



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

[H2020 - Grant Agreement No.101016608]

Deliverable D6.4

# Technoeconomic Analysis and Stakeholders Engaging (Final Report)

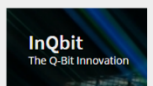
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## GLOSSARY

<b>Abbreviations/Acronym</b>	<b>Description</b>
3GPP	3 <sup>rd</sup> Generation Partnership Project
4G	4 <sup>th</sup> Generation of Mobile Networks
5G	5 <sup>th</sup> Generation of Mobile Networks
5GaaS	5G-as-a-Service
5G PPP	5G Infrastructure Public Private Partnership
AI	Artificial Intelligence
API	Application Programming Interface
CAPEX	Capital Expenses
CSP	Communication Service Provider
DESI	Digital Economy and Society Index
EC	European Commission
ENISA	European Network Information and Security Agency
EU	European Union
FoF	Factory of Future
GDP	Gross Domestic Product
GSMA	Global System for Mobile Communications Association
ICT	Information and Communications Technology
IMSI	International Mobile Subscriber Identity
IoT	Internet of Things
IT	Information Technology
KPIs	Key Performance Indicators
MPN	Mobile Private Network
mmWave	millimeter Wave
MNO	Mobile Network Operator
Network App	Network Application
NEF	Network Exposure Function
NFV	Network Function Virtualization
NH	Neutral Host
NHN	Neutral Host Network
NPN	Non-Public Network
NWDAF	Network Data Analytics Function
OPEX	Operational Expenses
PLMN	Public Land Mobile Network
PNI-NPN	Public Network Integrated NPN
QoS	Quality of Service
RAN	Radio Access Network
R&D	Research and Development
ROI	Return of Investment
SA	Standalone
SaaS	Software-as-a-Service
SME	Small and Medium-sized Enterprises
SNPN	Stand-alone NPN
TCO	Total Cost of Ownership
TSN	Time-Sensitive Networking
Virtual Machine	VM

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## EXECUTIVE SUMMARY

Within the EVOLVED-5G project, specifically in Work Package 6 (WP6)/Task 6.3 (T6.3), an analysis was conducted to explore the technoeconomic aspects arising from the introduction of the Network Applications (Network App) ecosystem. Network Apps are defined as third-party software entities that interact with the operating and managing software of an underlying network to deliver advanced services to vertical industries and/or network owners. This interaction is supported by APIs and can refer to the control, data, or management plane. The project's focus revolves around investigating interaction at the control plane, emphasizing network core exposure capabilities and standardized APIs for 5G Non-Public Networks (NPN) scenarios.

The analysis in this deliverable complements the approach presented in [Deliverable D6.2](#), and is divided in two main parts, namely technoeconomic analysis and stakeholder's engagement.

Regarding the technoeconomic analysis, firstly, updates on the business and economic impact of 5G are provided, considering recent economic figures and state-of-the-art approaches. Then, we complete the remaining actions of the technoeconomic methodology introduced in D6.2. For the first action of the methodology, namely the identification of *Business models and Value networks*, we created a business model canvas for the EVOLVED-5G [service package](#). It is noted that the EVOLVED-5G service package defines together with the platforms (network and compute infrastructures) and the marketplace, the EVOLVED-5G facility, i.e., a facility that can efficiently support the lifecycle of Network Apps. Regarding the second action, namely *business case viability study*, we dig into the actual costs needed for the EVOLVED-5G facility by getting input from the platform owners (service package hosts) and by exploring the characteristics of the components of the EVOLVED-5G service package. For the last action, *Impact of new technologies on business cases*, we study the literature for business cases related to a Software-as-a-Service approach, that fits well to the EVOLVED-5G service package.

Regarding the stakeholder's engagement, we summarize the various related activities conducted throughout the project's lifecycle. The goal was to delineate the nature, purpose, strategy, materials, and ultimate results of each activity. The engagement activities that took place are organised in two main classes, namely those provided through initiatives from individual project partners and those conducted at project level (including the engagement with 5GPPP, other associations and other projects. Cornerstone to the stakeholder's engagement (especially for SMEs and Startups) was the EVOLVED-5G Acceleration Program organised at project level and delivered successfully by IEA.

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# 1 INTRODUCTION

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## 1.1 Purpose of the document

This deliverable is the fourth and last 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 (Final Report)”*, is to outline the business and economic impact of 5G ecosystem, the technoeconomic aspects and business analysis in the context of the service package of the EVOLVED-5G project and the engagement activities for 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 and sustainability in these and in the future investments. Also, it is referred to 5G NPN and in general, to the private wireless growth.
- **Section 3. Technoeconomic aspects and business analysis:** This section includes the technoeconomic aspects of the EVOLVED-5G ecosystem. The business model canvas of the EVOLVED-5G service package is presented, while the business case of open-source software entrepreneurship is studied as a candidate for the EVOLVED-5G service package.
- **Section 4. Engagement of stakeholders on EVOLVED-5G:** This section describes the EVOLVED-5G stakeholders engagement activities, including remarks on the strategy and the purpose of engagement, and a summary of the impact of the activities conducted.

## 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

The primary objective of the Digital Decade related to 5G is to achieve coverage of all populated areas by 2030, with Standalone 5G (SA) playing a supportive role rather than being indispensable [1]. While SA can extend coverage in remote areas, its impact on digital inclusion, environmental goals, and cybersecurity is relatively minor compared to universal 4G or 5G coverage. The significant impact of 5G SA lies in enabling mobile operators to offer specialized network slices for specific purposes and facilitating SMEs' connectivity access. Monitoring MNOs' 5G SA deployments provides insights into their readiness for advanced services, but it's not the sole indicator, as verticals may use private networks. Tracking 5G SA deployment is useful for assessing progress but is part of a broader set of Key Performance Indicators (KPIs) measuring EU policy goals, including 5G coverage, local licensing, and Quality of Service (QoS).

The current state of 5G in the EU-27 involves widespread commercial launches, spectrum assignments, and the establishment of 5G corridors. All EU countries have now implemented commercial 5G services, with approximately 346,000 active 5G base stations across the region. The predominant 5G base station type utilizes Dynamic Spectrum Sharing with 4G bands. Notably, about 81% of the EU population is now covered by at least one foundational 5G network [1].

