 5G will be manageable and the operators can provide services to users as soon as possible, while they can improve their networks and have a parallel evolution with technology and demand. The mutual expansion in all types of areas is necessary so the digital division can be annihilated. As result, the MNOs, SMEs and third-companies have to move in parallel and make an organized and common effort to adopt 5G technology.

It is a fact that 5G technological evolution doesn't expand with the same rate globally. As a result, 40% of people around the world have no access to the Internet [24], especially in rural areas. One of the goals of European Commission is to overcome this digital division [27] which is a reality and reinforce actions, research and programs which have the intention to bring digital technology to businesses, citizens and public administrations. The study in [24] presents a generic model for the tecno-economic analysis, which proves that a 5G slicing with NHN network can be a solution for rural regions in India. This model can be adapted and examined for European purposes while this is a point of improvement.

From the financial perspective, a common conclusion which turns out from the above studies, is that a deployment solution with the lowest TCO does not always lead to the highest profit. It would be more beneficial for the industries to take into consideration and focus on a specific technology or deployment that can contribute to a smooth transition to 5G, because that can have an economic impact on the initial investments as well on profits. As a result, industries can come up with profitable solutions which will be viable in the long run.

These techno-economic analyses reveal the interest of operators to incorporate new technology but concerns about the costs, the viability of these models and how difficult can be the transition from the one technology generation to the other. However, it is proven that this transition is crucial and necessary and primarily beneficial and cost-efficient for the MNOs. The capabilities and the new types of services, which can be supported by 5G networks, will provide them the chance to expand their boarders and their profits. The right planning and economic analysis can lead the operators to adopt the most suitable and cost-efficient solution depending on the demand, the type of area and other technical criteria.

A successful and profitable transition to 5G networks is critical for the MNOs and their long-term growth in the telecom sector. Proper analysis is necessary to identify the right combination of cost-efficiency and profitability that will create an impact on the partial deployment or full-scale 5G networks. The technology of 5G can bring new opportunities to the network industry but the challenge is to identify the right strategy and decision-making that can lead to profitable investment of their resources.

2.3 5G-NPN AND PRIVATE WIRELESS GROWTH

The private 5G network is a dedicated local wireless network operated for the exclusive purpose of connecting devices which belong to an enterprise. It can deliver complete end-to-end security across the enterprise, ultra-low latency and high bandwidth connections. This type of network can be deployed as a Stand-alone NPN (SNPN) or as a public network integrated NPN (PNI-NPN) [28]. More specifically, an SNPN network operates by an NPN operator with no dependencies on the public 5G network. For this reason, the enterprise uses a local database to store subscriptions, and it has the control of the network and the data services. Also, the network can operate on a dedicated spectrum or use an unlicensed one [29].

On the other hand, the PNI-NPN is relying on network functions which are provided by a Public Land Mobile Network (PLMN) and allows public operators to support the NPN network. In this case, the network operator, who manages PNI-NPN and PLMN, ensures the spectrum resources and the service continuity [30]. In case of a UE wants to access PNI-NPN, it should have a subscription to the PLMN.

As the needs of industries and businesses increase, the growth of 5G private networks, especially of SNPN, is imperative. In 2022, the private 5G network market size was $1.61 billion and by 2030 is expected to reach $36.08 billion [31]. This increment can be justified by the variety and the range of 5G NPN usages and benefits, the new technological needs and the high demand, which are expressed by industries, for stable and secure connectivity to many devices. A part of this growth is the increment of the revenue of hardware (over 55%) which is necessary for the deployment of an NPN [32]. The hardware segment includes the Radio Access Network (RAN), the core network and the backhaul. Also, the software segment is at an interesting point in the market because it is expected to have high demand especially for cloud-based RAN, core and edge networks.

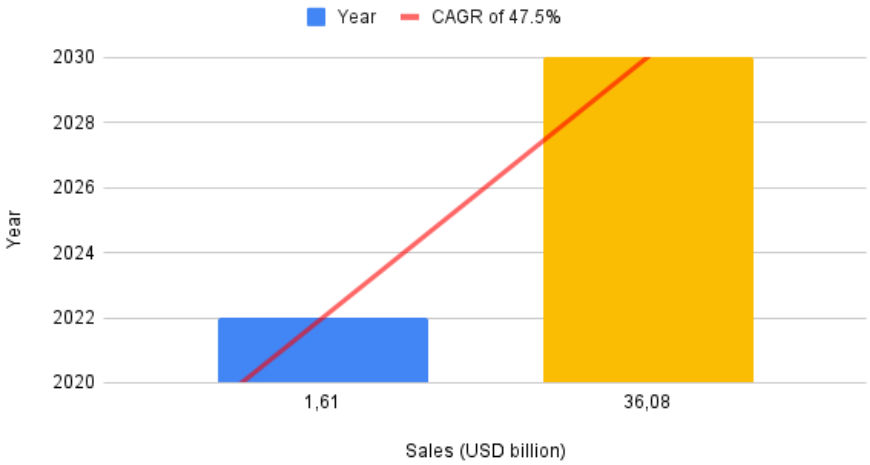


Figure 7. Global private 5G network market size and CAGR

Over the last few years more and more industries use private wireless network and invest in their own network. The enterprise customers begin to realize the necessity of a private wireless network which is focused to their own needs, provides them exclusive solutions and ensures seamless and secure connectivity which is vital for several applications such as the Industrial Internet of Things (IIoT). For example, industries of manufacturing, oil and gas and transportation will get benefit of a high-speed bandwidth connectivity during Time-Sensitive Networking (TSN) and real-time-based networking of a private 5G network. The above characteristics will help the industries to maintain a remote monitoring system for ships and containers (in transportation) and to develop a sensor-based model, industrial robotics and manage the IIoT devices (in manufacturing) [32].

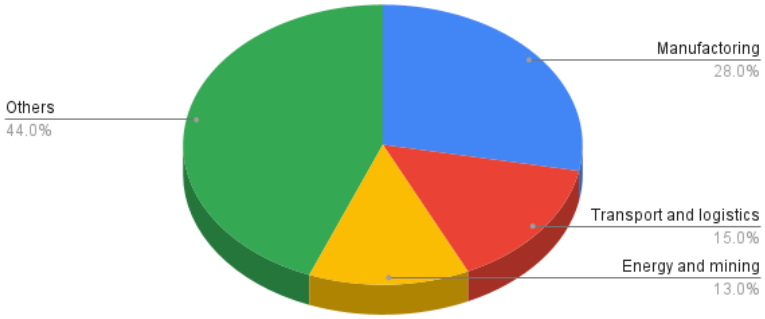


Figure 8. Market of private wireless network

According to Omdia's research - the Private LTE and 5G Network Tracker 1Q22 [33]- the top market, by number of announcements, is the manufacturing industry, secondly it comes transport and logistics, and lastly energy and mining. The percent which represents other types of industry, in total, it could be for enterprises and campus, healthcare, smart cities etc. [34].

This anodic trajectory of market of 5G private networks will be reinforced by the collaboration of industrial manufactures and technology companies. The goal of this collaboration is to established a private 5G network in which several industrial automated devices could communicate and function. By this partnership the companies will understand the actual needs of industry and then they can develop applications and deployments on a next generation NPN.

2.3.1 The private networks from the operators' perspective

According to the 2022 GSMA Intelligence report for the IoT and Enterprise [35], network operators have already realized the opportunity to increase revenues building upon the enterprises' digital transformation plans and expanding their basic connectivity services portfolio with other digital services such as Cloud, IT, IoT, security and other professional services. Indicatively, based on the analysis of eleven major operators, the report reveals that the average contribution of enterprises services to total telco revenues has reached 30% in 2020, and there is still significant room for growth. In the digital transformation opportunities for the operators, private networks are gaining momentum as they are becoming the backbone for innovative use cases. As depicted in Figure 9, 5G Private Networks for Industry 4.0 can be available in various flavors and as such are quickly becoming a multi-stakeholder game, raising the urgency for the operators to prepare and act fast.

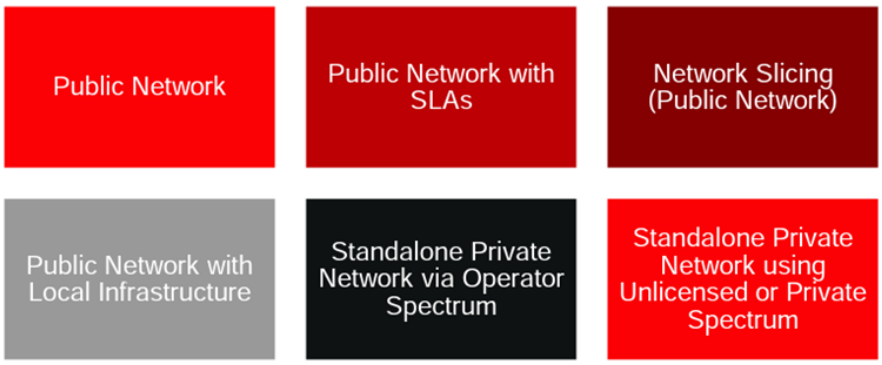


Figure 9. The range of options for manufacturing/ production/ supply chain enterprises from Public Networks through to Private/ Dedicated Networks.

Indicatively, all three major hyperscalers, Amazon (AWS), Microsoft (Azure) and Alphabet (Google Cloud), taking advantage of their cloud computing capabilities, have expanded their portfolios with their own offers of private 5G, and most have completed strategic acquisitions and hired from the mobile industry [35].

Against this immediate threat, operators are preparing to respond with slicing and edge computing and offer a hybrid offering, blending public and private infrastructures to achieve seamless interoperability with national or regional public networks for those devices and users moving outside the private site. In this way, they provide a unique offering, since enterprises enjoy all the benefits of both types of networks with the best blend of capacity, coverage, capabilities and cost [36]. To accomplish this, MNOs are capitalizing on the **5G SA (5G Stand Alone) network architecture** that inherently supports the digital transformation needs, with its Service-based Architecture and cloud-native functions, the advanced functionalities such as network slicing and Massive Machine type Communication (MMTC), Multi-Access Edge Computing (MEC), becoming a key enabler for the enterprise intelligent edge networks and sites. It is noteworthy that 5G SA services in Europe are now available in Finland, Germany and Italy and more deployments are expected in the next few years [37]. A lot of case studies have been built on top of the hybrid concept, such as Deutsche Telecom and Ericsson to provide industry solution for OSRAM [38] and Telefonica Germany and Ericsson to make 5G car manufacturing for Mercedes-Benz [39].

A lot of case studies have been built on top of the hybrid concept, such as Deutsche Telecom and Ericsson to provide industry solution for OSRAM [38] and Telefonica Germany and Ericsson to make 5G car manufacturing for Mercedes-Benz [39]. In Greece, COSMOTE has already implemented a number of related projects and

pilots such as the first 5G Campus Network in Greece for the Athens International Airport[2] in 2021, the Hellas Gold 300 meters underground [3] campus and Calpak's fully automated solar water production smart manufacturing campus[4]. Such initiatives stand as an evident proof of the interest and commitment of the operators to explore opportunities and lead the emerging market.

From the standpoint of the telecommunications operator, the business opportunity for MPNs comprises revenue not only from building and operating networks but also from the services and applications running on them. An enterprise may engage with a network operator, systems integrator, network equipment vendor or hyperscale cloud provider to build a network and then take over operations and maintenance once it is built, or the company could buy an MPN as a service from a communications service provider [40]. Already Deutsche Telecom has a set tariff and product offering[5]promising "improved public mobile network and virtual private network (IP VPN)", with prioritized data traffic for IoT devices".

In all circumstances, the raise of private cellular networks is highly dependent on clear national regulations, since NPN deployments are mainly utilizing licensed bands, and this is a game changing factor to be considered. A number of countries are looking to private networks to address Industry 4.0 objectives and awarding spectrum for vertical use e.g., Germany, Japan and France. By regions, Europe will be the region with higher activity followed by Americas and the Asia & Oceania.

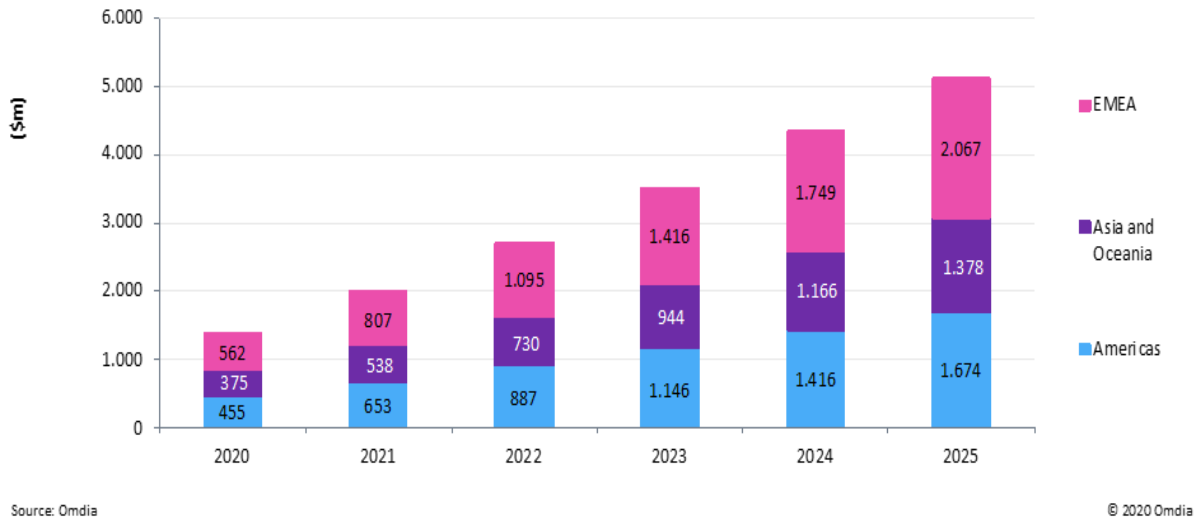


Figure 10. Private LTE and 5G market by region, 2020-25

According to GSA data[6], as of February 2022 there were 656 organizations deploying LTE or 5G private mobile networks. GSA's data points to the manufacturing sector as a strong adopter of private mobile networks, with 111 identified companies involved in known pilots or deployments, which is up from 51 at the start of 2021. As depicted in Figure 11, the leading verticals that will push this growth will be Manufacturing (including the FoF) and Energy and Utilities, followed by Transportation and logistics and Public Sector (Smart cities, etc.).

[2] https://www.cosmote.gr/cs/otegroup/en/5g_campus_network.html
[3] https://www.cosmote.gr/cs/otegroup/en/campus_network.html
[4] https://www.cosmote.gr/cs/otegroup/en/smart_manufacturing.html
[5] https://iot.telekom.com/en/networks-tariffs/5g-iot/campus-networks
[6] https://omdia.tech.informa.com/products/private-networks-intelligence-service

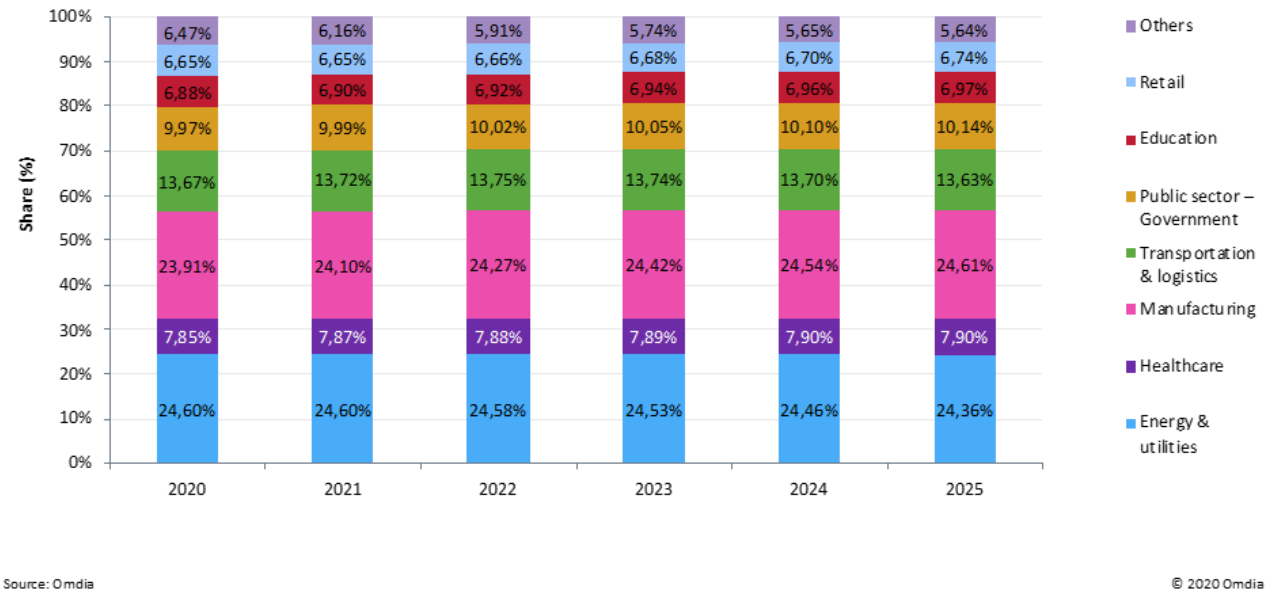


Figure 11. Industries share of the Private LTE and 5G networks market, 2020-25

Overall, the landscape described above, presents a great opportunity for Operators, especially in Europe, to capture the value from this growth and EVOLVED-5G is bringing meaningful and significant novelties for EU companies to be prepared for it.

2.3.2 The private networks from the verticals' perspective

The new generation private wireless networks focus on a connected world, more efficient and productive, supporting automation and wireless solutions. From the aspect of cost, it is cost-efficient investment because it provides great capacity, wide coverage and a connectivity layer which can operate in difficult radio conditions. It is the stepping stone for Industry 4.0 transformation, future-proof and it will support 85% of industrial cases.

First of all, the new generation networks will contribute to public safety and improve the effectiveness of first responders. In an emergency situation or a disaster, the fastest response leads to a successful live saving mission and that is possible with 5G system that guarantees broadband communication services and with mission-critical multimedia PTx communications to the frontline. More specifically, the firefighters can use 5G-enabled drones as well for search and rescue operations and as well for monitoring and predicting a fire [41]. In United States of America, it has been developed the First Responder Network Authority (FirstNet) [42], which is a dedicated network for first responders who can communicate in remote locations, send drones and even track firefighters from the implanted sensors in their clothes. So, to improve emergency call and alert management infrastructures, it can be implemented an IP-based ESInet for emergency call routing supporting multimedia and location information. An end-to-end Public-Warning System to allow authorities to send real-time, geo-targeted alerts. Last but not least, a drone network to enhance situational awareness [43].

The second use case of private wireless network is for airports. The 5G NPN provides reliability, secure connectivity and low latency for applications and services. The goal of this network is to alleviate the existing Wi-Fi network, which is going to be used mainly by passengers, retail tenants and guest, and to improve turnaround times, the efficiency and safety with real-time data and automation and focus to advanced operational services such as baggage handlers, screening to real-time streaming, services for airlines and more [44]. The third use case, similar to the second one, is for ports and promises to provide critical-communications capabilities everywhere, to boost operational efficiency and data security and to make sure that the dedicated IOT connectivity can support TOS data to smart devices, vehicles, staff and more. This private wireless network can ensure the data coverage for operational services (streaming video for remote operation, etc.) because of high-bandwidth and low latency [45].

During the pandemic of COVID-19, the necessity of the existence of 5G networks for the educational system was clear. Millions of students could not have access to the appropriate facilities and as a result they couldn't keep up and they missed education at all levels. As a result, distance learning came up as a solution, which requires technology facilities and devices and, the most important aspect/requirement, a stable, secure and reliable connection with the network [41]. Local authorities can be a part of the solution and prioritize the broadband initiatives and collaborate with technology companies to develop a 5G private network. With this way, it will be ensured that all children will have access to the Internet, and consequently to education, even if they live in remote and rural areas [46].

The need for reliable connectivity exists even in the universities and their campuses. The NPN network will enable wireless access for student housing and parts of campus and for university buildings so both students and staff will be connected everywhere [47]. Also, having a stable and secure connection with the network, universities can invest to evolved equipment such as smart boards, smart lighting, even to create a virtual reality (AV/VR) classroom, and provide to students and staff, office productivity tools on their mobile devices. In this context, universities can handle better matters of building, water and power and in general environment using building automation and control system. They also can optimize the security system by surveillance cameras, smoke sensors and emergency call buttons, all connected to the NPN network. So, by evolving their own wireless communications infrastructures which provides higher performance, reliability, mobility and flexibility, the education institutions can digitalize their services and operations and keep up with the different needs of staff and students [46].

Moving on, to manufacturing, a secure and scalable 5G private network will increase the capacity for more automation, mobile and collaborative robots, vehicles and legacy machines. More specifically, IIoT applications can be used to monitor processes and, this way, the failure probabilities of equipment can be reduced. Also, in the context of a smart factory, they can be placed automated cleaning machines, heating and cooling management machines, video cameras, fingerprint scanners or automated number plate scanners to ensure that only staff has access to the factory areas [47]. All these smart devices use the private mobile network and they are visible to it, so the IT management can be more efficient and simpler [48].

Additionally, an industry which has a lot of potentials by using a private 5G network is mining in which human and environment protection is very important. In particular, the IIoT, the autonomous vehicles, other automations and smart devices and the mining applications need reliable, secure and trusted connectivity. In Figure 12, it is clear that the 4.9G/LTE and 5G networks embrace all the requirements for a smart and automated mining industry.

Having as a base a 5G NPN, several digital technologies can be enabled such as autonomous vehicles (diggers, trains, crushers) which can be remotely monitored, elevated staff and IT systems which are going to communicate with headquarters, branch offices and data centers via a secure and reliable connection. Also, there are many use cases for the employee's and worker's safety and protection. For example, a system of situational awareness for workers which is going to protect them by providing them with 360-degrees visibility, and evaluating health and environmental conditions. The smart PPE wearables with geo-fetching applications will be very helpful to inform and alert workers where not to go for their safety. Beside those systems and applications, employees can be trained using an AR/VR system and learn how to handle properly difficult situations and fix problems quickly with guidance on AR glasses [49].

	Wi-Fi 5/6	TETRA P25	LoRaWAN Sigfox	Bluetooth BLE	4.9G/LTE 5G
High data-rates, low-latency	✓	✗	✗	✗	✓
Mission-critical	✗	✓	✗	✗	✓
Cyber-secure	✗	✓	✗	✗	✓
Predictable performance	✗	✗	✗	✗	✓
Coverage	✗	✗	✓	✗	✓
Mobility	✗	✓	✗	✗	✓
LP-WAN (IoT)	✗	✗	✓	✓	✓
Voice	✗	✓	✗	✗	✓
Multi-service	✗	✗	✗	✗	✓

Figure 12. Network's requirements of mining transformation

Another use case for a 5G private network of digitalization and automation is in power utilities. A utility has the ability to grid monitoring and to improve the grid reliability, efficiency and agility with a solution of delivering traffic for restoration and safety. Under these circumstances, by massive coverage, broadband capacity and secure connectivity, the power utilities can develop a secure Push-to-Talk, Push-to-Video and other mobile applications which can contribute to worker's safety and productivity [50]. Recently, UK Power Networks (UKPN) announced that they collaborate with Telco Vodafone for a powered smart grid pilot project. The goal of this project is to connect distributed and intelligent grid devices, to enhance the efficiency of UKNP's power grid and to improve its reliability by expanding its renewable energy resources [51]. This deployment of the infrastructure is an opportunity for a partnership with telecommunication providers and power utilities [52].

3 KEY ENABLERS FOR NETWORK APP MARKET GROWTH

We identify four enablers that are related to the Network Applications concept within EVOLVED-5G and are currently paving the way for a new business paradigm on top of 5G and beyond networks; namely *open APIs*, *microservice programming*, *open sourcing*, *analytics, and marketplaces*.

3.1 OPEN APIS

During the last decades, the use of APIs has served as a bridge between mobile operators and start-ups in emerging markets [53]. Operators have begun to consider whether to open their APIs, starting from APIs related to mobile messaging, operator billing etc.

Irrefutably this openness creates a powerful cycle of innovation as start-ups can combine several APIs to create new services. For example, a start-up can offer SMS-based localized content to its users depending on their city or area, and then charge them by deducting the amount from their mobile airtime. In the same direction, the TM Forum's 60+ REST-based Open APIs are developed collaboratively by TM Forum members working on Open API project. They are now widely adopted by the industry, with more than 500,000 downloads by 32,000 software developers from 2,300 organizations.

As it has been described in many EVOLVED-5G deliverables the Network App ecosystem provides innovation through the microservices paradigm, i.e., the paradigm where a collection of small services is defined, each one running in its own process and accessed via a lightweight interface, such as an HTTP RESTful API.

It is reported that the cost of integration and the complexity are reduced by turning to Open APIs and open architectures, and as a result operators can focus on innovation. Operators' current IT systems are using many different commercial software applications which are rising the complexity of integration, the customization, and the total cost. By turning to customer-facing systems which include support for Open APIs these parameters can be limited.

In the context of simplifying a wrapping system, Deutsche Telekom uses the Open APIs to introduce a single self-care mobile application for consumers. More specifically, it has developed the Harmonized API Layer (HAL) for future front-end solutions, for example customer self-care and ecommerce [54]. On the other hand, Vodafone Group, which is a leader on ODA, guides a transformation and creation of digital experience layers for operating companies based on "Flip IT" strategy. This means that the operating companies are gradually transformed in a digital way, depending on local challenges. Another use case is a project of Telefonica which uses Open APIs to expand its Movistar Play video to its entire customer base. The goal is the creation of a unified platform that enables faster activation for new customers and faster rollout of new video services.

The telecommunications industry may face some challenges during the adoption of APIs. The first and most important one is the generic nature of APIs. They need to be programmed to get the desired functionality which may be a challenge for CSPs while over the years they have reduced the number of software engineers and they mostly relay on suppliers and systems integrators to manage the network. APIs have the ability to be reusable, open and flexible but qualified engineers with software knowledge and skills are needed to support this venture. For this reason, companies which are interested on APIs should develop their own autonomous and professional team and embrace this attempt. The second one is the lack of suppliers' support for the APIs which is a mutual concern of CSPs and suppliers. There are few suppliers who are committed to APIs but most of them are not at the same maturity level and as a result the adoption progress is too slow. Other drawbacks are the difficulty of use and the lack of documentation, which are connected. It shouldn't be taken for granted that all developers have the knowledge of Open APIs, nor the experts have the answers for everything. That's why documentation is essential and it will be helpful for the implementation of APIs in various use cases [54]. Also, the way that Open APIs are tied to a catalog-driven architecture and a specific model, affects the way that changes can happen which incur cost [54].

3.2 MICROSERVICE PROGRAMMING

From the business perspective the microservices architecture can provide key opportunities for both the service providers and service consumers. For instance, microservices support consumer enablement, transparency, and choice. They can also extend the utility and reach of a specific business, while they can be deployed with a custom set of technologies. Microservices architecture gives the ability to businesses to develop software applications out of a variety of individual modules, which can be deployed independently. Each one of these services handles its own data, can be updated without rebuilding or redeploying the entire application and it can communicate with other services by using well-defined APIs [55].

There are several benefits of adopting this architecture. First of all, microservices can be easily and separately managed, updated and modernized, and they can be deployed with different technologies which can simply be changed (frameworks, libraries etc.) without rewriting the code of the system. As a result, technical debts and large-scale modernization expenses can be avoided. Secondly, microservices can be scaled independently depending on the sources and processing power requirements, which is cost-efficient. This independency allows businesses, based on their current goals and needs, to allocate time and resources for the creation or modernization of specific services. Also, microservices are isolated so in case of a fault acquires and it is unavailable, it will not affect the entire application or neither the schema update will have a problem, because only a single microservice will be affected while the different parts of application don't touch the same data [55].

A powerful core network can be formed combining 5G and microservices architecture. In particular, the 5G technology ecosystem structure can be shaped up as the microservices architectural structure. The microservices can easily be distributed within the 5G network and get updated in an isolated way so other services of the 5G ecosystem won't be disturbed. Last but not least, the microservices can provide hyper-connectivity to 5G connections since many methodologies such as session setup, scalability and procession transactions are sped up by them [56].

According to IBM Market Development & Insights survey about the business advantages of microservices [57], 87% of IT leaders and tech specialists consider that the efforts and the cost of microservice's adoption are worth it. Even though this adoption is very helpful and beneficial, 49% of companies, which have incorporated microservices, admit that they lack sufficient staff -especially DevOps- for the related projects. To manage the microservices, which increase the complexity of the system, the right advanced tools and platforms are necessary for the automated monitoring, flexible runtime deployment and container hot deployment [58]. Also, businesses have to find out the way to break down the system into modules and find an effective data strategy and security layers. As a result, 48% of businesses adopters that have concerns about the time and the costs will need to develop an application. Having in mind all the advantages and the concerns, 78% of the organizations that already use microservices maintain that they will likely increase investment into further development of microservices [59].

In a constantly changing market where a lot of transformations take place and technological needs are created, the open-source development model is rising. According to "The 2022 State of Open-Source Report" by OpenLogic and open-source initiative [60], 77% of respondents declared that they have increased the use of open software in their organizations. Also, a more positive opinion has been created to IT leaders for the enterprise open source which can be helpful for application development and modernization, IT infrastructure modernization and in general in digital transformation. A product that is widely known and used also in EVOLVED-5G platforms (Malaga and Athens) is Kubernetes [7], an open-source system for automating

[7] https://kubernetes.io/

deployment and management of containerized applications, which is utilized by 70% of IT leaders who work for organizations.

More and more enterprises adopt open-source products because of the lower total cost of ownership (TCO) than the proprietary products. The reusability of open-source software, allows the organizations to reduce the cost and speed up time to market. These factors, the no license cost and the overall cost reduction, are the main ones for European and UK organizations to use these products and technologies [59]. Over 37% of respondents of the survey of the above report, avowed that they are using open source, such as container technology, cloud-related tools and data technologies, to modernize their stacks [59].

From the IT perspective, these products are more secured, with better quality and they are more flexible to work in cloud and cloud-native-technologies. Based on the Red Hat Report [61], 82% of IT leaders are more likely to choose a vendor who has contributed to the open-source community. The reasons are that these vendors are familiar with open-source processes, perspicacious and adaptive to technical and technological changes and able to develop application features. Even though, in the last years, it was considered that the proprietary software was more secure than open-source, that perception has changed. According to the above report, 89% of IT leaders believe that open-source is as secure or maybe more secure than closed software. They consider that the security patches are well documented and can be scanned, which contributes to software supply chain security, and they can check the code which is already well-tested. An important fact with the open-source software is that many contributors, who are not necessary in the enterprise's team, can test, change, improve and make the code more secure [61].

However, there are some barriers to overcome, such as the concerns about the level of support and the compatibility with other applications and products. As it is claimed in [60], 51% of the participants in their survey indicated that they faced challenges during installation, upgrade and configuration. Also, they have to deal with the lack of internal skills which are referred to administration, support, and maintenance of infrastructure technology and are essential to manage and support an open-source project. Lastly, as referenced above, most of the IT leaders believe that there is security in open-source products but some of them have still concerns and second thoughts about the inherent security.

3.3 ANALYTICS POTENTIAL

The network data analytics is the process in which the network data is collected and analyzed with the intention of the improvement of network's performance, reliability, visibility and security. Most of these processes are getting automated while billions of sensors and devices are going to be connected in 5G networks. Having this amount of data to handle, the more-advanced analytics systems are using artificial intelligence (AI) and machine learning (ML) so the processes of monitoring, troubleshooting and other complex tasks can be improved and completed efficiently and faster [62].

The Network Data Analytics Function (NWDAF) is responsible for collecting network data from 5G Core network functions and performing analytics. It is developed by 3GPP based on technical specifications and it offers a standard set of use cases such as UE mobility and abnormal behavior detection (UE related), QoS sustainability (Service experience analytics) and identifying user data and network performance (Load and performance analytics). Some other cases, that are relying on connectivity and ultra-low latency, are drones for public safety and industrial uses which need to receive in real time instructions from a remote operator. For these specific cases, Nokia has developed the AVA NWDAF [63] architecture, so the edge and the central NWDAF instances can be at one and allow the CSPs to provide real time analytics at the edge network and to optimize user's experience.

The NWDAF is contributing to 5G openness while the external developers, as well as other partners, can have access to network data. More specifically, an external developer can use APIs and SDKs, which are using

network data insights, to create an app without having to know the underlying systems and in general how the processes of the network are working [64]. This function also helps the CSPs to evolve through the ecosystem creation on to value creation in which they can create services which are going to cover vertical enterprise market needs. This open ecosystem formed is not going to slow down the growth of the CSPs but to make them move from conventional to innovative creations and solutions.

In the context of EVOLVED-5G project, a 5G value proposal of the FoF applications has been declared by ZORT. That system detects and classifies network anomalies that can influence the industry performance. The goal of this application is to take advantage of the NWDAF, which provides analytics of 5G core to external entities, and the integration with the NSSF function that enables mitigations actions when an anomaly is detected. In addition, the potential of analytics is illustrated in a prototype developed by LNV (in the framework of EVOLVED-5G), aiming to solve the problem of "vertical application (vApp) server selection" [65]. This proof-of-concept realizes a data collection and prediction analysis loop based on feeding (through standardized APIs) the NWDAF with vertical application measurements (Figure 13). For the problem of vApp server selection, a *vApp statistics collector*, collects performance statistics from the available vApp server instances, and feeds them into NWDAF utilizing the *CAPIF manager* and the SDK libraries that EVOLVED-5G has developed. Based on the vApp performance statistics (and potentially, additional input from other network functions), the *NWDAF* derives application analytics per indicated vApp server, by consulting an *AI analytics engine*. *NWDAF* can then provide the vApp client with analytics in order for the latter one to select the most appropriate vApp server instance to connect to; for instance, the selection can be done based on latency criteria at a specific time of day and location. This AI-assisted vApp server selection approach exploits analytics (statistics and predictions) assisting in network optimization through enhanced connectivity and efficiently managing resource allocation in the scalable and highly complex vertical industry's scenarios.

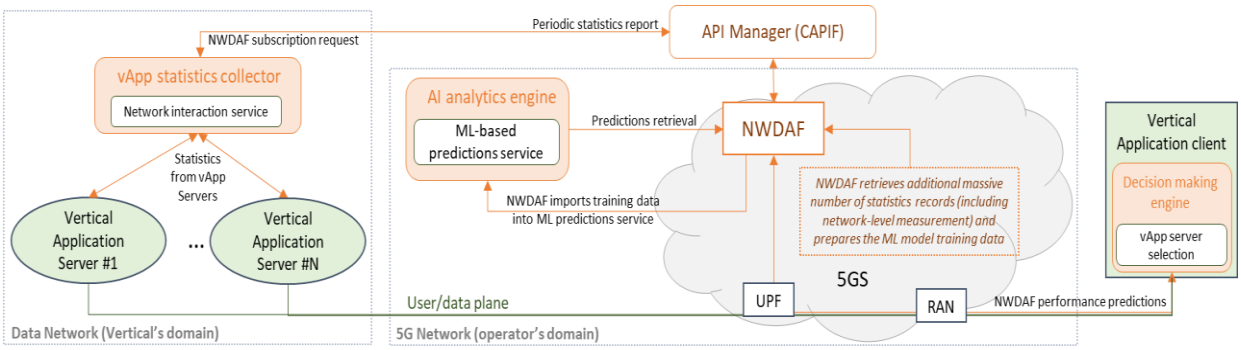


Figure 13. Exploiting NWDAF for AI-based decision making in 5G and beyond networks

3.4 DEDICATED MARKETPLACES

One of the main objectives of EVOLVED-5G project is to materialize the openness of 5G to vertical industries by creating a Network App development and verification environment (SDK). Following this direction, the means for enabling the digital market around the Network Apps should be provided.

In this context, vertical industries will be able to develop Network Apps, i.e., to compose services by consuming 3GPP APIs (native APIs) as well as other telco assets (referring to business support system – BSS APIs, e.g., service orchestration APIs). For example, a Network App could consume APIs that provide monitoring events and network slice configuration analysis to compose a service that guarantees quality of experience for latency-sensitive applications. A Network App should be a product that a provider offers to solve an identified problem of the end customer.

Dedicated Network App (services) and API Marketplaces can deliver measurable business value to both the provider and consumer of a service. The role of such dedicated Marketplaces is becoming critical at this point of time since the adoption of API backed services is broad but the tools for discovering, validating, managing, productizing and presenting the service capabilities are still dallying.

The last mile for a Network App is a properly functioning marketplace that ensures Network Apps are exposed for easy discovery and consumption by developers. Developers need an easy way to search, filter, find ratings, view reviews, and connect with an expert when needed.

The fundamental benefit of a dedicated Network App marketplace is that it accelerates the discovery and use of 5G services. The intention behind the realization of such a marketplace would vary including the following:

- Build a developer portal
- Create a partner ecosystem
- Enhance control over internal assets

But at the end marketplaces aim to provide end users with a simple way to find resources relevant to their business needs.

In that extend the marketplace can be a tool for different stakeholders to accomplish their business targets and objectives. For example, a product manager can package their services as products to monetize them easily and accelerate business profits, on the other hand consumers can find and procure relevant solutions for their problems in a single point of sourcing.