Country	Population coverage (September 2023 figures)	People covered (September 2023 figures)	Note (September 2023 figures)
Austria	91.7%	8.349.532	EC
Belgium	29.6%	3.482.549	EC
Bulgaria	67.2%	4.334.247	EC
Croatia	82.5%	3.176.469	EC
Cyprus	100.0%	920.701	EC
Czechia	82.6%	8.943.329	EC
Denmark	97.8%	5.804.607	EC
Estonia	43.3%	591.482	EC
Finland	94.7%	5.266.796	EC
France	88.8%	60.469.011	EC
Germany	93.2%	78.611.041	EC
Greece	85.7%	8.905.158	EC
Hungary	57.9%	5.556.670	EC
Ireland	83.9%	4.359.266	EC
Italy	99.7%	58.685.755	EC
Latvia	42.0%	790.897	EC
Lithuania	90.1%	2.573.151	EC
Luxembourg	93.2%	615.940	EC
Malta	100.0%	542.051	EC
Netherlands	100.0%	17.809.288	EC

Country	Population coverage (September 2023 figures)	People covered (September 2023 figures)	Note (September 2023 figures)
Poland	63.4%	23.313.943	EC
Portugal	75.0%	7.850.525	Operator announcement <sup>93</sup>
Romania	26.8%	5.096.919	EC
Slovakia	55.3%	3.004.518	EC
Slovenia	63.9%	1.353.040	EC
Spain	82.3%	39.551.329	EC
Sweden	20.5%	2.152.912	EC
EU 27	81%	362.111.124	

Figure 1: Population coverage

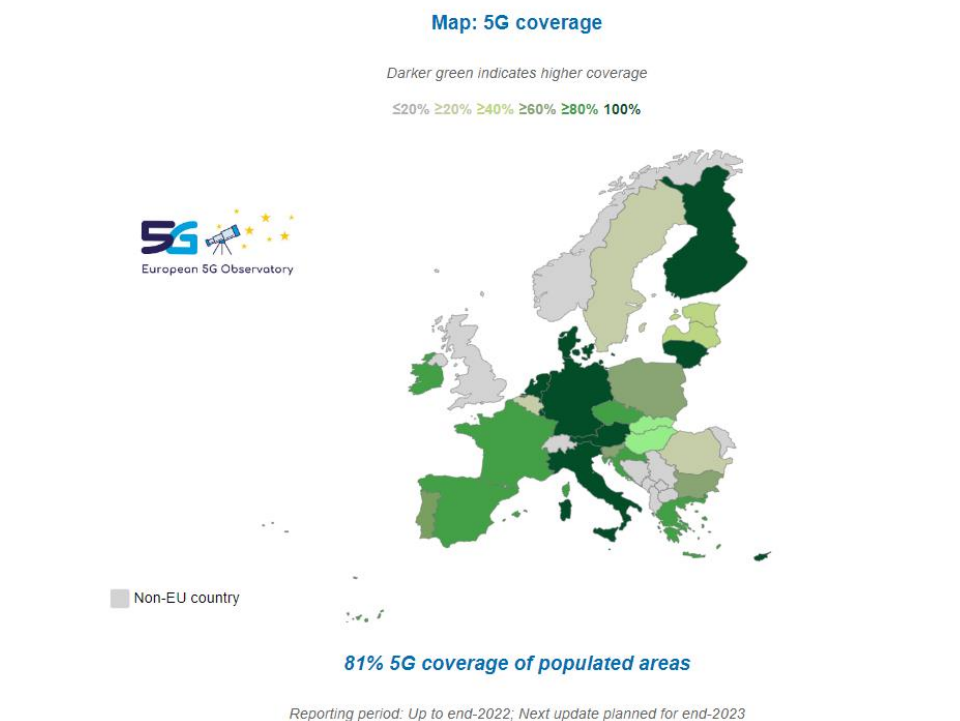


Figure 2: 5G coverage of populated areas

Regarding the allocated 5G spectrum, the 3.6 GHz band stands out as the most widely utilized globally, with all four regions in this comparison having assigned this valuable mid-band spectrum. The 28 GHz band has also seen significant adoption, particularly in South Korea, Japan, and the US. In the EU, the scenario is intricate due to individual countries assigning their spectrum [1]. Nevertheless, a majority of countries have assigned the 3.6 GHz band for 5G deployment. In contrast, only 11 EU Member States have assigned the 26 GHz band, which has experienced relatively lower demand thus far.

On average, 71% of pioneer bands in European Union Member States have now been allocated. In May 2023, Estonia successfully concluded its spectrum auction in the 26 GHz band, generating over €4.8 million [1]. All three major operators, namely Elisa, Tele2, and Telia, secured licenses. In September 2023, Sweden completed the allocation of the 900 MHz, 2.1 GHz, and 2.6 GHz bands, with spectrum licenses awarded to Telia Sweden, Hi3G Access (Tre Sverige), and Net4Mobility (a joint venture between Telenor and Tele2). Additionally,

Hungary finalized the allocation of the 32 GHz band to pave the way for a future 5G spectrum auction in the 26 GHz band. Lastly, in mid-October, Poland concluded its auction of the 3.6 GHz band, distributing a total of 400 MHz among four operators [1].

Among the Member States, the 3.6 GHz band has witnessed the broadest allocation, with 26 out of 27 countries assigning a minimum of 50% of the designated spectrum (equivalent to at least 200 MHz out of 400 MHz). Following closely is the 700 MHz band, where 24 out of 27 Member States have assigned a minimum of 50% of the targeted spectrum (at least 30 MHz out of 60 MHz). In contrast, the 26 GHz band has experienced the least allocation, with only 11 Member States majority-assigning it, signifying that merely 11 countries have allocated at least 50% (500 MHz) of the intended 1000 MHz [1]. The Figure 3 provided details the spectrum allocation by each Member State in the pioneer bands. As per the 700 MHz Decision and associated Commission Implementing Decision, along with the EECC, a country is required to assign 60 MHz in the 700 MHz band, 400 MHz in the 3.6 GHz band, and a minimum of 1000 MHz in the 26 GHz band to attain 100%. The percentages indicated in the table represent the extent to which spectrum has been allocated to operators relative to these specified values.

Country	% of band assigned		
	700 MHz	3.6 GHz	26 GHz
Total harmonised spectrum (100%)	60 MHz	400 MHz	1000 MHz
Austria	100.00%	97.50%	0.00%
Belgium	100.00%	97.50%	0.00%
Bulgaria	0.00%	90.00%	100.00%
Croatia	100.00%	100.00%	100.00%
Cyprus	100.00%	100.00%	0.00%
Czechia	100.00%	100.00%	0.00%
Denmark	100.00%	97.50%	100.00%
Estonia	100.00%	97.50%	100.00%
Finland	100.00%	97.50%	100.00%
France	100.00%	77.50%	0.00%
Germany	100.00%	100.00%	100.00%
Greece	100.00%	97.50%	100.00%
Hungary	83.33%	97.50%	0.00%
Ireland	100.00%	87.50%	0.00%
Italy	100.00%	80.00%	100.00%
Latvia	100.00%	87.50%	0.00%
Lithuania	66.67%	75.00%	0.00%
Luxembourg	100.00%	82.50%	0.00%
Malta	0.00%	75.00%	0.00%
Netherlands	100.00%	0.00%	0.00%
Poland	0.00%	100.00%	0.00%
Portugal	83.33%	100.00%	0.00%
Romania	50.00%	65.00%	0.00%
Slovakia	100.00%	100.00%	0.00%
Slovenia	100.00%	95.00%	100.00%
Spain	100.00%	95.00%	100.00%
Sweden	66.67%	100.00%	85.00%
Number of countries that have assigned at least 50% of the band	23	26	11

Figure 3: Pioneer bands assigned in the EU

The Global mobile Suppliers Association's report from July 2023 provides insights into the global progress of 5G Standalone (SA) networks [2]. It reveals that 115 operators in 52 countries are investing in 5G SA networks, with 36 operators in 25 countries having launched or deployed public 5G SA networks. While this report is comprehensive, challenges exist in accurately tracking 5G SA deployments in Europe. Discrepancies are evident, such as the case of Austrian operator Drei, which, according to its website, launched 5G SA in 2022 despite the GSA report placing it in the planning stage. Device availability plays a crucial role in 5G SA readiness, with 85.5% of announced 5G devices globally being 5G SA capable as of June 2023. However, the report does not provide a breakdown per country or region. Delays in 5G SA deployment may stem from factors like insufficient investments, lack of commercially viable use cases, competing priorities, and ongoing debates about big tech companies' contributions to network infrastructure.