The expansion of 5G to vertical industries such as Industry 4.0, Transportation, and Energy and the need for Network App services will add complexity to their adoption which in extend leads to the need for specific actions established through the marketplace:

- Bring Network App services together in a logical way providing universal management measuring the engagement and the consumption of all the Network App products in a multi-cloud, multi-protocol environment.
- Validating, securing, and governing these Network Apps by providing a panoramic view of the policies used to control them.
- Defining Network App products or bundles of Network App services providing all the information from how you measure the quality of experience inside the Network Apps to the type of pricing/subscription plans to achieve the best monetization results.
- Pairing relevant systems and platforms that deliver to the marketplace's members capabilities to avoid bottlenecks during on-boarding and provide valuable information and insights. (CICD services, Certification services, Forums, etc.)

- Measuring value and performance of the Network Apps providing feedback for improvement.
- Before any Network App can deliver measurable value, they must first be discovered. A dedicated Network App marketplace helps people to easily locate any 5G related Network App while supporting their development and governance.

4 TECHNOECONOMIC ASPECTS AND BUSINESS ANALYSIS

To best examine technoeconomic aspects of the EVOLVED-5G Ecosystem, we propose a four-step methodology based on the following iterative steps (Figure 14). Initial work for the first three steps is provided in this deliverable (Technoeconomic Analysis and Stakeholders Engaging - Intermediate Report), while the full analysis for the four steps is expected in the nest deliverable (Technoeconomic Analysis and Stakeholders Engaging – Final Report)).

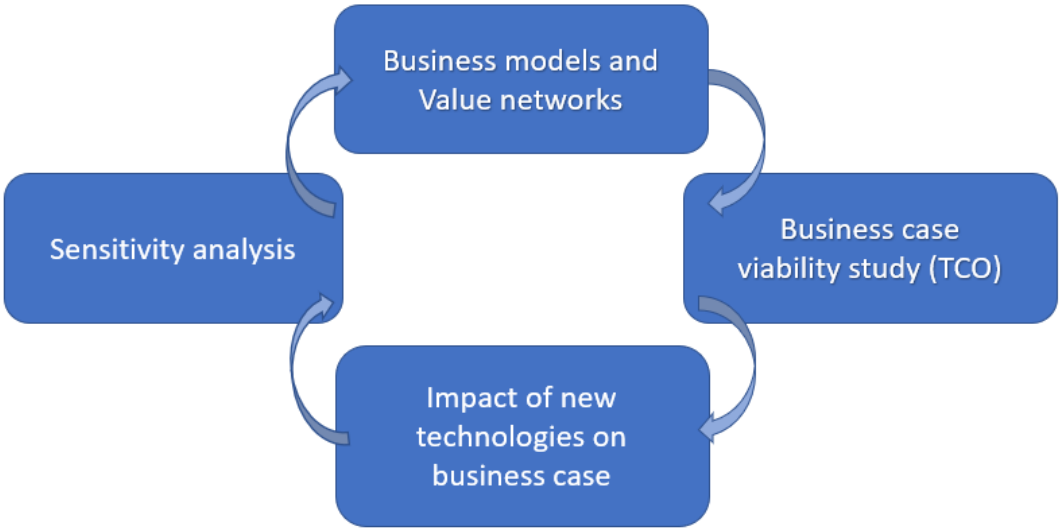


Figure 14. Techno-economics as part of business analysis

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

4.1 BUSINESS MODELS AND VALUE NETWORKS

4.1.1 Business models Identification

Business models have been proposed and developed for both firms and ecosystems. We begin with the definition of the business models for the firm (and how they are related with the firm's strategic plan), then we define the 5G ecosystem and propose relevant models for the 5G ecosystem. In our approach (proposed in Subsection 4.2), it is the first step of the entire business analysis, together with Value Network Analysis.

A business model describes qualitatively how one organization endeavors to create, capture, and deliver value in an economic or societal context. A business model is used both for the description of how entrepreneurs create growth opportunities, as well as how established organizations identify new commercial opportunities.

The business model definition of each firm ideally is the result of a nested process evolution and development as illustrated in Figure 15. The process starts from a firm's strategic plan that explains which specific long-term goals a firm expects to achieve and how. From its strategic plan the firm derives the business strategy, which sketches the steps needed to achieve the long-term goals. The next step in the process is the definition of a business model which identifies value propositions, customer segments, and concrete steps for the execution of the business strategy and describes how a firm creates, delivers and captures value in economic, societal and other contexts. Embedded in its business model each firm will define one or more business plans and formulate associated business cases that support the execution of the business strategy.

As it can been seen, business model (of firm) relies on business case. So, it is important to define the business case. A business case is the identification of a business need that can be satisfied by the introduction of new or adapted existing products and services. It provides a systematic reasoning and argumentation about the assumptions, target market situation, benefits and risks, needed investments, as well as projected cash flow when an organisation plans to satisfy the business.

Figure 15. Business model as a part of each firm's strategic plan

Specifically, in the fast-evolving 5G and beyond 5G market environment (with variable network deployments, products and services and competition of alternative technologies), this process is not so straightforward. The firms need to adapt to competitive pressures through sustainable and reliable business models. In the context of 5G-PPP projects, the white paper on *Business Validation in 5G-PPP vertical use cases*, proposes a flow of business development activities in 5G and beyond 5G ecosystems to guide the firms participating in these projects on positioning themselves in the ecosystem value network. The business development activities are inspired by lean start-up methodologies and are segregated in four phases:

Customer validation, Solution alignment, *Business Model*, and Growth Trajectory. So, business model in 5G markets is considered to be as on the four pillars on business validation in H2020 vertical 5G use-cases.

Figure 16. Business validation for H2020 vertical 5G use cases

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

Before we proceed with the business models for 5G ecosystem, we need first to define such an ecosystem and also define terms in 5G ecosystems which are essential for the full description and proposition of business models.

The White Paper in [66] provides definitions and early examples of 5G ecosystems. They aimed at equipping 5G stakeholders in telecommunication and vertical industry sectors with better understanding of ecosystem dynamics, the processes that take an ecosystem from birth to maturity, and the kind of strategies that are necessary to kick off its evolution Not the least, the wanted to emphasize that an ecosystem does not evolve and reach volume without potential tensions between stakeholders, which call for the need of balancing strategies and interests, hurdles mitigation and consensus creation. This white paper elaborated on the 5G ecosystem from two perspectives: the provisioning 5G ecosystem, and the 5G vertical ecosystem. In emerging 5G ecosystems, driving firms' strategies must focus on how to mobilize other contributors to take part in value creation. More specifically:

The 5G provisioning ecosystem encompasses those roles and actors who take part in developing, delivering, and providing 5G services. Traditionally, the telecom industry is seen as a value chain where network operators source the resources necessary to provide fixed and mobile telecommunication services.

The 5G vertical ecosystem black boxes the 5G provisioning ecosystem and focuses on other actors who work closely together as part of vertical industries. While roles and actors from the telecommunication sector are still present in this ecosystem, the emphasis is on yet other roles which apply 5G services in their value creation and can be domain specific.

Since EVOLVED-5G is targeting to vertical industries, we are focusing on 5G vertical ecosystem and the relevant roles. The roles in a 5G vertical ecosystem are a disaggregation of the 5G Service customer role in the 5G provisioning ecosystem. A first separation is between the role of the 5G Vertical enterprise customer which purchases 5G services, and the role which support the vertical enterprise customer to create and operate a solution in the vertical domain. The 5G service provided by a 5G Service Provider is one component in such a solution. Thus, seen from the 5G Service Provider side, the supporting role complements a 5G service and the role may be referred to as a complementor. Furthermore, this complementing role consists of many more specific roles and we therefore refer to the main role in plural – 5G Vertical complementors. The roles in 5G

vertical ecosystems include the relationship to the 5G provisioning ecosystem and the 5G Service Provider. It should be noted that the complementors are not only seen as providers of components in 5G empowered solutions; in an ecosystem context complementors are seen as critical holders and developers of knowledge which in turn is the basis for innovation in the vertical domain.

In this context a 5G value network is defined by way of a 5G ecosystem as a complex network or interconnected system, with focus on how 5G services are provisioned seen from within (introvert view) [67]. Such models reveal the internal complexity of a platform and hide the complexity of the interaction with customers and external partners. The introvert view refers to a team or group directly engaged in the construction of one or several 5G systems.

In contrast a 5G platform ecosystem is an interconnected system, where the focus is on how one 5G platform interacts with external stakeholders and customers. Such a model hides the internal complexity of a platform and reveals the complexity of interactions with external stakeholders and customers that can belong to other industry sectors (extrovert view) [67]. The complex relationships in value networks and platform ecosystems deviate from the idea of a Value chain, which models sequential relationships between value producing activities in control of one organization.

Due to the large number of business model configurations, we cannot emphasize one 5G business model, but rather derive different business models for the different opportunities that 5G facilitates. In the context of different partitions of the overall 5G ecosystem indicated above, and allowing finer granular segmentation, e.g., network creation, horizontal services, vertical applications etc., we can describe for each of the finer segments a specific ecosystem and associated business models for each participating firm.

Such proposed business models can be: **a collaborative, a non-collaborative and a slice-as-a-service business model.** It depends also on each partner's strategy which one they will adopt. In the next deliverable we will assign each one BM to each use case and also relate them with research challenges as soon there is feedback from the demos.

A discussion and preparation of a whitepaper on 5G Ecosystem Business Modelling –organized and led by 6G-IA "Business Validation, Models, and Ecosystems" Sub-Group (BVME-SG)- is ongoing and it is very likely that business models proposed here might be included in the next version of this whitepaper [68]

4.1.2 Value Network Analysis based on e3value Methodology

Value network analysis (VNA), as step one in the entire business analysis, is a methodology for understanding, visualizing, using, optimizing internal and external value networks and complex economic ecosystems [67]. "The methods include visualizing sets of relationships from a dynamic whole systems perspective. Robust network analysis approaches are used for understanding value conversion of financial and non-financial assets, such as intellectual capital, into other forms of value. The value conversion question is critical in both social exchange theory that considers the cost/benefit returns of informal exchanges and more classical views of exchange value where there is concern with conversion of value into financial value or price".

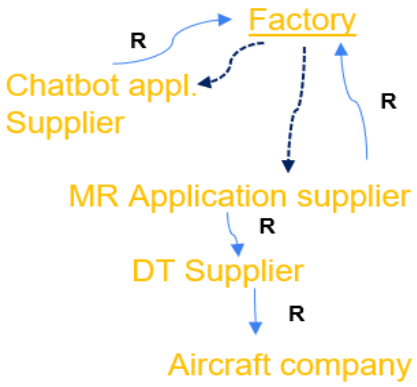
The proposed **e3value methodology** is a stepwise approach to develop business models for networked value constellations. These constellations are networks of enterprises who offer something of economic value to end users. Networks consist of end users (the customers), suppliers, and the suppliers of these suppliers. The e3value approach supposes an ideal network, in which all actors behave honestly; the e3fraud method can be used to analyze sub-ideal behavior; e.g., actors committing a fraud [68]. More specifically:

A. Tangible and intangible value streams between all partners: The key point of Verna Allee's Value Network Analysis (VNA) is the shift from a linear value chain with only a few partners to a more complex value network [69]. In these value networks intangible value streams are equally important

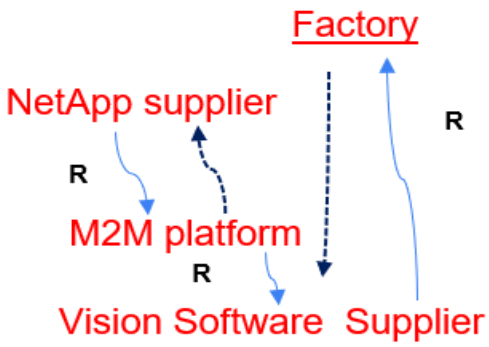
as tangible value streams in order to create value. Tangible value streams are contractual like goods, services and money. Intangible value streams, however, are knowledge or intangible benefits which support a product and are not contractual. VNA visualizes both types of value streams between all involved partners. This is in contrast with the e3 value model, which mostly neglects intangible value streams [69].

B. Activities or roles without value streams: Each actor can perform roles or activities in order to create value and the mapping of roles on their actors is referred to as a value network configuration. A value network configuration is not unique since different actors could take up different roles. We argue that the value streams in a value network configuration should be visualized between actors, as applied in VNA [69]. In contrast to the e3 value model, value streams between internal activities are not depicted since they do not represent a transfer of ownership [70].
C. Economic viability through scenarios: All of the compared frameworks recognize the usefulness of scenarios to capture possible future changes of the value network. These scenarios represent different versions of a value network based on giving a value to one or more parameters. The e3 value model, however, solely uses these parameters to determine the economic viability of the network in quantitative numbers. This economic viability is determined by the actors' profitability, which is calculated by identifying their costs and revenues in the value network [71].
D. Two types of change: An examination of the e3 value model shows that there are two types of change in a value network: a change in the structure of the value network, such as actors (dis)appearing, and a change of its economic viability [71].

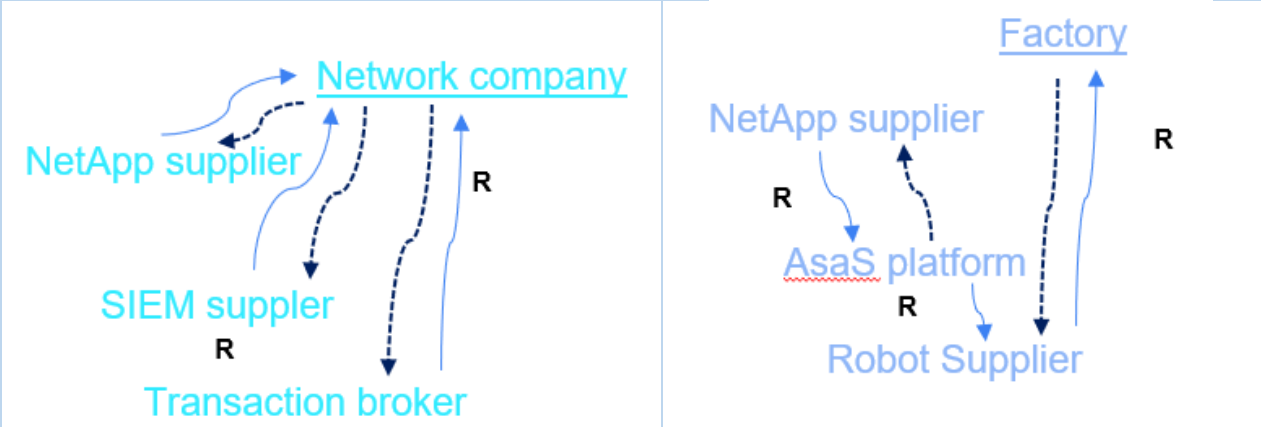
Following the methodology described above, we are proposing the following four value network models for each use case. Solid line **R** denotes the relation between partners and dotted line shows the revenue stream from the customer to the supplier of the services.



Network *Apps for Interaction of Employees and Machines Leader*



Network *Apps for FoF Operations*



Network *Apps for Security Guarantees and Risk Analysis*

Network Apps for Production Line Infrastructure

Figure 17. Value network models for all use cases

4.2 BUSINESS CASE VIABILITY STUDY

The goal of EVOLVED-5G is to create new and realistic opportunities for generating competitive advantages for the European ICT sector and more specifically the 5G market. The vision of innovative and demanding applications and services is set to transform the telecom industry that will benefit from the same level of agility as what is available today in the IT world: time to market for new innovative services will be significantly improved, and the overall Total Cost of Ownership (TCO) will be reduced. TCO is the main key driver for a techno-economic analysis. A techno-economic analysis and work examines primary costs, benefits, risks, uncertainties, and timeframes to evaluate the attributes of technologies developed and produced in the project. The economic performance of the solutions will be calculated taking into account a life cycle perspective, which considers initial costs, operational costs, maintenances, substitution, etc.

A TCO model as well as revenue assumptions are used to judge the viability of the business cases. In addition, given the costs associated with different business models, performance-cost trade-offs can be identified, and their impact calculated. Finally, indirect benefits (i.e., non-monetary benefits for direct users or positive effects on the economy or society) should be included in the business case evaluation, especially for public stakeholders. In order to evaluate the economic viability of the selected scenarios (use cases) a generic TCO is built. The model considers both the Capital Expenditures (CAPEX) and the Operational Expenditures (OPEX) as well as overhead costs (e.g., marketing, helpdesk, etc.).

CAPEX contributes to the company's fixed infrastructure and are depreciated over time. For an operator, they include the purchase of land and buildings (e.g., to house the personnel), network infrastructure (e.g., IP routers) and software (e.g., the network management system). Note that buying equipment always contributes to CAPEX, independent from the fact whether the payment is made at one time or spread over time.

OPEX do not contribute to the infrastructure itself; they represent the cost to keep the company operational and include costs for technical and commercial operations, administration, etc. For an operator, OPEX is mainly constituted of rented and leased infrastructure (land, building, network equipment, fiber) and personnel wages. This classification is illustrated in Figure 18.

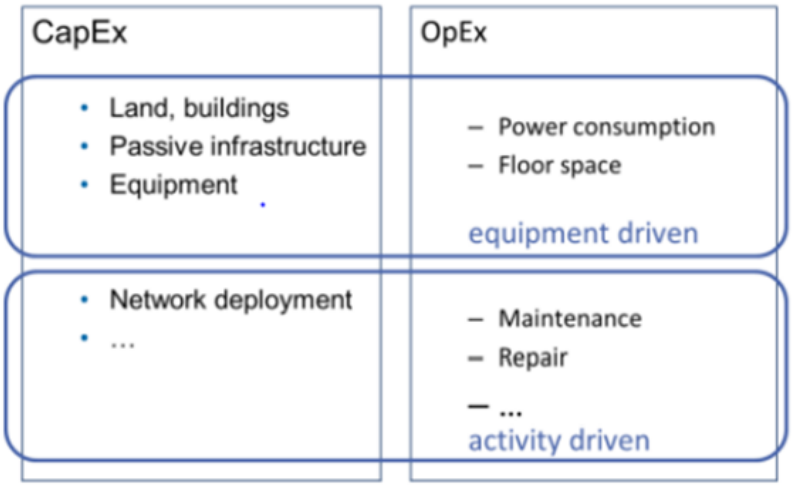


Figure 18. Cost structure

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

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

Maintenance costs are counted in the OPEX costs.

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

Specific TCO models will be described and developed for each use case in D6.3 in parallel with the development and testing of the use cases. We expect that in some use cases the CAPEX costs will be dominant, on the other hand in some others the operational and maintenance costs, costs will be higher.

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

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

One of the challenges would be to define a value proposition and identify where edge computing and AI are driving values for specific sectors and businesses. Different business models compared and concluded by a cost-benefit analysis for the most relevant use case should be investigated. The techno-economic analysis should identify the main reasons why Network Applications are playing a vital role in 5G and Industrial markets and analyze emerging architectures and edge platforms where industries need to agree on functions, interfaces, and technologies in order to realize digital products and services.

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

4.3 IMPACT OF NEW TECHNOLOGIES ON BUSINESS CASES

In EVOLVED-5G project and especially in Deliverable D4.2, potential benefits of 5G have been described, referring to a specific list of applications that belong to four pillars of the **manufacturing sector**, namely interaction of employees and machines, management of factory operations, security and risk analysis, and production line robotics. Considering the target Network apps that will be developed within EVOLVED-5G, and lie within the above-mentioned pillars, we summarize in Table 1 the main benefits that they expect from 5G.

Table 1 5G as enabler for the EVOLVED-5G Network Apps

Network App name	Relation to 5G features
Remote assistance in AR	Time-sensitive networking mechanisms can ensure a smooth real-time collaboration for end users. Besides the raw performances, 5G also gives access to tools to monitor the state of the network. This is a crucial feature to be able to notify end-users as soon as possible when a network issue occurs. The goal is to trigger the most appropriate adaptations so that end-users can continue their work without being too disturbed, which could otherwise be hazardous in the industrial contexts we target.
Chatbot assistant	5G openness provides the location information of the cell that a UE is connected, which can be used directly by the service in order to gain location awareness of the workers. Indeed, a locally installed 5G network has the potential to offer such indoor positioning information of each connected UE based on the NEF API. More specifically, for the chatbot use case, the factory will be mapped into cells according to the coverage of the installed 5G small cell antennas. The respective database will indicate the machines that fall under each of the factory areas providing the functionality of a specific machines' list.
Digital/physical twin	There are three main benefits gained through access to 5G capabilities for the development of Digital / Physical composite repair twins. First is the guarantee of a satisfying QoS and Security (Authorize users) when remote bonding is performed, second, retrieve User Equipment (UE) location information and thus information that result from the location such as the environmental conditions, and third the ensuring of the communication link during the bonding process.
CAFA-NetMapper	The high network speed and low latency of 5G networks allows running real-time computer vision applications close to the performance as if they run in local computer. The low latency is crucial in directing moving robots in confined indoor environments to avoid its collision with people, building structures and other equipment. The notification about the QoS loss allows the vApp to stop the computer vision and send the signal to the robot to stop its movement. Access to 5G capabilities will allow using one central computer with fast connections to multiple camera points.
Smart irrigation 5G Agriculture	Two main benefits derived from the use of 5G connectivity are provided. First, sensors do not need to be pre-configured with information about the location where they will be deployed. This greatly reduces the complexity when preparing the terrain, and also allows immediate reuse of the sensors in another location when needed. And second since the location information is taken from the network, sensors do not need to make use of GPS signals, which reduces both the energy consumption and the cost per sensor.
QoS and SLA/SLS monitoring capabilities	Since 5G has the potential to offer network performances required by the factory process, the solution/Network App (in combination with the corresponding vApp) presented utilizes 5G network functions available, to provide assured QoS for the communication links, i.e., the Network App's

	responsibility is to configure and monitor the 5G radio network QoS according to SLA requirements set via vApp. 5G enables the Network App to collect various radio, network and cloud related performance metrics (e.g., location-based info such as Cell Id/gNB id, QoS status) used as a quality indicator of the 5G NR, as well, within the 5G, the user has, among others, a possibility to select the preconfigured slice to accommodate the SLA requirements.
Anomaly Detection	The availability of rich and on-demand access to 5G system monitoring and analytics via NEF, allows a variety of inputs to become available at the Network Anomaly detection application. The development, integration and validation burden are minimised and solutions can be built on top on well-behaving, tested and certified software APIs. The need to provide workarounds in accessing in-premises information is limited. The accuracy of anomaly detection can now be improved by exploiting 5G esoteric information otherwise not available outside of customised Non-Public Network (NPN) installations.
Traffic Management	Increased bandwidth, lower latency and increased availability are offered by 5G networks and are mandatory in order to properly secure the network. The security administrator of the network is able not only to counter a threat more efficiently, but also to avoid one, using the increased security measures provided by the 5G Core Network. 8Bells proposed solution with Network App (in conjunction with vApp) provides monitoring of the 5G core through the proper use of suitable APIs.
ID Management and Access Control	The technology of 5G has two main benefits, increased bandwidth and lower latency. The enhanced operation of 5G networks allow the usage of different SaaS to communicate rapidly from different locations, in order to perform identity and access management without obstructing network service. Furthermore, the capability of 5G to monitor and obtain information about UEs gives the opportunity to perform continuous authentication and restrict or lower the access level in case of suspicious behavior.
5G Security Information and Event management	Extending a SIEM system with 5G capabilities enhances the platform by offering access to 5G security information, such as real-time monitoring and updates on the security status of the 5G NPN devices. As a result, the security administrator of an Industry 4.0 environment can have a clearer and more complete picture of the underlying industrial network. FOGUS, with the development of its Network App, aims to bridge the communication gap between SIEM and 5G NPN devices.
5G Teleoperation	The Teleoperation of TIAGo robot requires to transmit at high-speed video streams and readings about the sensors and the feedbacks. The connection also needs to be stable without a lot of jitters. And the connection also needs to be secured between the user and the robot. Thanks to the 5G capabilities we would know when the quality of connection required can be guaranteed and when not, this will allow our vertical application to be more robust and have several states in function of the 5G QoS. A direct secured 5G connection will also enable safe teleoperation
Robot Localisation	As the 5G networks evolves and the industry begins to adopt public and private 5G networks a door opens regarding data-intensive applications with low latency. Leveraging technologies like 5G will help to scale up robotic industrial applications around the world and not only in private environments.

	5G provides several technologies which directly address problems of robotics: • Related to network edge computation it can provide extremely efficient latencies to perform critical time-based robot control tasks. • Enough bandwidth to externalize on-board computation to external computation. • Robotics fleets are more scalable • Network slicing to provide the necessary network quality of service for time-critical applications with high computation. • As a use case: Roboticists can now address known problems such as global indoor positioning since the 5G core can provide this information through Network Apps. In fact, 5G can provide an extended sensory system for every robotic system. • The orchestration of a fleet of mobile robots to enable the centralized control of autonomous mobile robots to perform logistics tasks in the agile production line.

4.3.1 Interaction of Employees and Machines

4.3.1.1 IMMERSION USE CASE

Technological impact

Using 5G greatly facilitates or even enables the use of Augmented Reality (AR) features for remote assistance scenarios. First of all, mobility is important for workers, who may need to move across several areas of the factory. Tethered connections are thus often not suitable. Nonetheless, WiFi networks are not always deployed within factories. There can be multiple reasons explaining this phenomenon, including security concerns. 5G allows wireless connections and offers additional software services and security aspects. For instance, 5G networks offer the capacity to track UE locations and have a fine control over network connections depending on factory areas. Other 5G services include QoS monitoring. These aspects are important to notify end-users in real-time in case of network issues. With QoS monitoring, a 5G-enabled application could potentially warn users and adapt its available functionalities. This would avoid confusion and erroneous manipulations on industrial machines, which could be hazardous and costly. Finally, 5G can offer QoS levels matching with real-time collaboration requirements. This is crucial to better support the workers and experts with more complete AR features and guidance compared to only audio calls or 2D visio-conference features. In particular, the performances of 5G allow to consider real-time collaboration around shared and complex 3D models or even virtual replicas of the factory.

Financial impact

Thanks to 5G, IMMERSION aims at attracting new customers and offering new AR services for remote assistance to industrial clients. First, the company wants to take advantage of the developed IMM Network App (to be) deployed in the Marketplace. Our goal is to showcase the involvement of the company in 5G technologies and their combination with AR. Our Network App will be used as a demonstrator to attract new industrial customers interested in Extended Reality (XR) applications and services. Next, we also expect financial impacts from the technical progresses made during the project. Evolved-5G was the occasion for IMM to explore 5G connectivity of some AR devices like the HoloLens 2 from Microsoft. Since this technological barrier has been overcome, we envision to make some of the existing IMM products compatible with 5G. In particular, we aim at further developing our remote assistance bricks. This will help us to reach both our current customers already using some of our hardware and software products (XR devices, collaboration platforms, etc.), but also new customers.

4.3.1.2 GMI AERO USE CASE

Technological Impact

5G will provide new, unique capabilities for the implementation and exchange of data related to bonded composite repairs of aircraft structures:

- ANITA 4.0 hot bonder(s) used for repair curing will be connected though 5G in order to transmit in real-time all related data to the Engineering Centre of aircraft manufacturer / airline / MRO.
- Development of composite repair physical / digital twin will help GMI and the associated aeronautical industry to perform a technological leap in the face of global emerging competitors by providing innovative solutions, adapted to the specific aircraft requirements, not available yet on global scale.
- Optimization of the integration of systems in the airframe along with the validation of important structural advances.
- Progress on the production efficiency and manufacturing of aircraft composite structures.
- Avoidance of part scraping during manufacturing, as well as in MROs, airlines and composite plants, by increasing the range of application of bonded composite repairs.

Financial Impact

The introduction of physical/digital twin capabilities, supported by EVOLVED-5G developments in the portfolio of GMI equipment and services, is expected to have a direct financial impact as it will:

- Assist in the reinforcement of the competitiveness and the performance of EU transport manufacturing industries and related services.
- Facilitate the development of the next generation of transport means.
- Further exploit the advantages of light composite structures.
- Enabling new manufacturing and maintenance techniques for both existing and new composite structures, in order to retain areas of EU leadership in the transport sector.

GMI being part of this ecosystem will be directly positively affected by these global advancements and innovations. To this end, GMI has already included EVOLVED-5G expected developments within its advertising material and exploitation strategy, so as to increase the impact of the project results. Brochures and related material are available through GMI AERO - Link page (gmi-aero.com)

4.3.1.3 INFOLYSIS USE CASE

Technological Impact

Using 5G, the INFOLYSiS chatbot app will gain additional features for indoor use in Industry 4.0 environments:

- Optimization of chatbot apps for the provision of additional services relying on 5G
- Indoor location awareness of workers through connected UE based on the NEF API and installed 5G small cell antennas
- Interaction between the developed vApp and the Network App for user location and machine identification over a chatbot app
- Fast malfunction reporting
- Easy to access manuals and documentation of factory machinery and equipment
- Central administration of errors and updates. Access control based on user location

Financial impact

Thanks to 5G, INFOLYSiS will create new chatbot based products and services targeting new markets and sectors:

- Foster INFOLYSiS IoT and 5G R&D activities coupled with chatbot technologies
- Enrich the know-how and the research expertise of the company in 5G technologies under Industry 4.0 environments

- Encourage the development of Industry 4.0 chatbot based applications using the 5G network capabilities
- Provide new maintenance opportunities/services to Industry 4.0 technical teams through the provision of Intent-driven Chatbots for precise machine's maintenance in indoor industrial spaces
- Taking advantage of the INF Network App deployed in the Marketplace to address new markets and customers by showcasing/promoting the involvement of chatbots in 5G Industry 4.0 environments

4.3.2 Factory of the Future Operations

4.3.2.1 CAFATECH USE CASE

Technological impact

CAFA Worker robots are primarily focused on performing maintenance and situation monitoring tasks within the area of Industry 4.0. CAFA will create two applications within the EVOLVED 5G project: NetMapper and Video Analyzer. The Network App helps analyze the quality of the 5G network and thereby decide whether it is necessary to adjust the volumes of data or video streams sent from the robot. Said Network App (called NetMapper) is also necessary for other robotics companies that use robots or remotely controlled sensors in the field of Industry 4.0 that are controlled over a 5G network. The Video Analyzer application analyzes the wearing of Personal-Protective-Equipment (PPE) by employees in near real-time. This application can be used as a starting point to develop further applications because the architecture and core components of Computer Vision analytics remain the same. The purpose of CAFA is to introduce both NetMapper and Video Analyzer applications to various Industry 4.0 stakeholders.

CAFA Network App is an app for interfacing with NEF (Network Exposure Function) over CAPIF (Common API Framework). The Network App mostly runs in the background and helps with the distribution of network information. CAFA Video Analyzer is a vertical App which contributes to video analysis. It takes network quality of service-related messages from a Network App and turns on/off video analysis based on network conditions. There is a custom (CAFA native) interface between these two apps.

The technological impact is primarily that applications in general cannot easily get internal information about the mobile network otherwise. We do not want to grant any special rights to third-party applications for security reasons. CAFA applications take advantage of the fact that reporting takes place through CAPIF-I, then both the mobile network operator and the application developers have a better overview of what is happening.

Financial Impact

The logistics and maintenance robotics has magnitude order growth in recent years, and this has generated increased demand for communication solutions for mobile robots.

The main financial impact is that by using one Pipeline, which helps the developer go through all the necessary steps (semi-automatically) to get from validation to publication as comfortably as possible.

This allows developers to offer more applications to organize different tasks for different robots. All in all, this improves the quality of applications and provides financial benefits to:

- application developers, who find it easier to sell/license their applications;
- Robotics companies for businesses that get a wider range of applications;
- mobile network operators who can sell more customers and services.

4.3.2.2 INTERNET INSTITUTE USE CASE

Technological impact

Although the challenge of providing a stable connectivity for industrial IoT (and M2M) devices exists also in 5G, the latter provides useful features that may facilitate solution of the challenge. As the term "stable connectivity" refers to assuring SLA/SLS defined by the customer, the solution would not include monitoring relevant parameters of the connectivity only but should also require means to enforce certain measures to assure quality of the service agreed by SLA. To achieve this, 5G enables customer Network Apps to configure

the 5G radio network with new optimal parameters to achieve required QoS/SLA. Utilizing Network App approach and giving the fact 5G infrastructure enables multiple places where applications can run (far-edge, edge, cloud), gives even more opportunities for the development of new and enhanced flexible, special-purpose customer applications (primarily due to extended possibilities for customers (potential) ability to steer network functions). From the technological point of view, it is also worth noting that approach introduced in 5G may also enable low instantiation and reconfiguration time of the applications, enables scalability and global compatibility due to global 5G standards among other benefits of the 5G ecosystem.

Financial Impact

In practice, 5G is (still) related to considerable infrastructure investments on one side, and, on the other side, there is limited commercial availability of 5G UEs supporting specific functionalities that might be required for FoF applications. Thus, certain target users may not be yet ready or willing to adopt new technologies and for some users a certain learning time period is expected before adopting 5G technologies. Therefore, (significant) financial impact is still to come. The latter is quite likely since a few FoF stakeholders are not only showing interest in 5G custom applications/services but are also actively involved in PoCs. Another positive connotation for the financial impact may be the ability of expanding business worldwide due to global 5G standards. Otherwise, potential business might be threatened by specific market entrance barriers and specific regulation requirements in different regions such as, for example, frequency spectrum limitations.

4.3.2.3 ZORTENET USE CASE

Technological impact

The technological impact of 5G and cybersecurity technologies in the Industry 4.0 domain could be significant, as these technologies have the potential to enable the development and deployment of more advanced, intelligent, and secure systems and services. 5G technology, with its high speeds and low latency, could enable faster and more efficient data transfer and processing, allowing for real-time data analysis and decision-making in Industry 4.0 environments. This could lead to increased productivity and efficiency, as well as the development of new, data-driven services and applications. Additionally, the use of 5G technology in Industry 4.0 environments could enable the deployment of more advanced cybersecurity measures, such as advanced encryption and authentication methods, to protect against cyber threats and ensure the security and privacy of sensitive data. This could help improve the overall security of Industry 4.0 systems and services and enable the development of more secure and reliable applications and services. Overall, the technological impact of 5G and cybersecurity technologies in the Industry 4.0 domain could be significant, and could lead to the development of more advanced, efficient, and secure systems and services in this domain.

Financial impact

The financial impact of 5G and cybersecurity technologies in the Industry 4.0 domain could be significant, as the adoption of these technologies could lead to increased productivity and efficiency, as well as the development of new, revenue-generating services and applications. For example, the use of 5G technology in Industry 4.0 environments could enable the deployment of more advanced and efficient systems and services, such as real-time data analysis and decision-making, which could lead to increased productivity and efficiency in these environments. This could result in cost savings and increased profitability for companies operating in the Industry 4.0 domain. Additionally, the development and deployment of new, data-driven services and applications enabled by 5G technology in Industry 4.0 environments could generate new revenue streams for companies in this domain. For example, companies could develop and sell new data-driven products and services, or provide data analysis and other services to customers, generating new sources of income. In terms of cybersecurity, the use of advanced technologies such as 5G could help to improve the security of Industry 4.0 systems and services, reducing the risk of cyber-attacks and other security incidents. This could lead to cost savings, as companies would be less likely to incur the costs associated with security breaches and other incidents. Additionally, the development and deployment of secure, reliable Industry 4.0 systems and services

could enhance the reputation of companies in this domain, potentially leading to increased customer trust and loyalty. Overall, the financial impact of 5G and cybersecurity technologies in the Industry 4.0 domain could be significant, and could lead to cost savings, increased revenue, and enhanced customer trust and loyalty for companies operating in this domain.

4.3.3 Security Guarantees and Risk Analysis

4.3.3.1 EIGHT BELLs USE CASE

Technological impact

For the Security Guarantees and Risk Analysis pillar, as it has been defined in the EVOLVED-5G project, 5G is expected to enhance connectivity capabilities within a factory, due to the 5G NPN deployments and to bring advanced security capabilities. It is expected that 5G NPN (Non-public Networks) will progressively replace the networks that currently support industrial infrastructures and especially networking operations in the manufacturing industry. However, the evolutionary shape of 5G networks and their modular architecture requires an equal plug-and-play functionality in each environment for proper adaptation. To explore this impact and take advantage of this opportunity, 8Bells designed and developed an intelligent traffic mechanism to optimize the number and sequence of service functions based on traffic identification. This technological solution identifies traffic patterns in an asynchronous way without limiting the throughput of the overall system and it goes beyond the limitation of the data traffic able to circulate on the current network settings. Due to the synergy of Network App and 5G networks, the traffic is controlled, and policy functions are applied by the switch when QoS is below a certain threshold. This element takes advantage of the 5G openness concept and the EVOLVED-5G network applications.