The introduction of 5G SA prompts considerations regarding its potential economic benefits and alignment with EU policy objectives, encompassing cybersecurity, SME support, and bridging the digital divide. While certain features of 5G SA may have a more modest economic impact, they often align with key EU policy goals. Notably, enhanced coverage and network slicing emerge as features with substantial economic benefits, contributing significantly to broader policy objectives. Improved network reliability, efficient bandwidth allocation, reduced battery drain, and enhanced security contribute to both economic and policy objectives, such as ensuring robust digital infrastructure, effective spectrum use, environmental sustainability, and cybersecurity resilience. Moreover, 5G's enhanced coverage holds economic significance, particularly in underserved regions, aligning strongly with EU goals of fostering digital inclusion and reducing regional disparities. The improved indoor signal not only benefits user experience but also supports digital innovation and sustainability objectives. Network slicing, with its potential to enhance industrial efficiency, aligns with innovation and sustainability goals, promoting technological advancements and resource efficiency—a crucial aspect of EU policies.

The EU Digital Decade Communication underscores the significance of digital business transformation, emphasizing the pivotal role of 5G. According to the communication, key digital technologies, including 5G, IoT, edge computing, AI, robotics, and augmented reality, will be central to innovations in new products, manufacturing processes, and business models, particularly focusing on equitable data sharing in the data economy.

In Europe, the encouragement of 5G vertical trials is facilitated through the 5G Public Private Partnership project (5G PPP), supported by €700 million in European Union research funding grants, matched by €3.5 billion in private investment from 2014 to 2020 [1]. Additionally, the 5G-PPP Vertical Engagement Task Force (VTF) has been established to coordinate and monitor activities related to collaboration with various vertical sectors, including automotive, manufacturing, media, energy, e-health, public safety, and smart cities.

Specifically, the EVOLVED-5G project focuses on the manufacturing industry and it becomes evident that 5G can liberate machinery from the constraints of fixed locations by substituting cables with wireless connectivity, thereby affording manufacturers a significantly higher level of adaptability. It's worth noting that when compared to alternative wireless technologies that might, in theory, provide this kind of flexibility within a factory setting, such as Wi-Fi 6, 5G stands out due to its notably superior speed, integration of a unified control system and network core (meaning it encompasses more than just the wireless interface), improved coverage and reliability, and the potential to integrate into a public 5G network.

Also, it can achieve precise demands with enhanced quality, scalability, and swiftness, all while reducing expenses. This can be accomplished by implementing production lines that are more adaptable and responsive, allowing for quicker and more effortless reconfiguration. Finally, 5G can expedite the

advancement of intelligent ecosystems that are interconnected and capable of self-orchestration, enabling them to promptly foresee and tackle challenges and seize opportunities.

In the context of a 5G smart farm, numerous sensors have been deployed to collect real-time data on weather (air and soil parameters), crop growth and even animal behavior. This data can be collected by 5G-enabled drones equipped with multispectral sensors. Also, other 5G machines can be used, which can remain connected to 5G network even if they work out of the farm. The [5GARGIHUB](#) is a project of the Horizon 2020 supported by the European Union (EU) and it has as goal to establish a 5G Mobile Private Network (MPN) Hub at a demonstration farm in Mosonmagyaróvár in Hungary. The use cases that have been enabled is about the row crop cultivator in field crop production, the machine-to-machine connection in field crop production and finally the weed monitoring and spraying plan with machine-to machine connection in field crop production.

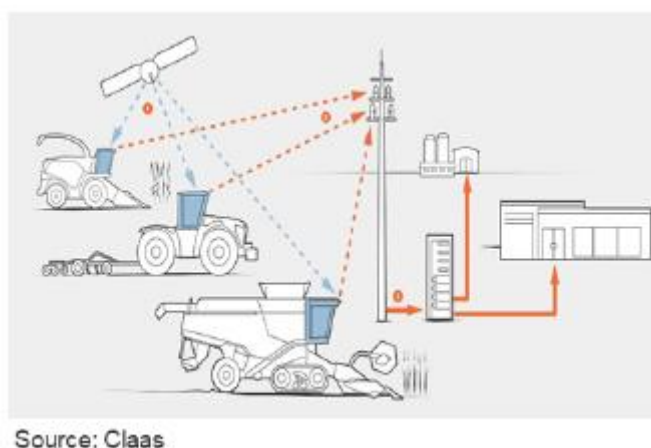


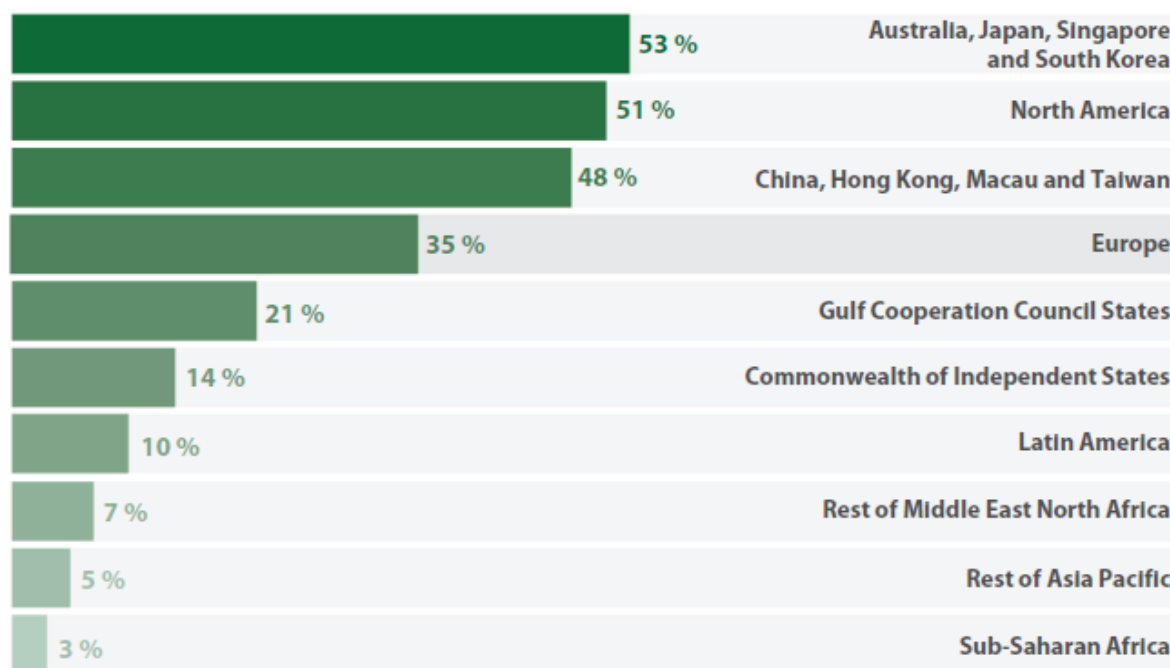
Figure 4: Remote detection of machinery via cellular network

Even though most sectors of economy are going to change and evolve, we can notice that some countries focus on the deployment of specific sectors. For example, Spain is the leading country in the deployment of public 5G networks and in smart cities [3]. Also, France is centered on the smart cities, and it is a leader in the mobility and transportation. On the other hand, Germany and Italy have interest in the automotive sector. Italy's interest is growing from the automotive sector in further deployment of 5G networks and especially one private ones. Germany takes initiatives in manufacturing area having a wide range of national industrial leaders. That can make Germany a leader in manufacturing industry.