Financial impact

The financial impact of 5G and cybersecurity technologies in the Security Guarantees and Risk Analysis pillar could be significant, as the adoption of these technologies could lead to increased security and network efficiency, as well as the development of new, revenue-generating services and applications. 5G openness in conjunction with the API-based approach has been perceived approach in industry having significant financial impact so far in the context of 5G API market. Additionally, the development and deployment of secure, reliable Industry 4.0 systems and services could increase the reliability of the products/services offered by 8Bells in this domain, potentially leading to increased customer trust and company's brand name. Taking advantage of the Network App and vApp (Switch) deployed in the Marketplace 8Bells may address new markets and customers by showcasing/promoting the operation of intelligent switches in 5G Industry 4.0 environments. Such new services and applications enabled by 5G technology in 5G NPN will generate new revenue streams for 8Bells and other SMEs offering similar services.

4.3.3.2 FOGUS INNOVATIONS & SERVICES USE CASE

Technological impact

For the Security Guarantees and Risk Analysis pillar of Industry 4.0, as it has been defined in the EVOLVED-5G project, 5G is expected to enhance connectivity capabilities within a factory, due to the 5G NPN deployments and to bring advanced security capabilities, especially for the mobile devices of the employes. It is also important to notice that the 5G NPN deployments bring an unpreceded technical advantage for the IT administration in Factory, and this is the capability to combine the existing fixed or wireless infrastructure with the mobile network devices in the area, under a unified and secure control system. To explore this impact FOGUS designed and developed a 5G Security Information and Event Management System (SIEM), by taking advantage of the 5G openness concept and the EVOLVED-5G facility on network applications lifecycle support.

Financial impact

The financial impact of 5G and cybersecurity technologies in the Security Guarantees and Risk Analysis pillar of Industry 4.0, is yet to be unveiled. However, the signs are very optimistic due to the following reasons. First, the API-based approach followed from 5G openness is already a well perceived approach in industry having significant financial impact so far in the context of Telecom API market. Second, openAPI project (TMForum) and the microservice architecture have attracted high interest for many stakeholders, an interest that is expected to affect financial indicators as well. Finally, already the EC has targeted the 20% of the 5G research budget towards SMEs and Start-ups. This is a clear message that the 5G economy is going to be fueled from a wider set of stakeholders, since multiple SMEs will get the required knowledge and will make their products more 5G-enabled.

4.3.3.3 INQBIT USE CASE

Technological Impact

5G and future wireless technologies have the potential to bring significant benefits to society, such as faster internet speeds and more connected devices. However, with these benefits come new security challenges. Security guarantees and risk analysis are crucial in ensuring that these technologies are secure and can be trusted by individuals and organizations. Security guarantees refer to the measures and technologies put in place to protect against potential security threats. For example, 5G networks use advanced encryption and authentication methods to secure communication between devices. Additionally, risk analysis is used to identify potential security vulnerabilities and assess the potential impact of a security breach. Withing EVOLVED-5G such security measures are implemented as Network Apps to protect personal and sensitive information and ensure the integrity of communications and data transmission. Without these guarantees and risk analysis, individuals and organizations may be hesitant to adopt and utilize 5G and future technologies, hindering their potential impact. Towards this end IQB is developing Network Apps to enhance state-of-the-art CAPIF protocol with novel authentication and authorization schemes, allowing single-sign on of vertical applications to mobile operators seamlessly. Hence IQB is promoting technological advancement from the cybersecurity word to the 5G/6G ecosystem, to ensure the secure and trustworthy of 5G and beyond technology, it's crucial for protecting personal and sensitive information, and ensuring the integrity of communications and data transmission, and for the full adoption of the technology by individuals and organizations.

Financial impact

It is anticipated that cybersecurity in Industry 4.0 and the Internet of Things (IoT) would have a substantial financial effect. Industry 4.0 refers to the incorporation of cutting-edge technology, such as artificial intelligence, the Internet of Things, and cloud computing, into manufacturing and other businesses. This integration is anticipated to boost efficiency and production, but it also introduces new cyber-attack risks. Cybercriminals are increasingly targeting IoT devices because they frequently have inadequate security measures and are connected to networks containing sensitive data. A successful assault on an IoT device can result in data breaches, money loss, and reputational harm to an organization. IQB invests substantially in technology to reduce these threats, including network security, endpoint protection, and threat intelligence solutions. Complying with legislation and standards such as the General Data Protection Regulation (GDPR) and the Cybersecurity Information Sharing Act (CISA) can assist to safeguard against cyber-attacks (CISA). In conclusion, the financial effect of cybersecurity in Industry 4.0 and IoT is a cost for organizations to safeguard their infrastructures and data, as well as an opportunity for the suppliers of cybersecurity solutions to expand their company and income.

4.3.4 Production Line Infrastructure

4.3.4.1 PAL ROBOTICS USE CASE

Technological Impact

To function efficiently, robots need to exchange huge volumes of data with off-board systems, sensors, the workforce, and the cloud, especially in industrial setups. Obviously, with more robots working together at the same time, some limitations with the current network system can arise. In particular, with network issues from the point of view of:

- Going beyond the limitation of the data traffic able to circulate on the current network settings
- The need for access to more computational power on the internet, clouds or on other machines to share the computational load, especially for deep learning algorithms and shared control, needed to improve performance
- Possibility to teleoperate and monitor the robot from distance
- Being able to make a better check of security with the system

Current wireless protocols cannot fully support such information exchange, either in terms of latency, bandwidth, or reliability. To achieve this, 5G enables customer Network App to configure the 5G radio network with new optimal parameters to carry out required reliable high-bandwidth low-latency 5G connection ensuring if QoS is guaranteed or not.

Financial Impact

The warehouse and logistics sector has experienced unprecedented growth in recent years, and this has generated increased demand for robotized warehouse and inventory management systems. In addition, the continued growth of e-commerce is expected to contribute to the demand for warehouse and logistics robotics. Robotics and automation are rapidly becoming key success factors in the manufacturing sector. From autonomous mobile robots and automatic storage systems to track & trace technologies and advanced supply chain software, they are a game-changer enabling increasingly speedy, safe and error-free distribution, shorter time to market and ultimately lower costs for businesses and consumers. The rapid growth of these sectors brings the need to have not only one robot working in the corresponding facility but to have more robots collaborating in terms of fleet management. Network Apps explore the improvements introduced by the adoption of 5G technologies for more efficient communication flow, both in terms of speed and bandwidth, from the cloud and to the robot, guaranteeing a specific QoS. In this context, the 5G technologies together with the mobile industrial robots are expected to have a direct financial impact as they will:

- Increase factory productivity thanks to the more efficient communication flow
- Save time
- Precise deliveries
- Automate monotonous, repetitive, and often injury-prone manual material transportation
- Optimize production operations
- Fast ROI
- Off the shelf applications
- Easy to deploy, flexible task modification
- Increase in competitiveness, productivity improvement and reduction of labor costs mostly due to operational excellence and minimizing of waste and minimizing mistakes
- Non-invasive solution within the production line, which allows sharing the person-robot space

4.3.4.2 UMS USE CASE

Technological Impact

Integration with existing warehouse management systems needs flexibility in order to make robotic solutions effectively deployable in a variety of sectors. With traditional network options and existent applications, data and instructions transfer mode could limit the capacity of robot to execute different tasks effectively; thanks to the synergy of Network App and 5G networks, accurate information is instantly transmitted, allowing operators to receive real-time inventory updates. Inventory management and fleet operations become significantly easier. Using 5G networks makes it much easier to designate optimal storage spaces for items such as inventory.

Financial Impact

Robot installations hit a new record level after a strong recovery from the pandemic year, with new industrial robot units increasing by 31% up to 517,000 (IFR, World Robotics Report 2022[8]), the highest in history. With this increase comes fragmentation of robotic systems, with collisions and inefficiencies, and 5G localisation can offer many benefits for robotics in indoor logistics environments. By improving the accuracy and precision of location tracking, 5G can help robots navigate complex environments and avoid collisions in more centralized systems. Ultimately, 5G localization produces direct and indirect cost savings and increased profitability through:

- A reduced risk in the downtime of robotic operations
- Optimisation of individual robots
- Optimisation of logistics processes through robotic teams
- A reduced risk of workplace accidents
- Future scalability through adding new robots “on demand”
- Flexibility in the modification of robotic processes
- Increased market competitiveness due to the process flexibility, and ability for facilities to change more easily

[8] https://ifr.org/downloads/press2018/2022_WR_extended_version.pdf

5 MAPPING EVOLVED-5G STAKEHOLDERS TO 5G ECOSYSTEM

As it has been clarified in WP2 deliverables of the project, the set of stakeholders related with the EVOLVED-5G framework comprises the entities that subsist independently to the existence of the EVOLVED-5G ecosystem but at the same time they are identified as candidates for assuming a role in it. That is, they are actors pursuing a goal that can be fulfilled by the EVOLVED-5G framework or providing a service that affects the design of the EVOLVED-5G framework. These stakeholders were taken into account for collecting the business and user requirements of the EVOLVED-5G platform. The set of stakeholders is not exclusive but can potentially be augmented by additional entities of the 5G ecosystem, which might develop interest for Network Apps and their development process in the future. In this direction we have mapped the stakeholders related with the EVOLVED-5G framework to the ongoing work of 5G-PPP and SNS JU, within the Vision and Societal Challenges – VSC WG (and specifically within the sub-group Business Validation Models and Ecosystem - BVME). In that WG the 5G stakeholder and an accompanying glossary have been defined[9]. In the table below we have applied a mapping of the main categories of 5G stakeholders to the EVOLVED-5G ones. As it can be observed the EVOLVED-5G stakeholders are a kind of specification to the 5G ones (Table 2).

5G Provisioning Stakeholders (by 5G-PPP)		EVOLVED-5G Stakeholders
5G Industry and Research	Connectivity Providers	5G network providers
	Technology Providers and Developers	5G HW/SW providers
	SMEs	(Industry 4.0) SMEs
	Research	Academia
5G Complementary Industry		Virtualization platform providers
Policy makers and Financing Bodies		*No further specification*
Standards and Open Source Organizations		*No further specification*
5G-related Organisations - associations		Telecom certification authorities

Table 2 Mapping 5G-PPP stakeholders of EVOLVED-5G stakeholders

We follow the work of BVME WG and we contribute where possible towards: i) the update of the 5G provisioning Stakeholders, ii) the identification of the 5G use case Stakeholders, and iii) the introduction of the 5G-PPP Enablers and Facilitators that affect the interaction between provisioning and use case stakeholders. More updates will be included in the next deliverable of T6.3.

Some initial comments have been provided as part of the activity in 5G-PPP for defining the stakeholders of 5G provisioning and use case ecosystems. Based on the projects analysis:

- Policy & Financing Bodies need separate categories because they have distinct roles in the 5G operations. Policy bodies (e.g., NRA's, BEREC) play a pivotal role in the 5G market by setting regulations and conducting policies. On the other hand, Financing bodies provide financial means for 5G services, infrastructure, and network operations.
- Splitting 5G Industry and Research will allow for the creation of two separate categories, wherein *"5G-related Organizations"* will include both industry and research organizations that are actively involved in the development and implementation of 5G services and networks
- SMEs and Startups are not in line with the role-based approach of the rest of the ecosystem, which is why they should be removed from the categorization. SMEs and Startups should be accounted for in a separate category, such as *"Innovative 5G Companies"*, which will highlight the contributions of these stakeholders to the 5G ecosystem.

Another initiative that will help us to identify and engage the industry is our accelerator program. The Evolved-5G Acceleration Program is a five-month blended learning support program designed to support the growth

[9] https://5g-ppp.eu/revised-5g-ppp-stakeholders-picture-and-glossary/

and development of SMEs, entrepreneurs and developers in the 5G industry. This program will provide participants with immersive training, master classes in entrepreneurship, live case studies, business model innovation workshops, funding and finance guidance, networking and action plan development. In addition, participants will receive virtual mentorship and coaching, as well as access to online dialogue functions used to exchange ideas and experiences.

This program will help to engage SMEs, entrepreneurs and developers in the 5G industry by providing them the necessary training, resources, guidance and support required for them to be successful. Networking opportunities with other SMEs, big companies and experts in the 5G is also another important element that the Acceleration program will offer to its participants.

6 SURVEY ON NETWORK APP RESEARCH AND MARKET POTENTIAL

6.1 SCOPE AND DEVELOPMENT APPROACH

The EVOLVED-5G online survey has been created and delivered in the context of Task 6.3 of EVOLVED-5G project. In Figure 19, the steps of the deployment of this survey are shown. The initial step was to declare the objectives of this survey. The first goal of this survey was to outline the view of the responders about embracing the exploitation of mobile network openness. As mobile network openness, it is defined the provisioning of common/standardized APIs from the network to third parties for enabling secure interaction with network nodes or functionality. Additionally, the second goal of this survey was to unveil business and technological aspects that are related to establishing an ecosystem around the development of Network Applications. These applications are third party ones which interact with a mobile network to provide network or vertical oriented services. In principle, they can assist and enhance either the network operation and management process or a vertical application.

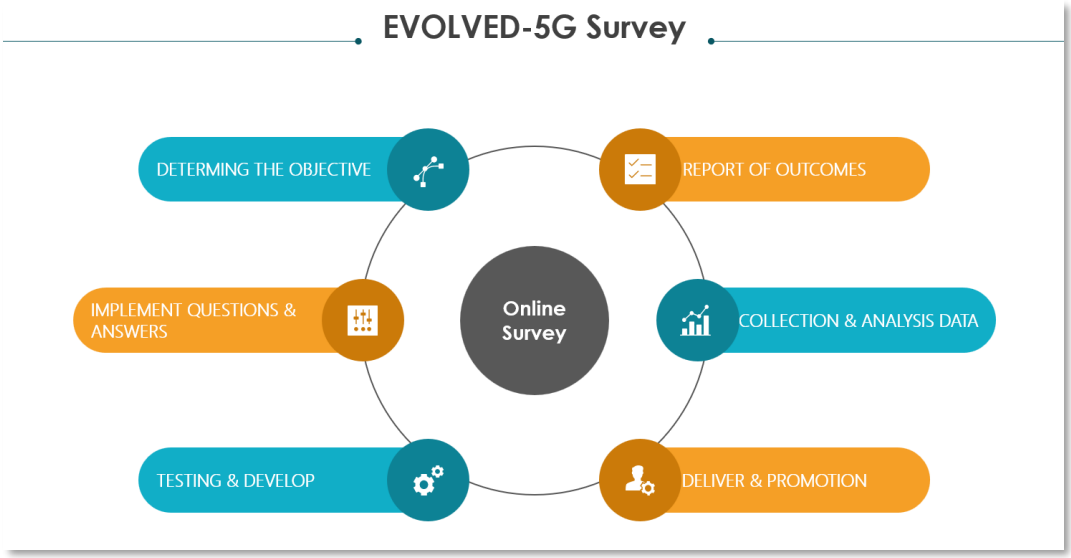


Figure 19. Steps of development of the online survey

Having set the general objectives/goals, we worked on defining short, focused and relevant questions which could lead to better quality and quantity of responses. Also, it was important to identify the most likely answers, so the filling out of the online survey could be easier and quicker for the responder. The list of questions and the potential answers are analyzed later in this section.

Having done the above steps, the following one was the development of the survey by choosing the right platform and tool, providing where needed configurations and metadata to assist the reader/responder. The structure of the online survey had to be clear, easy to filled out and understandable. We introduced a main page with some information about the goal of the survey, the duration and a disclaimer about the personal data which are required, such as the company email of the responder. Then the first section of the survey was about the profile of the responder. The second section includes questions about Network Applications, for example how challenging from the technical and financial perspective is to adopt the mobile network openness, the main advantage of it etc. The survey, in total, contains 10 questions, which are all required for completing the survey. Together with some questions we provide definitions of technological terms, so the reader/responder can have all the necessary information to answer.

A testing and validation process was followed to make sure that the responder wouldn't face any challenge or problem while completing the survey. For this process we had two rounds of questions and answers checking

by the consortium, and a pre-publication phase where the survey was available to check potential technical problems, or mistakes in the logic followed (order of questions, type of answers, etc.).

The next step was the promotion of the survey to the partners of the potential responders, including the 5G-PPP community. The EVOLVED-5G social media has been used to accomplish this task. Targeted emails and posts were used as well. Also, in the context of Acceleration Program set by WP6 of the project, the applicants of the program were kindly asked to fill out the online survey.

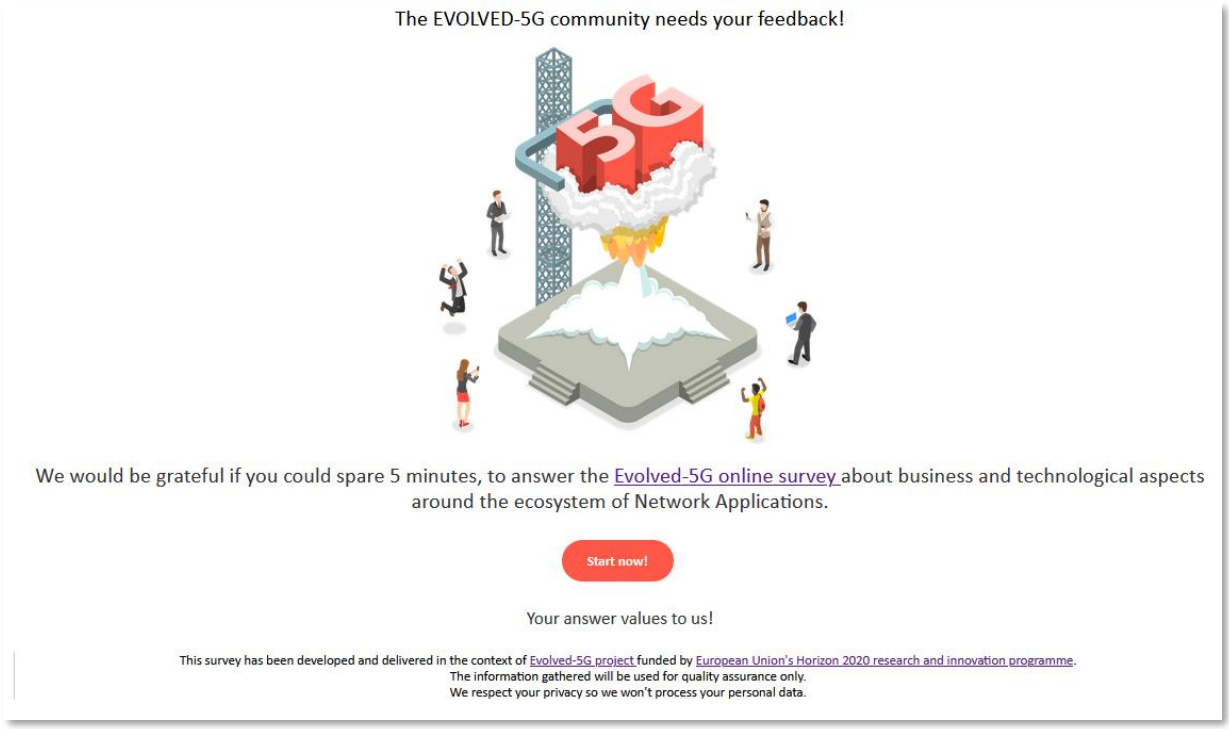


Figure 20. Example of Email body, sent for attracting responders

Figure 21. Posts on social media of EVOLVED-5G

One of the last steps was to collect and analyze the data. Later in this section we provide this analysis. For each question, outcomes and insights have been highlighted. As part of the analysis, was the creation of charts, diagrams, graphs and infographics which contribute to the visualization of the results.

6.2 Structure Of The Online Survey

The online survey consists of the home page and two different sections as it has been described above. In home page, the purpose of this survey is written on and some information about the required time and the personal data that have to be provided. These sensitive data are not processed but they are exclusively collected for quality assurance reasons.

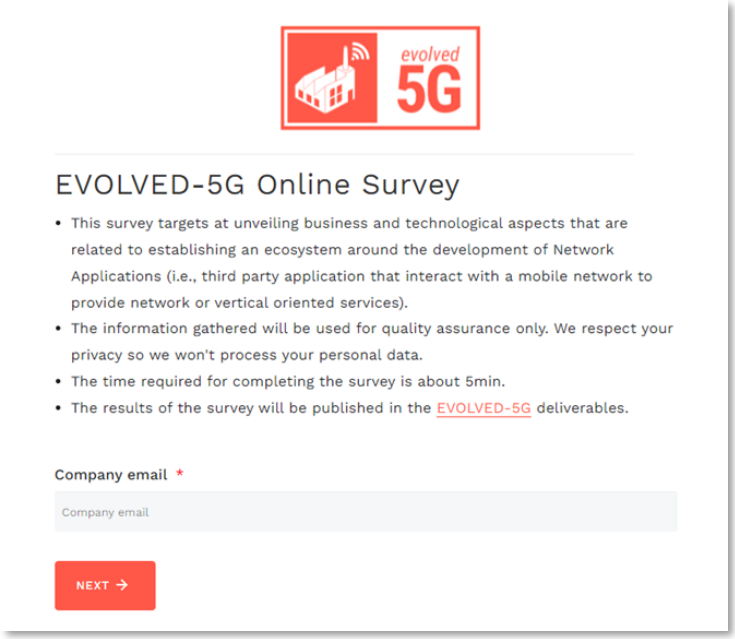


Figure 22. Home/Initial page of the EVOLVED-5G online survey

In the first section, the questions are about the profile of the responder. More specifically, the first question is about the institution where the replier works. The possible answers are:

- Hardware (HW) or Software (SW) provider for the telecom domain
- Hardware (HW) or Software (SW) Certification authority/organization
- Virtualization/Cloud platform provider
- Network provider (e.g., MNO or experimentation network owner)
- Vertical service provider -big industries
- Vertical service provider (e.g., SME, Vertical and App development companies)
- Education, Research, Training or Business acceleration centers
- Other

The second question is about the role which the responder has in his/her working environment. The options are the above:

- Manager/decision maker (e.g., people in charge of the business strategy)
- Solution Architect/Senior engineer
- Admin/technical staff of a commercial or experimental network
- Admin/technical staff of a virtualization/cloud platform
- Software developer (e.g., developer of Mobile or Network Applications)

- Experimenter/tester (conduction of verification, validation or certification tests)
- End-user/ service consumers (e.g., end user of a 5G device)

The last question of this section focuses on participation in related projects from the call H2020-ICT-41-2020 (5G-PPP phase 3.6). The answers are:

- YES, and also in project(s) from the call H2020-ICT-41-2020 (5G-PPP phase 3.6)
- YES, but not in one from the call H2020-ICT-41-2020 (5G-PPP phase 3.6)
- NO

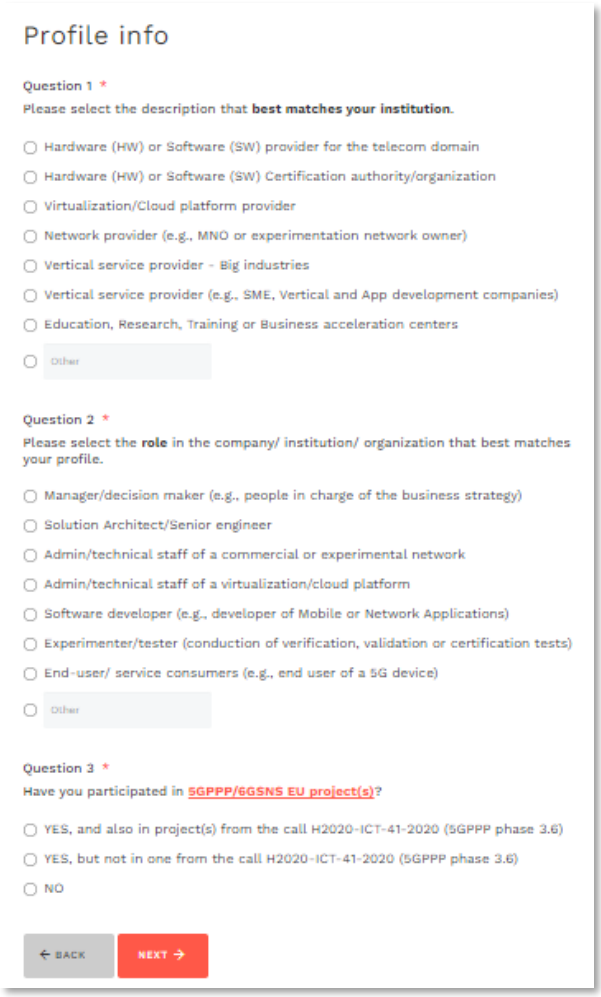


Figure 23. Questions for the responders' profile in the EVOLVED-5G online survey

In the second section, the questions target on Network Applications and the contingent advantages of them. In particular, the first and the second question focus on how challenging can be from financial and technical perspective respectively, for the responder's business, the adoption of the exploitation of mobile network openness. Both of these questions have as answer the options of the above scale:

- Extremely challenging
- Very challenging
- Moderately challenging
- Slightly challenging
- Not at all challenging

The next question is about the main advantage that can be achieved by the openness of a mobile network for potential interaction with third parties. The recommended answers are:

- Better performance of my service/application
- Better management of the resources used for offering my service/application
- Potential to upgrade my services by adding new features
- Potential to develop new innovative services
- No advantage/gain is foreseen
- Other

The fourth question is about how likely is to achieve some advantages by using Network Apps. The responder can choose as answer from the below options.

- Very unlikely
- Unlikely
- Neutral
- Likely
- Very likely

The next question is for the evaluation of the potential of a Network App ecosystem. This refers to the business and technological ecosystem that emerges from the development of Network Apps. It can include any type of facility that supports the development, testing and hosting of the Network Apps, publicly available Network Apps (e.g., through a Marketplace), and the Stakeholders that participate in the Network App development, testing and business exploitation.

- The Network App ecosystem will affect our business in next decade
- The Network App ecosystem will affect our business within the next 5 years
- The Network App ecosystem will have low or no impact to our business
- Other

Continuing to the sixth question, the responder should take into consideration his/her working environment and choose the initial step for reaping the benefits of the Network App ecosystem by the following list.

- We would invest in software development
- We would invest in the deployment of 5G private networks
- We would invest in the collaboration among the involved stakeholders
- We see some benefit, but we would not invest on any direction
- We see no benefits of the Network App ecosystem
- Other

In the last question, regarding of the market where his/her business belongs, the replier, has to select the aspects that are going to affect the most the economic growth of Network Apps ecosystem.

- The API-based programming and the development of standard/common APIs
- The growth of open-source projects for 3rd party network optimizations
- The introduction of analytics in mobile networks (enabling AI services)
- The wider offering of open infrastructures for Network App lifecycle support
- The development and proliferation of related Network App marketplaces
- The allocation of EU funding for research in that direction
- Other

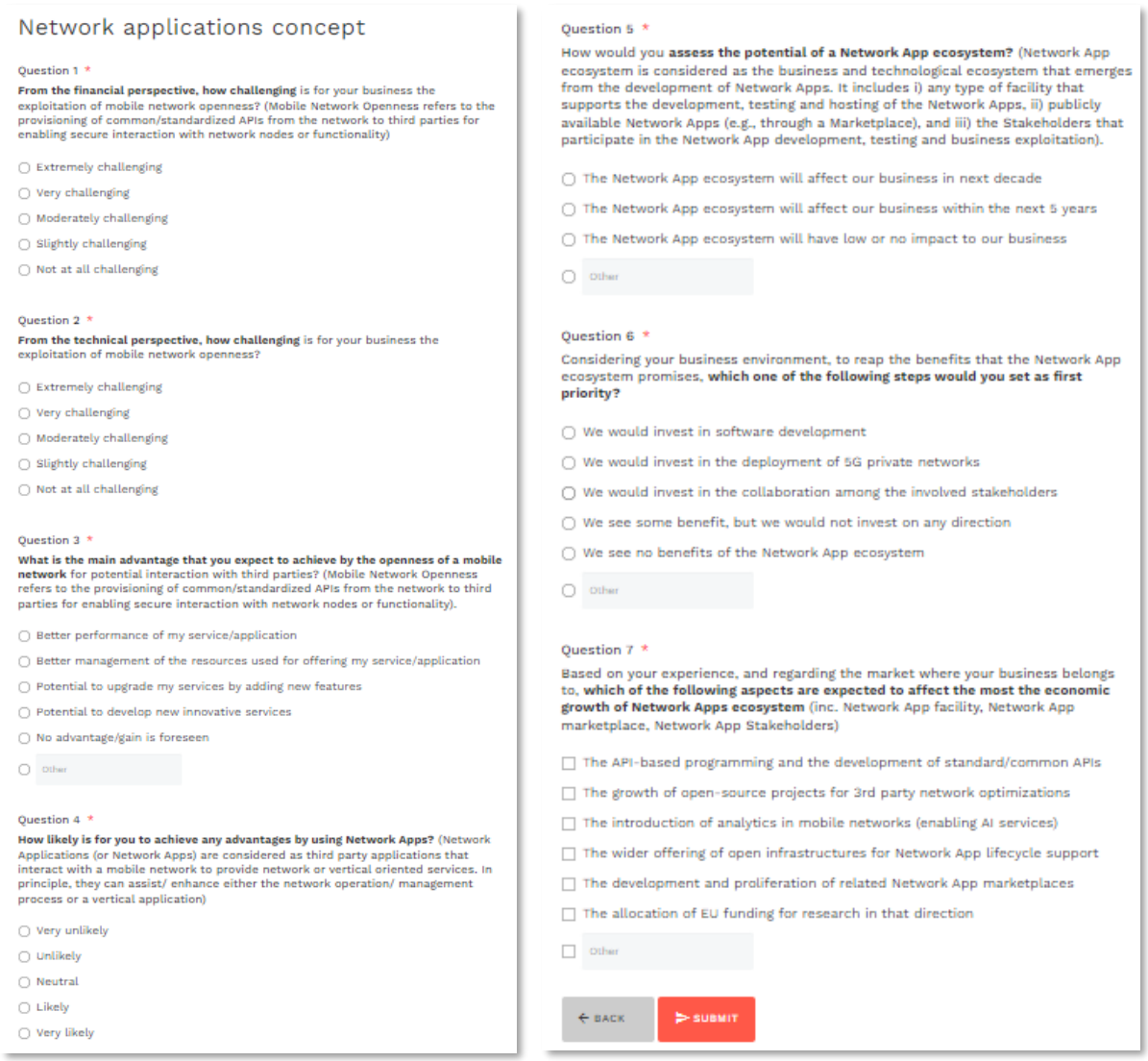


Figure 24. Main set of questions of the EVOLVED-5G online survey

6.3 Summary And Outcomes

The potential of private 5G networks (5G-NPN) and specifically their interaction with over-the-top applications is quite high and yet to be unveiled. From our survey, it is also clear that 5G-NPN can be very beneficial for vertical industries at technical and financial level. However, as also indicated in the survey, the adoption and deployment of 5G NPN, may have some obstacles and challenges, since those networks disrupt the way that mobile networks were provisioned so far (target private deployments, use higher spectrum bands, etc.). Another outcome from our online survey is the optimistic view that the responders have about the exploitation of the mobile openness and the concept of Network apps. It is encouraging that most of them do think that there are lot of advantages, and they expect some kind of impact on their businesses in the next 5 years. This argument is further boosted by the fact that the majority of the responders are decision makers and managers, so they are in charge and in a place where they can take initiatives and be creative. From the technical perspective the use of standardized APIs is a well-perceived choice, meaning that the EVOLVED-5G approach seems to be in the right direction for long term exploitation. Finally, a high percentage of the responders require more financial support from the EC in the concept and believe that AI and open sourcing are critical factors for the success of the Network app ecosystem. Figure 25 below summarizes the major response of each question that composed the EVOLVED-5G online survey.

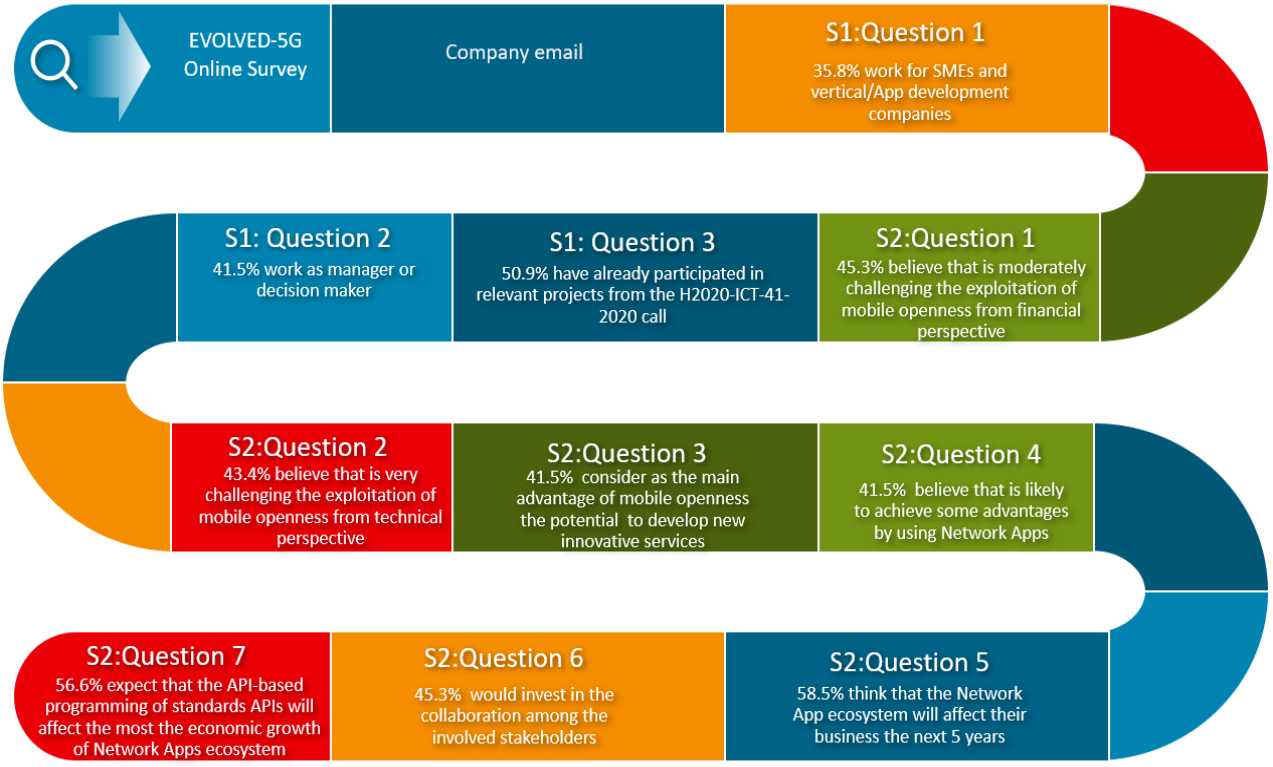


Figure 25. Indicating the major response per question of the EVOLVED-5G online survey

6.3.1 Responders' synthesis

More than 50 individual responses received, representing different profiles and stakeholders that belong to four major categories, namely, research centers, telco platform providers, SMEs, and vendors (HW and SW providers). More precisely, 35.8% of the responders were people working for vertical service providers, such as SMEs and vertical and App development companies. The second most dominant answer was by 18.9%, from people working in education, research, training or business acceleration centers. In the third place we have two equal voted answers by 17%, namely Network providers, such as MNO or experimentation network owner, and hardware or software providers for the telecommunication domain. The rest of the responders were distributed among stakeholders such as consultancy, R&I, independent test labs, and SME- network test and measurements solution provider.

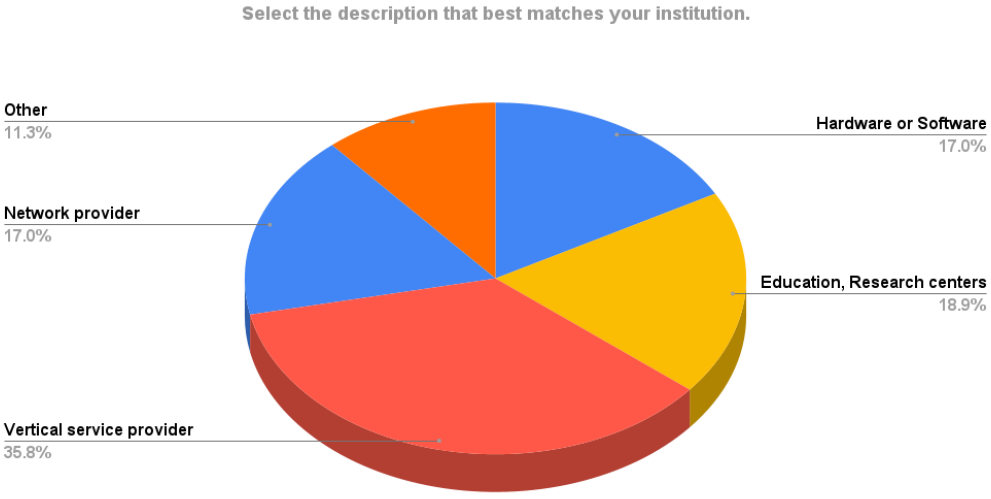


Figure 26. Synthesis of the institutions represented by the responders

Targeting on the role of the responders in their institutions (second question in the survey), the majority of the responders (41.5%) work as managers or decision makers, which means that they are people in charge of the business strategy. By 18.9% of responders chose, that they are working as solution architect or Senior engineer. The next, more selected, answer was the Software developer (of Mobile or Network Apps) by 17%. And lastly, 5.7% of them are end-users and service consumers, and the rest of them added their own answers. The supplementary ones were: Consultant, Reacher scientist, R&D manager, R&D director, R&D project coordinator, Professor and Technician in instrumentation and measures. On the other hand, there were some answers which hadn't been selected at all, such as Admin or technical staff of a commercial or experimental network, Admin or technical staff of a virtualization/cloud platform and Experimenter or tester who focus on conduction of verification, validation or certification tests.