#### 2.1.1.1 Deployment delays and concerns

During the initial phase of 5G deployment, various significant challenges impeded its progress. These included issues like the allocation of spectrum, the substantial cost and security concerns of required equipment, and the disruptive impact of the Covid-19 pandemic. While some of these obstacles have been successfully overcome, others continue to hinder the development of 5G technology.

In 2021, the Global System for Mobile Communications Association (GSMA) highlighted the diverse phases and varying rates of progress in 5G deployment within the EU compared to the rest of the world [4]. To illustrate this, Figure 5 indicates that by 2025, 51% of all mobile connections in North America will be 5G-based, whereas Europe is projected to have 35% of its mobile connections on 5G networks. This serves as an indicator that the majority of EU Member States must remain steadfast in their efforts to extend 5G coverage to all populated areas by 2030, as meeting the 2025 deadline carries a substantial risk.



Source: GSMA. The Mobile Economy 2021.

Figure 5: The percentage of 5G connections out of the total mobile connections expected by 2025

To begin with, many EU countries have taken proactive steps to achieve nationwide 5G coverage, addressing the spectrum allocation requirements. Nevertheless, there remain countries where additional efforts are needed, necessitating government support to advance in this direction. Furthermore, mobile operators must augment their infrastructure investments in order to address specific constraints, including the increased propagation challenges posed by high-frequency spectrums and to enhance radio interfaces and antennas to optimize the efficiency of the new spectrum [5].

Although the management of the Covid-19 pandemic has improved and is no longer at its peak, its repercussions persist in the technology sector, particularly in chip production. In particular, in 2021, the automotive industry faced severe challenges, with some companies experiencing slow progress in chip supplies as the shortage extended into its third year. German automaker Volkswagen AG anticipates continued production difficulties in 2023. Conversely, Tesla INC (TESLA.O) has garnered recognition for its adept handling of chip shortages by adapting its software to use different or fewer chips when needed [6]. The chip storage issue not only impacts the automotive industry, a primary sector expected to embrace and implement 5G technology, but it also extends its influence on the equipment essential for 5G, which incorporates various chips.

Additionally, a plethora of concerns have arisen regarding the appropriateness of the equipment for 5G, primarily due to the fact that many of these components originate from countries outside of Europe. This divergence in the equipment's country of origin raises apprehensions both in terms of security and the self-sufficiency of equipment production.

The use of 5G equipment from non-European vendors, particularly those originating from the People's Republic of China (PRC), has sparked significant discussions among EU Member States due to concerns related to security. Specifically, issues surrounding confidentiality and privacy have emerged, as telecom operators frequently entrust their data to data centers. This poses a risk that such data may be stored on 5G equipment

provided by vendors located in non-EU countries with differing levels of legal and data protection compared to the EU.

In October 2020, the Swedish national regulatory telecom authority (PTS) imposed certain conditions for participating in the auction of 5G spectrum, including restrictions on the use of products from Chinese vendors for new installations and central functions related to radio frequency bands. Additionally, any existing infrastructure from these vendors must be phased out by January 1, 2025, at the latest.

In Germany, the IT security act 2.0 introduced in May 2021 mandates the certification of critical components before their authorization for use. Many German Mobile Network Operators (MNOs) expressed a preference for a unified European certification process conducted under the auspices of European Network Information and Security Agency (ENISA), serving as a European "one-stop shop," rather than having to navigate multiple national certifications. The act also grants the Federal Ministry of the Interior the authority to prohibit the use of critical components if they are deemed a threat to national security.

In general, the majority of Member States, specifically seventeen out of twenty-four with legislative authority, have either implemented or are planning to adopt an ex-ante approach aimed at regulating the deployment of 5G equipment from high-risk providers. Additionally, nineteen Member States have made the decision to compel the removal of existing equipment supplied by these vendors.

While MNOs are responsible for ensuring the secure rollout of 5G, utilizing equipment procured from technology vendors, and Member States bear the responsibility for national security, it is essential to acknowledge that 5G network security represents a matter of strategic significance for the entire single market and the EU's technological sovereignty. As a result, concerning the technical and security aspects of 5G networks, the Commission and EU agencies provide support and facilitate the coordination of actions undertaken by Member States.

In the context of the self-sufficiency of equipment production, the EU's recognition of the significance of technological reliance has led to initiatives aimed at establishing chip manufacturing within Europe, with companies like Intel pledging their support [7]. The European Commission has introduced the European Chips Act, which aims to equip the EU with the essential tools and technological prowess for the development, production, and packaging of advanced chips. To achieve this objective, the act will mobilize over 43 billion euros from both public and private sources. The ultimate target is to increase the EU's current market share to 20% by the year 2030 [8], since in 2020, Europe accounted for only 10% of the one trillion microchips manufactured worldwide.

#### 2.1.2 Security concerns

5G is set to facilitate the connectivity of a greater number of devices than ever, particularly within the realm of the IoT. In 2018, there were approximately 22 billion connected devices in operation across the globe, and this number is projected to surge to approximately 50 billion by 2030. This means that an extensive network of interconnected devices encompassing a wide range of items, from smartphones to household appliances can be a possible target of cyber-attacks [4].

5G security involves protecting the underlying 5G infrastructure, including hardware, software, network traffic, users, and data. The convergence of cyber and physical security controls is critical for this purpose. 5G networks' extensive connectivity increases the attack surface, making them potentially vulnerable to more sophisticated security threats. The proliferation of IoT devices, which often lack built-in security, adds to the risk. Additionally, the expansion of networks and increased mobile usage challenge organizations to maintain visibility and control, making it difficult to identify and respond to potential attacks [9].

In the context of the European Union's 5G deployment, several security concerns have emerged, primarily influenced by the technology's strategic importance and the nature of its implementation.

5G technology is recognized as being of strategic importance for the entire single market. The European Commission, in its 2019 recommendation on 5G cybersecurity, underscored that many critical services depend on 5G networks [4]. This dependency makes the consequences of widespread disruptions especially severe. Furthermore, any significant vulnerability or cybersecurity incident in one Member State could impact the EU as a whole.



Source: European Commission.