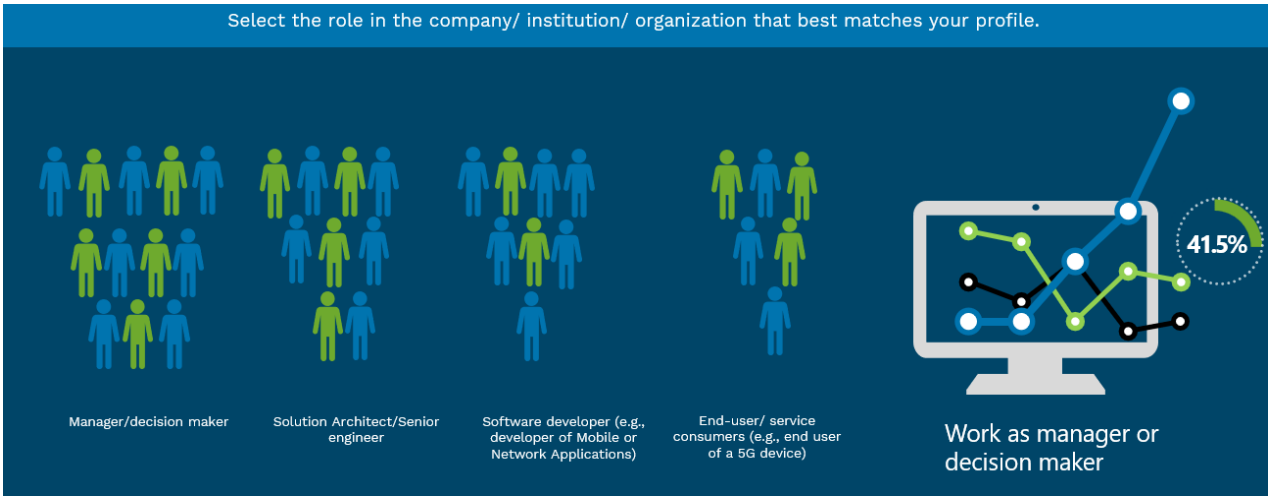


Figure 27. Responders profile

6.3.2 Responders' familiarity

The third question of the survey (and the last from the first section) was targeted to the level of familiarization of the responders with the concept of network applications. Since this concept has been defined and studied for the very first time in the projects of the call H2020-ICT-41-2020 (5G-PPP phase 3.6), the question was directed to the past participation of projects of that call. Basing on the results, 50% of the responders had already a kind of knowledge of the concept. The sample of the responders also included a percentage of 35% with people that had no participation in 5G-PPP EU projects. This is an interesting insight the implies that the results are not biased.

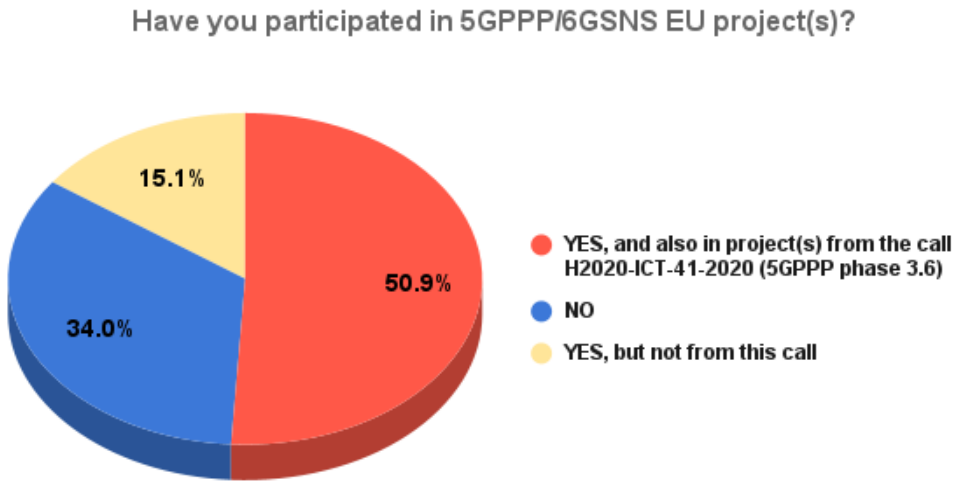


Figure 28. Part participation of the responders in related EU projects

6.3.3 Analysis of the responses

Moving on to the second section of this survey, which focuses on Network Application related questions, in the first one, 24 out of 53 repliers- almost half of the total ones- find the exploitation of mobile network openness moderately challenging in financial way. In the scale of the existing answers, it is in the middle which can be construed as a possible but with obstacles scenario. On the other hand, 19 responders think that this exploitation can be very challenging. As it is shown in the above diagram, 4 of the participants don't see any obstacle to this scenario and 3 of them consider it sightly challenging. Last but not least, the final 3 responders consider that this attempt is extremely challenging, from financial perspective.

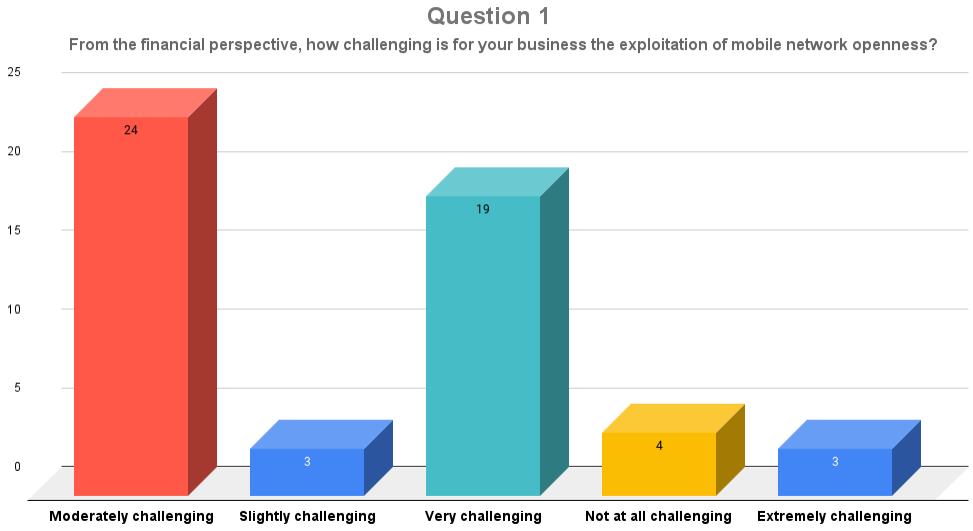


Figure 29. Openness and Network App ecosystem - Question 1

Taking into consideration the same question but from a technical perspective the result changes. More specifically, most of the responders, 23 of them, believe that the exploitation of the network openness in their business can be very challenging. The second most dominant answer- 21 out of 53 people have chosen it - is moderately challenging. The following one is extremely challenging and lastly, the slightly one. It is interesting to notice that none of the repliers think that this exploitation can be considered as not at all challenging which means that everyone believes that there are some challenges in this venture.

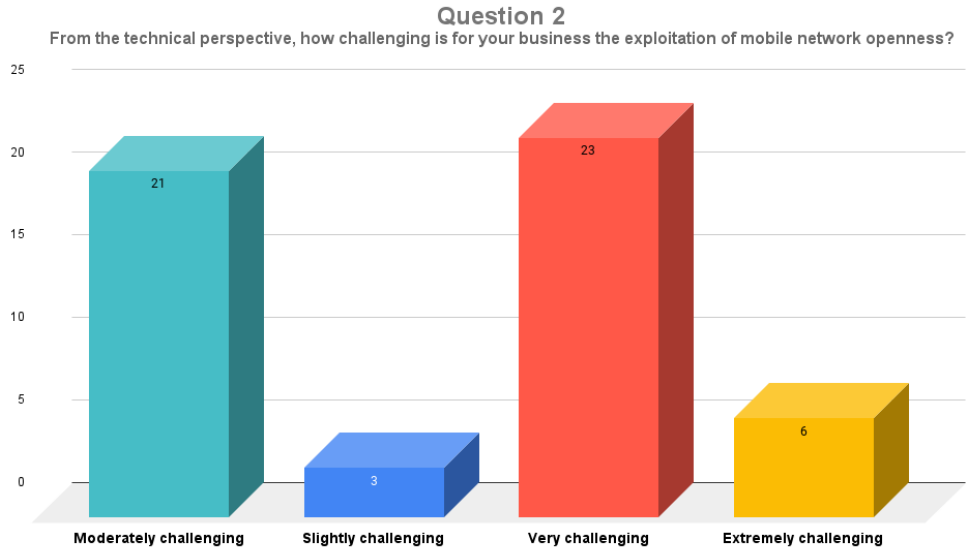


Figure 30. Openness and Network App ecosystem - Question 2

Based on the above two questions and their outcomes, it is clear that there is some allowance to take this decision and make this exploitation happen in the first case. Most of the responders have a positive attitude to this scenario when it is examined in a financial way. In the second question, the majority finds this attempt very challenging, from a technical perspective. It could be an interesting topic for research, to examine further and specify the challenges and the obstacles which could be accrued in the process of the exploitation of mobile openness.

The third question focuses on the main advantage of the openness of a mobile network for potential interaction with third parties. Based on the most voted answer- by 41.5%, that advantage is the potential to develop new innovative services. Then, 28.3% of the responders believe that they are going to have better management of the resources which are used for offering existing services and applications. The 17% sees potential to upgrade the services by adding new features and the 7.5% of the repliers believe that the performance can be better of their service and app. The rest of them, either have answered that there isn't any advantage and gain by this, or they do consider that this can be beneficial for innovative service development or even they think that it can be helpful to establishing an open market for QA/certifications of standards-based 5G core and mobile network components.

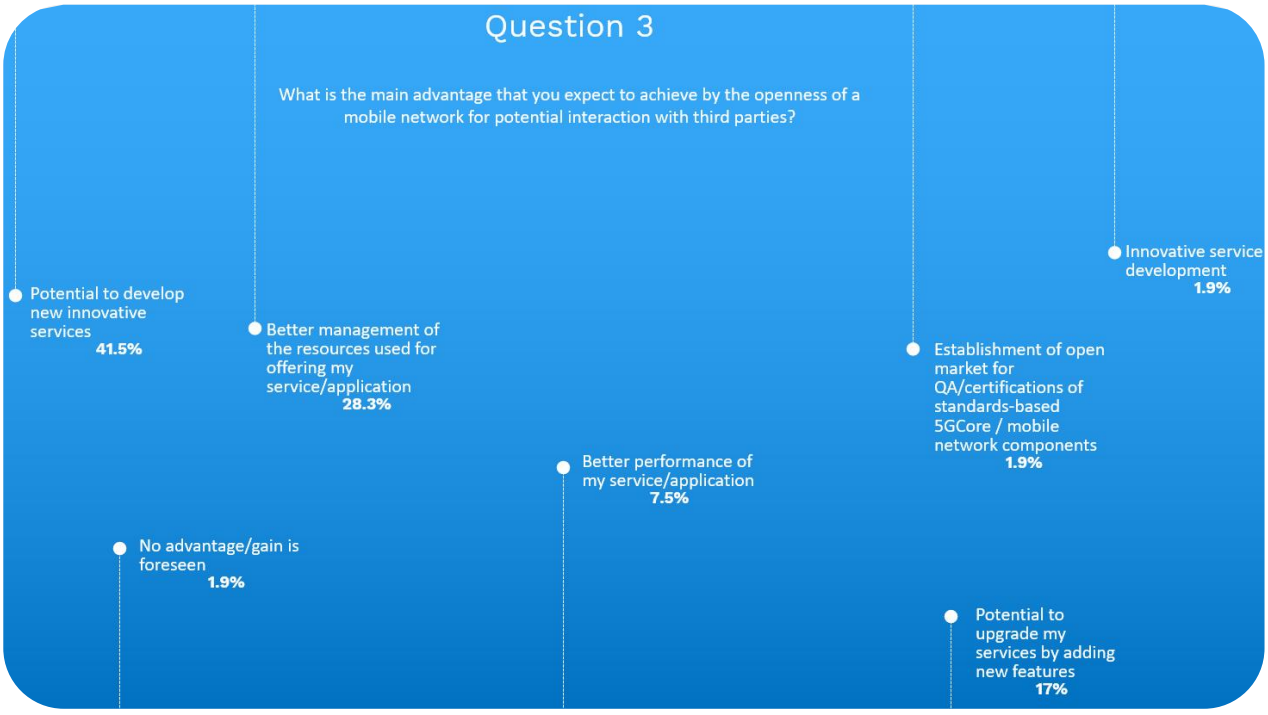


Figure 31. Openness and Network App ecosystem - Question 3

By declaring the possible advantages, the fourth question comes to find out how likely it is to achieve some advantages by using Network apps. Major part of the participants feel that it is likely to achieve some advantages by using a Network app. Specifically, 15 out of 53 people maintain that this is very likely. Moving on to those who are neutral, and then to those who don't find this likely at all. The general feeling of the participants is positive and optimistic. Only 8 of 53 participants found this idea unlike or very unlike.

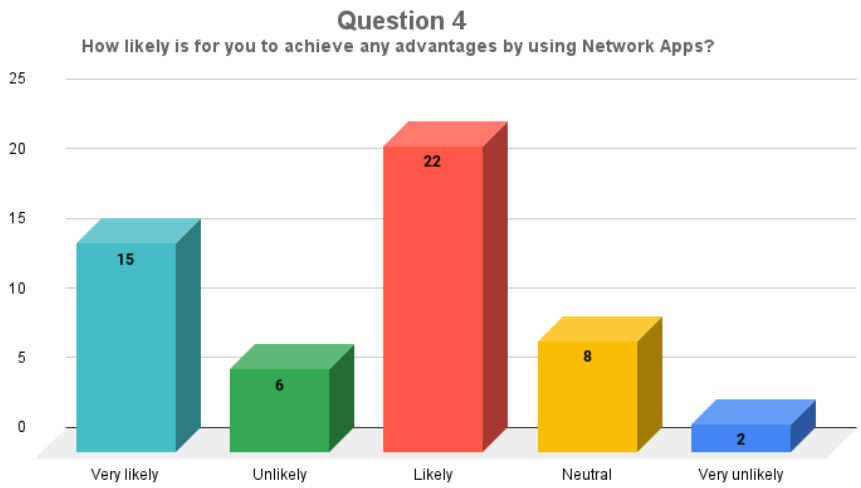


Figure 32. Openness and Network App ecosystem - Question 4

In the fifth question, 58.5% of the responders have confidence in the idea that the Network App ecosystem will affect their business in the next 5 years. In longer period of time, within the next decade, 32.1% believe that this can be possible. On the other hand, 7.5% of the participants have added as an answer that they see a low or even no impact in their business. Lastly, only 1.9% think that maybe the potential benefits are not visible yet. Overall, once again, the majority has a more optimistic approach and feeling.

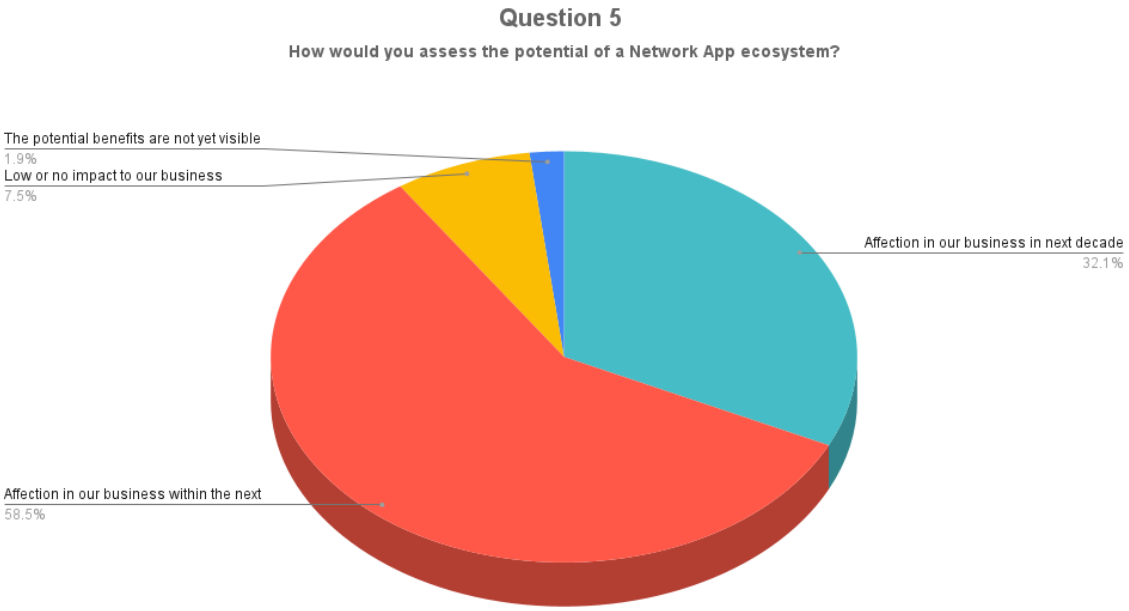


Figure 33. Openness and Network App ecosystem - Question 5

The following question is about the initial steps which have to be taken for reaping the benefits of a Network App ecosystem. Almost half of the repliers would invest in the collaboration among the stakeholders involved. That could be a quicker and smoother way to embrace this ecosystem while the collaborators may have the experience, the knowledge and the resources which are needed. In second place comes the answer of investing in software development by 28.3%. Then the choice of investing in the deployment of 5G private networks, comes in third place by 13.2%.