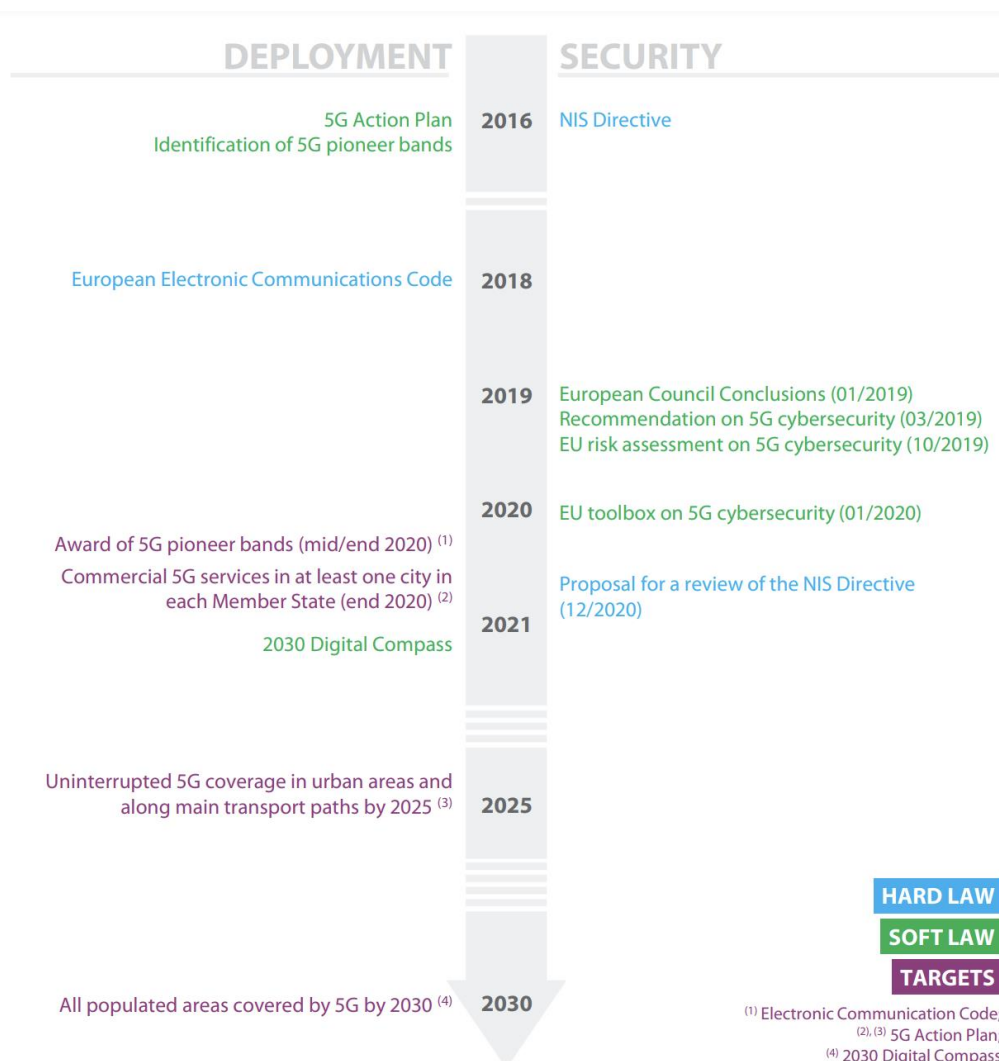
Figure 6: The extensive network of devices which are connected to 5G

More specifically, unlike 4G and previous network technologies, 5G deployment is based on numerous smaller indoors and outdoors antennas and base stations to improve the throughput [10]. When the user communicates with the cell tower or the antenna the precise location is known to the network whether user is indoor or outdoor. This sensitive information can be in danger, in case of a Semantic Information Attack happens, which targets to the location data of users, and it has as goal to cause harm by incorrect information. Another possibility is the leaking of this data by Access point selection algorithm [11] in 5G mobile networks.

Beside these attacks, there are vulnerabilities in the AKA protocol that is responsible to mutually verify and authenticate the device and the tower and eventually to establish a protected and secure communication. An attacker using the International Mobile Subscriber Identity (IMSI) [12] can uncover the identity of the mobile subscriber and monitor his activities. Even though the attacker cannot have access to the content of the user's messages and phone calls, he can know the amount of them and even after the user has left the area, the attacker still has the ability to track the number of past and future calls and messages.

As 5G networks are poised to underpin a diverse array of services and applications, their accessibility presents a substantial security concern at both national and EU levels. In the event that malicious individuals were to infiltrate a 5G network, they could potentially compromise its fundamental functions, leading to service disruptions or the seizure of control over critical infrastructure. This is especially pertinent in the EU, where critical infrastructure often spans multiple borders. Research indicates that the economic ramifications of cybercrime could be staggering, with estimates suggesting it may amount to as much as €5,000 billion annually worldwide, equivalent to over 6% of the global GDP in 2020.

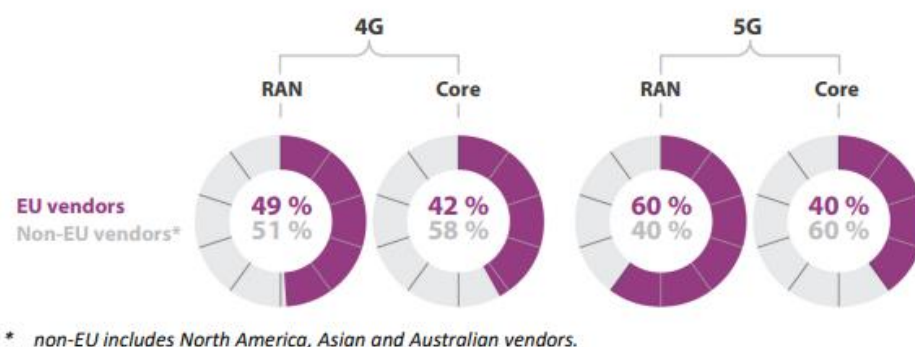
For this reason, the EU is developing a policy framework and regulations to deal with the possible attacks and to prevent them as soon as possible. Figure 7, shows the key targets in parallel with the policy framework relating to the deployment and the security of the 5G technology.



Source: ECA.

Figure 7: Main policy documents and key targets relate to 5G development

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 8 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. In general, only a third of EU countries had implemented bans on Huawei in critical areas as of 2020. Germany, for example, has been considering banning certain components from Huawei and ZTE in its telecom networks to address security concerns [13]. 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 [4].



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 8: 4G and 5G equipment in the EU by EU and non-EU vendors

This effort must be embraced and reinforced by the MNOs, who are responsible for the secure deployment of 5G using reliable and secured equipment sourced from technology vendors and by Member States who are responsible for national security.

	Commission and EU agencies	Member States authorities	MNOs & 5G vendors
Allocation and assignment of 5G pioneer bands		✓	
Defining EU 5G policy	✓	✓	
Deployment of 5G networks			✓
Investment and funding	✓	✓	✓
National security		✓	
Security of 5G networks		✓	✓
Support and coordination of Member States' actions	✓		

Source: ECA.