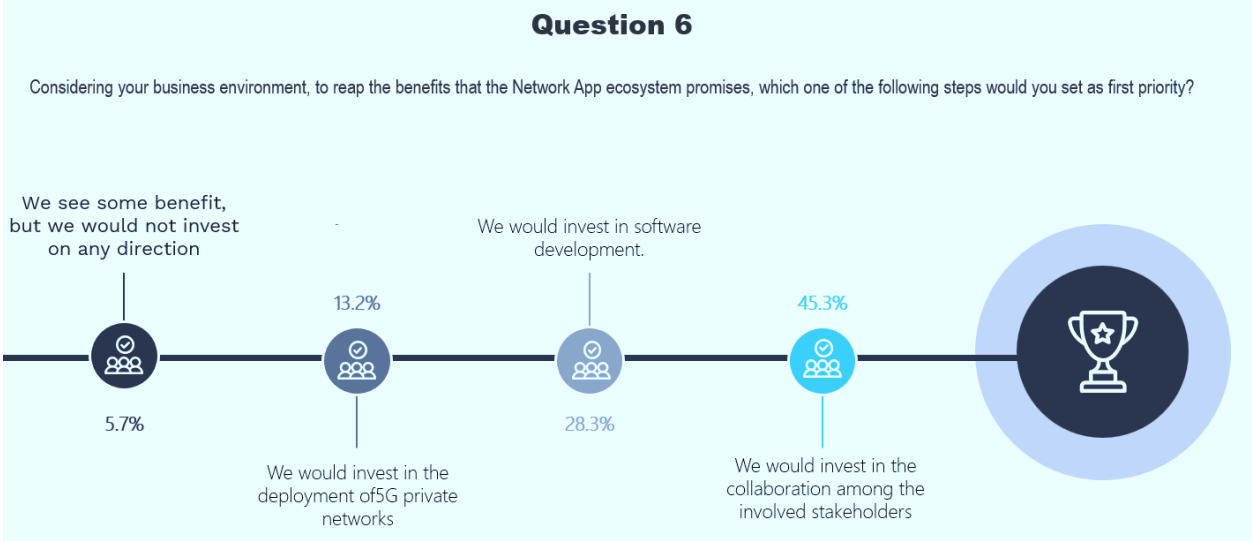


Figure 34. Openness and Network App ecosystem - Question 6

The last question in the survey is about the aspects which are expected to affect the most the economic growth of Network App ecosystems. The greater part of the responders has chosen API-based programming and the development of standard and common APIs. As it can be shown from the chart in Figure 35, the second most voted answer is the allocation of EU funding for research in that direction. Then, the introduction of analytics in mobile networks, enabling AI services, follows by 33.3% and the wider offering of open infrastructure for Network App lifecycle support. The next top selected answers are the growth of open-source projects for 3rd party network optimizations, development and proliferation of related Network App marketplaces and the last is more utilization of slicing.

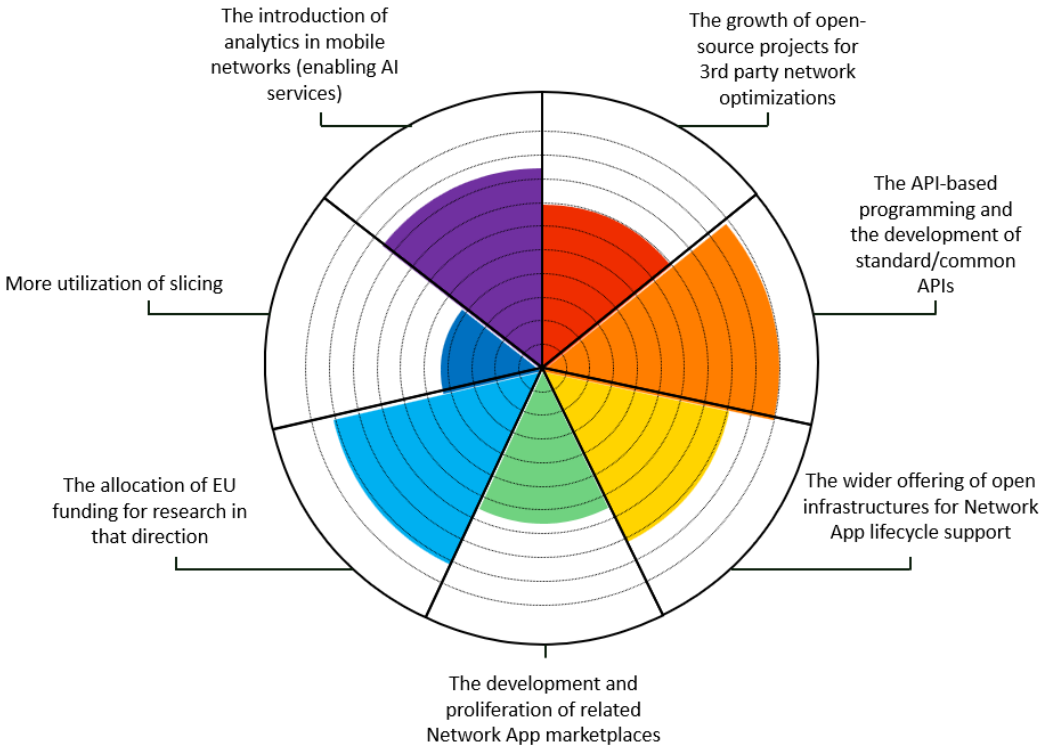


Figure 35. Openness and Network App ecosystem - Question 7

7 REFERENCES

[1] M. Mas, J. Fernández de Guevara, J.C. Robledo, M. Cardona, R. Righi, S. Samoili, M. Vazquez-Prada Baillet, "An Analysis of ICT R&D in the EU and Beyond," European Commission, 2020.

[2] W. Chow, T. Tandetzki, R. Meakin, "pwc," pwc, [Online]. Available: https://www.pwc.com/gx/en/industries/technology/publications/economic-impact-5g.html. [Accessed 3 October 2022].

[3] "digital-strategy.ec.europa.eu," European Commission, 16 September 2022. [Online]. Available: https://digital-strategy.ec.europa.eu/en/policies/desi. [Accessed 3 October 2022].

[4] J. WANG, H. ROY, S. ALAM, T. RAO, S. AHSHRUP, W. MCCLUSKEY, "The impact of 5G on the European economy," Accenture Strategy, 2021.

[5] "European Commission," European Commission, 7 June 2022. [Online]. Available: https://digital-strategy.ec.europa.eu/en/policies/5g-action-plan#:~:text=The%205G%20Action%20Plan%20is,and%20businesses%20across%20the%20EU.&text=Very%20high%2Dcapacity%20networks%20like,225%20billion%20annually%20by%202025. [Accessed 4 October 2022].

[6] A. Turtelboom, F. Fornaroli, C. Ishik, N.E. Brokopp, P. Pesce, J. Bright, R. Gorajski, Z. Gullová, A. Latinov, N. Westphal, "European Court of Auditors," 2022. [Online]. Available: https://www.eca.europa.eu/Lists/ECADocuments/SR22_03/SR_Security-5G-networks_EN.pdf. [Accessed 4 October 2022].

[7] "GSMA," GSMA, 24 May 2022. [Online]. Available: https://www.gsma.com/membership/resources/the-mixed-picture-for-5g-in-europe/. [Accessed 4 October 2022].

[8] S. Pattheeuws, K. Karamanoğlu, J. Niebuhr, "strategy&Part of the PwC network," [Online]. Available: https://www.strategyand.pwc.com/de/en/industries/telco-tech/countering-the-threat-to-europes-5g-rollout/countering-the-threat-to-europes-5g-rollout.pdf. [Accessed 5 October 2022].

[9] Gadgets Now Bureau, "Gadgets Now by The Times of India," Gadgets Now by The Times of India, 23 June 2022. [Online]. Available: https://www.gadgetsnow.com/us/news/top-3-reasons-why-there-is-a-chip-shortage-right-now/articleshow/92412026.cms. [Accessed 6 October 2022].

[10] S. Kechiche, "OOKLA," OOKLA, 23 February 2022. [Online]. Available: https://www.ookla.com/articles/5g-europe-mapping-the-future-q1-2022. [Accessed 5 October 2022].

[11] "European Commission," European Commission, 8 February 2022. [Online]. Available: https://ec.europa.eu/commission/presscorner/detail/en/IP_22_729. [Accessed 25 September 2022].

[12] E. Chivot, R. Jorge-Ricart, "European Leadership Network," European Leadership Network, 10 September 2020. [Online]. Available: https://www.europeanleadershipnetwork.org/commentary/the-eus-approach-to-5g-and-the-reshaping-of-transatlantic-relations/. [Accessed 3 October 2022].

[13] "Vodafone," November 2021. [Online]. Available: https://www.vodafone.com/sites/default/files/2021-11/building-open-ran-ecosystem-europe.pdf. [Accessed 26 September 2022].

[14] "Orange," 18 November 2021. [Online]. Available: https://newsroom.orange.com/europe-urged-to-act-now-to-build-open-ran-ecosystem/?lang=en. [Accessed 24 September 2022].

[15] "European Commission," European Commission, 11 May 2022. [Online]. Available: https://ec.europa.eu/commission/presscorner/detail/en/ip_22_2881. [Accessed 3 October 2022].

[16] J. S. Walia, H. Hämmäinen, M. Matinmikko, "5G Micro-operators for the Future Campus: A Techno-economic Study".

[17] C. Bouras, A. Kollia, "Techno-Economic Analysis for Programmable Networks," pp. 2-19.

[18] F. Yaghoubi, M. Mahloo, L. Wosinska, P. Monti, F. Farias, I. C. W. A. Costa, J. Chen, "Techno-Economic Framework for 5G Transport Networks," IEEE Wireless Communications, October 2018.

[19] E. J. Oughton, K. Katsaros, F. Entezami, D. Kaleshi, J. Crowcroft, "An Open-Source Techno-Economic Assessment Framework for 5G Deployment," vol. 7, 2019.
[20] G. Smail, J. Weijia, "Techno-economic Analysis and Prediction for the Deployment of 5G Mobile Network".
[21] H. Frank, C. Colman-Meixner, K.D.R. Assis, S. Yan, D. Simeonidou, "Techno-Economic Analysis of 5G Non-Public Network Architectures," IEEE Access, vol. 10, 1 July 2022.
[22] P. Paglierani, I. Neokosmidis, T. Rokkas, C. Meani, K.M. Nasr, P.S. Khodashenas, "Techno-economic Analysis of 5G Immersive Media Services in Cloud Enabled Small Cell Networks: The Neutral Host Business Model".
[23] A. Jha, D. Saha, "Techno-Economic Analysis of 5G Deployment Scenarios involving Massive MIMO HetNets over mmWave: A Case Study on the US State of Texas," in 51st Hawaii International Conference on System Sciences, 2018.
[24] S.K. A. KUMAR, R. W. STEWART, D. CRAWFORD, S. CHAUDHARI, "Techno-Economic Study of 5G Network Slicing to Improve Rural Connectivity in India," IEEE ComSoc, vol. 2, 2021.
[25] I. A. Gedel, N. I. Nwulu, "Low Latency 5G Distributed Wireless Network Architecture: A Techno-Economic Comparison," inventions, vol. 6, no. Technologies Enabling Smart Grid in Distribution Networks and Microgrids 2.0, 2021.
[26] S. K. A. Kumar, E. J. Oughton, "Techno-Economic Assessment of 5G Infrastructure Sharing Business Models in Rural Areas," IEEE Access, vol. 4, 2016.
[27] M. Negreiro, "The EU digital decade: A new set of digital targets for 2030," European Parliamentary Research Service, 2021.
[28] P. Cohen, "RCRWirelessNews," RCRWirelessNews, 11 April 2022. [Online]. Available: https://www.rcrwireless.com/20220411/5g/what-are-non-public-networks-in-3gpp-parlance. [Accessed 4 October 2022].
[29] M. Dryjański, "Rimedo Labs," Rimedo Labs, 4 January 2021. [Online]. Available: https://rimedolabs.com/blog/private-5g-networks-technology-architecture-and-deployment/. [Accessed 4 October 2022].
[30] "ETSI," May 2022. [Online]. Available: https://www.etsi.org/deliver/etsi_ts/128500_128599/128557/17.00.00_60/ts_128557v170000p.pdf. [Accessed 4 October 2022].
[31] "Research and Markets," Research and Markets, April 2022. [Online]. Available: https://www.researchandmarkets.com/reports/5318371/private-5g-network-market-size-share-and-trends?utm_source=BW&utm_medium=PressRelease&utm_code=fm4755&utm_campaign=1707848+-+Global+Private+5G+Network+Market+Analysis+Report+2022%3a+A+%2436+Billion+Market. [Accessed 5 October 2022].
[32] "Grand View Research," [Online]. Available: https://www.grandviewresearch.com/industry-analysis/private-5g-network-market#:~:text=Report%20Overview,49.0%25%20from%202022%20to%202030 [Accessed 5 October 2022].
[33] P. Tomasi, "Omdia," Omdia, 2 August 2022. [Online]. Available: https://omdia.tech.informa.com/OM024483/LTE-and-5G-Private-Networks-Tracker--2Q22-Database. [Accessed 4 October 2022].
[34] C. Williams, "Nokia," Nokia, 12 May 2022. [Online]. Available: https://www.nokia.com/blog/the-state-of-the-private-wireless-market-2022-for-industry-40/. [Accessed 5 October 2022].
[35] GSMA Intelligence, 9/2022, “5G for the enterprise: headway, hurdles and the horizon for operators”, https://data.gsmaintelligence.com/research/research/research-2022/5g-for-the-enterprise-headway-hurdles-and-the-horizon-for-operators

[36] Hybrid Networks, https://www.gsma.com/iot/manufacturing/private-networks/hybrid-networks/
[37] GSMA 2022 Mobile Economy Report Europe (10/2022), https://www.gsma.com/mobileeconomy/europe/
[38] https://www.ericsson.com/en/news/2018/11/deutsche-telekom-and-ericsson-partner-to-provide-industry-solution-for-osram
[39] https://www.gsma.com/iot/manufacturing/benefits-use-case/mercedes-benz-5g-factory/
[40] Mobile Private Networks, Exploring the CSP Opportunity, https://inform.tmforum.org/research-and-analysis/reports/mobile-private-networks-exploring-the-csp-opportunity/
[41] D. Graham, "World Wide Technology," World Wide Technology, 30 November 2020. [Online]. Available: https://www.wwt.com/article/from-public-safety-to-richer-remote-education-five-use-cases-for-5g. [Accessed 6 October 2022].
[42] [Online]. Available: https://www.firstnet.gov/about. [Accessed 5 October 2022].
[43] "Nokia," Nokia, [Online]. Available: https://www.nokia.com/networks/industries/public-safety/. [Accessed 5 October 2022].
[44] "Nokia," Nokia, [Online]. Available: https://www.nokia.com/networks/private-wireless/airports/. [Accessed 5 October 2022].
[45] "Nokia," Nokia, [Online]. Available: https://www.nokia.com/networks/private-wireless/ports/. [Accessed 5 October 2022].
[46] "Nokia," Nokia, [Online]. Available: https://www.nokia.com/networks/industries/education/. [Accessed 5 October 2022].
[47] “AWS," AWS, [Online]. Available: https://aws.amazon.com/private5g/. [Accessed 6 October 2022].
[48] "Nokia," Nokia, [Online]. Available: https://www.nokia.com/networks/industries/smart-manufacturing/. [Accessed 5 October 2022].
[49] "Nokia," Nokia, [Online]. Available: https://www.nokia.com/networks/industries/mining/. [Accessed 5 October 2022].
[50] "Nokia," Nokia, [Online]. Available: https://www.nokia.com/networks/private-wireless/utilities/. [Accessed 5 October 2022].
[51] "Vodafone," Vodafone, 22 July 2021. [Online]. Available: https://www.vodafone.co.uk/newscentre/press-release/5g-for-uk-power-networks-world-first-smart-substation-trial/. [Accessed 6 October 2022].
[52] G. Wolf, "Energy Tech," Energy Tech, 10 March 2022. [Online]. Available: https://www.energytech.com/energy-efficiency/article/21235804/5g-and-the-grid-challenges-and-opportunities. [Accessed 5 October 2022].
[53] M. Bayen, "GSMA," July 2016. [Online]. Available: https://www.gsma.com/mobilefordevelopment/wp-content/uploads/2016/07/GSMA_Mobile-operators-start-ups-in-emerging-markets.pdf. [Accessed 3 October 2022].
[54] D. Bushaus, T. McElligott, "tmforum," January 2021. [Online]. Available: https://www.tecnotree.com/wp-content/uploads/2021/01/TM-Forum-Open-API-Economy-Report_Jan-2021.pdf. [Accessed 4 October 2022].
[55] "Microsoft," Microsoft, [Online]. Available: https://learn.microsoft.com/en-us/azure/architecture/guide/architecture-styles/microservices. [Accessed 4 October 2022].
[56] A. F. Castillo, "Cloud Computing Technologies," 30 October 2021. [Online]. Available: https://cloudcomputingtechnologies.com/what-5g-does-for-microservices/. [Accessed 7 October 2022].
[57] "IBM," [Online]. Available: https://www.ibm.com/downloads/cas/OQG4AJAM. [Accessed 7 October 2022].
[58] P. Jarman, "Microservices- A new application paradigm," Infosys.

[59] D. TEAM, "Digiteum," 14 April 2022. [Online]. Available: https://www.digiteum.com/advantages-microservices-architecture/. [Accessed 7 October 2022].
[60] "The 2022 State of Open Source Report," OpenLogic by Perforce and open source initiative, 2022.
[61] P. Cormier, "Red Hat," Red Hat, 22 February 2022. [Online]. Available: https://www.redhat.com/en/resources/state-of-enterprise-open-source-report-2022. [Accessed 8 October 2022].
[62] "cisco," cisco, [Online]. Available: https://www.cisco.com/c/en/us/solutions/analytics/what-is-network-analytics.html. [Accessed 8 October 2022].
[63] "Nokia," Nokia, [Online]. Available: https://www.nokia.com/networks/bss-oss/nwdaf/?did=D00000001197. [Accessed 7 October 2022].
[64] A. Purohit, "Light Reading," 23 February 2022. [Online]. Available: https://www.lightreading.com/partner-perspectives-(sponsored-content)/the-money-is-in-verticals---how-analytics-unlocks-5g-value-/a/d-id/775484. [Accessed 8 October 2022].
[65] E. Pateromichelakis, D. Dimopoulou and A. Salkintzis, "NetApps Enabling Application-Layer Analytics for Vertical IoT Industry," in IEEE Internet of Things Magazine, vol. 5, no. 4, pp. 130-135, December 2022, Doi: 10.1109/IOTM.001.2200212.
[66] Hallingby, Hanne Kristine, Fletcher, Simon, Frascolla, Valerio, Gavras, Anastasius, Mesogiti, Ioanna, & Parzysz, Fanny. (2021). 5G Ecosystems. Zenodo. https://doi.org/10.5281/zenodo.5094340.
[67] D5.1, Ecosystem analysis and specification of Business and Economic KPIs, project 5GVINNI, July 2019 [Online]. Available: https://zenodo.org/record/3345665.
[68] 6G – IA Whitepaper on 5G Ecosystem Business Modelling (discussions/calls November 2022).
[69] V. Allee, "Value Network Analysis and value conversion of tangible and intangible assets," Journal of Intellectual Capital, vol. 9, no. 1, pp. 5-24, 2008.
[70] https://www.thevalueengineers.nl/tutorials/model-analyze-value-model/
[71] V. Allee, "Reconfiguring the value network," Journal of Business strategy, vol. 21, no. 4, p. 36-39, 2000.