Figure 9: Responsibilities for a secure growth of 5G

Considering the above risks and vulnerabilities, ENISA has presented an updated 5G Cybersecurity Toolbox including key publications by ENISA such as the [ENISA EECC GUIDELINE](#), the [5G Supplement to the EECC Guidelines](#), and the [5G Threat Landscape](#). The first one has as goal to ensure that the providers assess risks and take appropriate security measures. The second one is focusing on the cybersecurity of 5G networks at the policy level relating to the EU 5G toolbox and at the technical level for new technologies, for example virtualization, slicing and edge computing. Finally, the 5G Threat Landscape, centers to the vulnerabilities and threats assessments and it provides in-depth information about the exposure of assets of the 5G architecture.

To conclude, the EU faces a complex array of security concerns in the deployment of 5G technology, ranging from strategic risks to implementation challenges and the vulnerabilities inherent in a more connected and technologically advanced network. The response to these challenges involves both technological solutions and regulatory actions at the EU and member state levels.

## 2.2 5G VIABILITY, SUSTAINABILITY AND RELATED INVESTMENTS

Here we summarize surveys and reports which have as goal 5G viability, sustainability, 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.

**Investigating the Sustainability of the 5G Base Station Overhaul in the United States [14]:** This paper explores the distinctions between 4G/LTE and 5G base stations, focusing on the materials facilitating the transition. 5G, as a next-generation wireless communication technology, holds the promise of substantial improvements in bandwidth and latency. Achieving this involves leveraging millimeter-wave wireless communication and massive MIMO antenna arrays. The upgrade necessitates new base stations and equipment, as the existing 4G infrastructure falls short of meeting 5G requirements. Notably, the quantity of base stations varies significantly, with 5G demanding more to achieve broader coverage.

A critical inquiry arises concerning the sustainability of a 5G infrastructure heavily reliant on materials that are limited and extracted from nature. The environmental impact could be considerable, given that 5G components require a greater amount of new materials not essential in 4G networks. While approximately 30% of minerals and metal materials can be recycled, the challenge lies in the complexity and cost of the recycling process, especially when materials are mixed with others. Many of these materials, such as rare-earth and precious metals, are not easily reused. Gallium and germanium, essential components for 5G, are expensive and challenging to mine, and copper, a key resource, faces severe constraints. Beyond the intrinsic materials, the deployment of these new base stations exacts a substantial environmental toll—from sourcing and transporting to manufacturing and installation. Greenhouse gas emissions occur at every step, and recycling proves largely impractical due to the limited availability of metals. Despite these challenges, 5G exhibits potential to reduce energy consumption compared to 4G, owing to enhanced power management and performance. This could translate to lower energy usage in communication, thereby diminishing net greenhouse gas emissions that would otherwise persist with the continued use of inefficient 4G networks. To address the environmental costs associated with raw material acquisition and processing, a strategic approach involves integrating 5G with existing 4G infrastructure. Maintaining the 4G infrastructure in the long term becomes crucial, offering a balanced solution to mitigate the environmental impact of transitioning to this new generation of wireless technology.

**An Economic Feasibility Model for Sustainable 5G Networks in Rural Dwellings of South Africa [15]:** The research assesses the economic viability of a hybrid network model that integrates terrestrial and aerial networks to deliver 5G coverage in rural regions. This study indicates that this network can be constructed with affordable monthly subscription fees for end-users, providing favorable returns for service providers in rural areas. Conversely, for large yet sparsely populated suburban areas, the conventional terrestrial network with base stations proves more suitable. This network utilizes cellular nodes mounted on unmanned aerial vehicles (UAVs) to extend network coverage from the sky to users while leveraging terrestrial cellular nodes. The deployment of such a network is envisioned to facilitate the achievement of sustainable development goals, including improved healthcare, poverty reduction, and enhanced infrastructure in less developed regions worldwide. Thirteen locations in South Africa were chosen for the study, encompassing five district municipalities, four township areas, three rural residential areas, and one low-income area. Three scenarios were considered for each location, employing three network types: UAV-based, Hotspot-based, and LC-based. The analysis incorporated capital expenditure (CAPEX), operational expenditure (OPEX), internal rate of return (IRR), return on investment (ROI), and power requirements. These factors were used to determine recommended monthly user subscription fees for Internet access per GB and per minute. The findings indicate that deploying the proposed hybrid 5G coverage in large but sparsely populated areas is more expensive, making the traditional LC-based system more profitable in such cases. Conversely, implementing the hybrid

architecture in rural residential areas incurs lower costs and generates higher revenue compared to low-income areas. The analysis also highlights that, with the proposed model, the optimal monthly subscription fee is significantly lower than the current data bundle prices offered by telecommunications providers in South Africa.

**Energy Efficiency Concerns and Trends in Future 5G Network Infrastructures [16]:** This paper explores the deployment of 5G at a time when energy efficiency is a critical consideration for addressing societal and environmental concerns. The focus is on how 5G technology, designed to be more energy-efficient than previous generations, contributes to sustainability goals. Key aspects include the use of low-power, small antennas, and efficient technology that activates transmission power only when necessary. 5G incorporates power-saving modes and supports greener energy consumption, enabling better management of renewable resources and real-time monitoring of energy use in smart homes and cities. Energy efficiency is a fundamental concern in planning new mobile networks, and 5G plays a crucial role by promoting measures for energy savings and effective energy management. It leverages high-capacity, ubiquitous, and low-latency networks, along with technologies like virtualization, edge computing, AI-enabled analytics, and cloud, to support industries in adopting energy-efficient procedures. The intelligent use of resources facilitated by 5G can lead to reduced energy consumption in various sectors, including smart energy management, reduced office space and business travel requirements, efficient supply chains, and automated vehicle management. As technology evolves, 5G provides opportunities to integrate AI/ML mechanisms to further reduce energy consumption in networks. The paper identifies potential trends in the evolution of "smart" communication networks, promoting cognitive solutions to achieve significantly lower energy consumption by dynamically adapting to emerging needs. In summary, 5G not only addresses the immediate concerns of energy efficiency but also offers a platform for ongoing innovations to enhance sustainability across industries.

**5G network deployment and the associated energy consumption in the UK: A complex systems' exploration [17]:** This study focuses on modeling the development of 5G base stations in the UK over the next decade using an agent-based model (ABM) to evaluate economic and environmental impacts. The ABM offers advantages such as modeling location at a postcode level, capturing spatial interactions, and incorporating socio-political variables crucial for 5G deployment. The research questions address changes needed for optimal economic performance, the impact of geopolitical restrictions on deployment costs, and the energy cost and carbon footprint of the UK's 5G deployment strategy. Results reveal that high-demand regions are concentrated in urban areas, yet most CAPEX are spent on suburban and rural areas. Geopolitical restrictions on major suppliers incur additional costs of £630 million to £1.19 billion, significantly impacting 5G deployment in rural areas. Microcells, rather than Macrocells, contribute most to power consumption, posing challenges to local power infrastructure and increasing energy costs for MNOs. Implications for decision-makers include the importance of the 700 MHz and 26 GHz frequency bands in 5G deployment, the need to prioritize deployment in administrative and economic capital areas due to cost constraints, the urgency to enhance the energy efficiency of base stations to counter rising energy costs, and the recommendation to utilize renewable technologies for both environmental sustainability and cost-effectiveness in 5G networks compared to traditional fuel sources.

**Techno-economic assessment of 5G infrastructure sharing business models in rural areas [18]:** The paper categorizes 5G network sharing strategies into four types: No Sharing, Passive Sharing, Active Sharing, and NHN. In the No Sharing model, each operator establishes their independent network, while in Passive Sharing, multiple operators jointly utilize non-electronic components like towers and site compounds. Alternatively, Active Sharing involves operators sharing all passive and electronic telecommunication elements, excluding different spectrum bands and the network core. Lastly, NHN entails operators sharing both passive and active components with each other and potential slice tenants. This paper's research delves into forthcoming infrastructure sharing strategies for rural areas, based on the premise that most locations already possess

some existing infrastructure assets that offer basic connectivity, such as 2G, 3G, or 4G. It explores future infrastructure sharing strategies for rural areas, emphasizing the need for solutions tailored to generic rural settings. The study aims to analyze the cost of reducing the digital divide over the next decade by leveraging existing infrastructure to provide higher quality service. The techno-economic assessment of 5G infrastructure sharing models in rural areas reveals that the NHN strategy significantly reduces overall costs compared to other strategies, potentially increasing viability by 30–90%. However, successful implementation requires a comprehensive strategic approach considering technology, policy, and local challenges to achieve universal mobile broadband connectivity by 2030, in line with UN Sustainable Development Goals.

**A Survey on Green 5G Cellular Networks [19]:** This article provides a concise survey of green 5G cellular networks, addressing research issues and challenges associated with enabling techniques for eco-friendly broadband wireless networks. The push toward green power in cellular networks has led operators and standardization authorities to collaborate on reducing carbon footprints, particularly through the development of environmentally friendly 5G green radio cellular base stations. The overview covers the 5G wireless system architecture, new protocol stacks, and hybrid multiple access schemes, such as the combination of orthogonal (OFDMA) and non-orthogonal (CDMA) approaches. The telecommunications industry's commitment to reducing CO<sub>2</sub> emissions involves minimizing energy consumption and upgrading to green cellular infrastructure. The primary goal of 5G networks is to create a common platform for MNO and handset manufacturers to collectively decrease the environmental footprint of their products. Noteworthy features of 5G include enhanced throughput, lower outage probability, higher bit rates, cost-effective deployment, improved spectral efficiency, and eco-friendly handset and network models. The concept of eco-friendly green radio cellular base stations using renewable energy resources is emphasized. Looking ahead, the major challenges include cost-effective operation, spectrum sharing, infrastructure sharing, supporting diverse radio technologies in a common platform, and establishing a foundation for renewable energy infrastructure. The paper envisions the evolution of 5G networks beyond 4G, highlighting the convergence of multiple standards in a single device and platform, as well as the hybrid multiple access scheme combining CDMA-OFDMA for improved performance. The adoption of green-powered base station sites, utilizing cost-effective hybrid renewable energy resources like solar, wind turbines, and fuel cells, is anticipated by 2020, aiming to reduce energy consumption and greenhouse gas emissions for energy-efficient green technologies.

**5G for Remote Areas: Challenges, Opportunities and Business Modeling for Brazil [20]:** In this study, the focus is on creating opportunities to connect underserved regions in Brazil by proposing alternative and scalable business models for deploying 5G networks in remote areas. The research includes an analysis of challenges, opportunity assessment, business cases, deployment models, incurred costs, and generated revenues for a 5G network. The deployment analysis considers two primary modes: Direct Connectivity, involving full deployment of 5G as Radio Access Network (RAN) technology, and Backhaul Connectivity, involving full deployment of 5G as Backhaul technology. Simulation results suggest that a tailored 5G system for remote areas (referred to as 5G-RANGE) with Direct Connectivity could potentially cover 75% of the unconnected population by deploying fewer than one thousand 5G sites. For Backhaul deployment, a similar population could be reached, but only around 48% of the unconnected population could be connected due to LTE sector limitations per 5G site. Both deployment modes have associated costs and revenue considerations, with the Backhaul Connectivity mode being more capital-intensive. The proposed business model revolves around the collaboration of a MNO and a Remote Managed Infrastructure Operator (RMIO), local third parties responsible for deploying and operating the access and transport network. The model is applied to four use cases (voice and data, backhaul, e-Health, and smart farming), and the financial impact is analyzed through a Profit and Loss (P&L) assessment. The results indicate a fair distribution of value generated between the RMIO and the MNO in both deployment modes, with Backhaul Connectivity being more capital-intensive but having similar paybacks to Direct Connectivity. The study provides insights into the financial viability of the proposed business model and its potential impact on connecting unconnected populations in remote areas.

**Techno-economic impact of filterless data plane and agile control plane in the 5G optical metro [21]:** This paper focuses on the optical metro segment, particularly the metro transport region and the access and core-facing edge nodes. The optical metro network is gaining attention due to the demands of 5G performance-aware applications, requiring attributes such as bandwidth, latency, reliability, and accommodating many end users for IoT applications. The paper emphasizes the need for an integrated transport + IT solution, incorporating storage/compute functions through network function virtualization (NFV). The future optical metro network is envisioned to go beyond traditional traffic backhauling. It should dynamically provision and allocate network + IT resources, including storage and compute, using wavelength division multiplexing (WDM) transport. The paper presents a benchmark of realistic metro scenarios considering topology, traffic, resilience requisites, and operational choices, addressing the challenges posed by 5G in the metro context. Two technological choices are assessed in the study: the cost savings achievable through a dynamic control plane capable of on-demand resource provisioning and the use of filterless optical architectures as a cost-effective alternative to reconfigurable optical add-drop multiplexers (ROADMs) limited to specific metro nodes. The economic implications of these decisions are analyzed through a techno-economic evaluation, considering short-, medium-, and long-term traffic scenarios under the METRO-HAUL project. Results indicate that an agile control plane offers CAPEX benefits, achieving savings of 10% to 13%, with energy savings in transponders and IT resources ranging from 20% to 40%. The utilization of filterless nodes in specific metro nodes is identified as a cost-effective strategy, showing minimal impact on spectrum waste, and limited additional WDM link requirements. The paper concludes that control plane agility is a future-proof and cost-saving option for carriers, and the deployment of filterless nodes in certain metro nodes is a favorable approach for optimizing economic benefits. The work serves as a baseline for exploring technological alternatives and can be extended to address the deployment of data-center functions in different contexts.

**Potential Applications of 5G Network Technology for Climate Change Control: A Scoping Review of Singapore [22]:** Addressing climate change stands as the foremost challenge in the pursuit of sustainable development, as it threatens to thrust millions into poverty. In response to an escalating urban crisis fueled by greenhouse gas emissions and climate threats, countries are urgently seeking policies that promote green and smart city innovations. A thorough examination of literature focused on the application of the upcoming 5G network technology in Singapore reveals several key insights. Firstly, there is a demonstrated need for a high-bandwidth, low-latency, and customized network to support diverse requirements, particularly in smart facilities management. Singapore has prioritized the concept of 5G-enabled smart cities to enhance public comfort, energy efficiency, environmental friendliness, and intelligence within buildings. Notably, low-rise institutional buildings and schools show promise in achieving zero or positive energy targets. Smart management practices, encompassing energy, waste, water resources, agriculture, risk factors, and economy in smart cities, play a crucial role in reducing climate change and aligning with sustainability goals. The efficacy of such smart management relies on technologies like the Internet of Things (IoT) and artificial intelligence, with 5G offering superior transfer speeds, low latency, reliable experiences, high connection, and traffic density, and enhanced spectral and energy efficiency at lower operational costs. Singapore has committed to a substantial reduction in greenhouse gas emissions by 2030, with the buildings sector playing a pivotal role in achieving this goal through the implementation of smart city concepts. In summary, the adoption of new 5G network technology is poised to positively impact energy, waste, risk, water resources, and economic management, leading to increased sustainability and lower climate change impacts.

**A comprehensive survey on Green ICT with 5G-NB-IoT: Towards sustainable planet [23]:** The ICT sector has revolutionized organizational operations, enhancing productivity and global economic output. However, the environmental stability is at stake due to greenhouse gas (GHG) emissions from the ICT sector, which are expected to escalate with the proliferation of ICT services. To address this, there is a shift towards renewable energy sources to reduce electricity consumption from nonrenewable sources. The integration of ICT in various sectors, such as logistics, traffic management, education, health, and agriculture, can contribute to

reducing carbon emissions. This survey paper explores green techniques in ICT to minimize energy consumption in key contributors like Data Centers, Access Networks, Base stations, and smart user devices/sensors. It discusses the role of 5G NB-IoT as a greener physical layer solution for massive IoT applications. Key findings include the classification of techniques to reduce Data Center-generated carbon emissions, the importance of adaptive power consumption techniques with predictive analysis, the impact of Access Networks densification and the use of Aerial Base Stations, the role of Mobile Edge Computing and Fog Computing, the significance of artificial intelligence in environmental sustainability, and the potential of recovering waste heat for GHG emission reduction. The field of Green ICT, encompassing technologies like 5G NB-IoT, is gaining traction for its potential to contribute to environmental sustainability.

In [Deliverable 6.2](#), our primary focus was assessing the feasibility of adopting 5G in a more techno-economic context. We explored the possibility for MNOs and, in specific instances, individuals (especially for private networks) to embrace 5G networks. Drawing insights from our previous deliverable and an examination of over ten studies, we have determined that transitioning from 4G to 5G can be achieved seamlessly, with a minimal initial investment, by leveraging existing infrastructure. That approach allowed for manageable costs and timeframes in the adoption of 5G, enabling operators to promptly offer services to users. Simultaneously, they could enhance their networks and progress in tandem with evolving technology and demand. Collaborative expansion across various sectors was imperative to eliminate digital divides. Consequently, MNOs, SMEs, and third-party companies needed to synchronize efforts and collectively strive to adopt 5G technology.

From a financial standpoint, a recurring conclusion from those studies was that a deployment solution with the lowest Total Cost of Ownership (TCO) did not always correlate with the highest profit. Industries were advised to consider and prioritize technologies or deployment strategies that facilitate a smooth transition to 5G, as that could have economic implications for both initial investments and long-term profits. By focusing on specific technologies, industries could devise profitable solutions that remained sustainable over time.

Those techno-economic analyses underscored operators' interest in adopting new technology, while also expressing concerns about costs, model viability, and the challenges associated with transitioning between technology generations. Despite these concerns, it was established that this transition was not only crucial and necessary but also highly beneficial and cost-efficient for MNOs. The expanded capabilities and new services supported by 5G networks presented opportunities for MNOs to enhance their reach and profitability. Strategic planning and economic analyses played a pivotal role in guiding operators to choose the most suitable and cost-effective solutions based on factors like demand, geographical considerations, and other technical criteria.

In this deliverable, our objective is to broaden our focus to assess not only the feasibility from a techno-economic standpoint but also the sustainability of adopting and proliferating 5G technology. On one hand, as observed in the reports examined in this deliverable, the development of new types of equipment and 5G components can potentially contribute to environmental harm and pollution. On the other hand, there are countries seeking to invest in 5G technology with the goal of leveraging it to reduce energy consumption and improve the management of water resources.

The EU Digital Decade Communication underscores the pivotal role of digital technologies, such as artificial intelligence, 5G, cloud and edge computing, and the Internet of Things, in achieving the sustainability goals outlined in the Green Deal across various sectors. The European Telecommunications Network Operators' Association (ETNO) highlights its members' initiatives to reduce emissions and energy consumption, emphasizing the deployment of new mobile high-speed networks, especially 5G, for improved energy efficiency [24].

The efficiency improvements linked to 5G deployments stem from its operational efficiency and architecture, which emphasizes infrastructure sharing to reduce costs. Additionally, fiber network deployments are expected to enhance energy efficiency. Test pilots by Ericsson demonstrate that 5G technology can be up to 90% more energy-efficient than 4G in terms of energy consumption per unit of traffic. Vodafone's trials in Central London resulted in a 43% reduction in energy consumption [24].

While short-term energy usage for mobile operators may increase, 5G incorporates smarter operations with sleep modes to break the historical link between new standards and rising energy consumption. In the realm of climate action, the GSMA aims for the mobile industry to achieve net-zero carbon emissions by 2050 [24]. Major mobile operators, including Verizon, Telefónica, and Vodafone, have set ambitious goals to reach net zero or achieve significant emissions reductions by specific deadlines.

Operators are focusing on energy-saving measures, including optimizing energy consumption, and integrating renewable energy sources. For instance, initiatives by Vodafone involve deploying more efficient network equipment, phasing out less energy-efficient 3G networks, and implementing systematic energy-saving measures. Several operators, including Deutsche Telekom, Turkcell, and Vodafone, are committed to using renewable sources, with a reported 23% increase in the use of renewable energy sources by ETNO members overall [24].



Figure 10: 5G and sustainability

The EU is urged to promote and invest in digital transformation, recognizing its critical role in attaining sustainability goals across various sectors. Digitalization presents new opportunities for monitoring air and water pollution, as well as optimizing energy and resource usage. The communication advocates for a digital sector that prioritizes sustainability, ensuring that digital infrastructures and technologies become more verifiably sustainable, energy-efficient, and contribute to a circular and climate-neutral economy and society in alignment with the European Green Deal.

## 2.3 5G-NPN AND PRIVATE WIRELESS GROWTH

### 2.3.1 The private networks from the operators' perspective

It is evident from the analysis presented in [Deliverable 6.2](#) that there are mutual benefits from the integration of 5G networks into industrial premises. While various modes of involving 5G in Industry 4.0 were documented, based on public networks with or without SLAs and slicing, and/or including local/dedicated

infrastructure, the interest is put-on Non-Public Deployments, using un-licensed, private or operator-owned spectrum according to the national regulations in place per case [25].

From the 3GPP standpoint, the non-public network is a network that is intended for non-public use and includes the concept of private network, which is an isolated network deployment that does not interact with a public network. In practical terms these networks are also called 5G Campus networks. 3GPP has supported the development of the NPN concept targeting effective network control, low latency, guaranteed indoors coverage, higher performance and security based on vertical/entity specific roles and positions. 5GPP State of the art analysis on NPN argues that NPNs are the ideal choice to meet the diverse requirements of the verticals as highlighted in Figure 11 below [25].

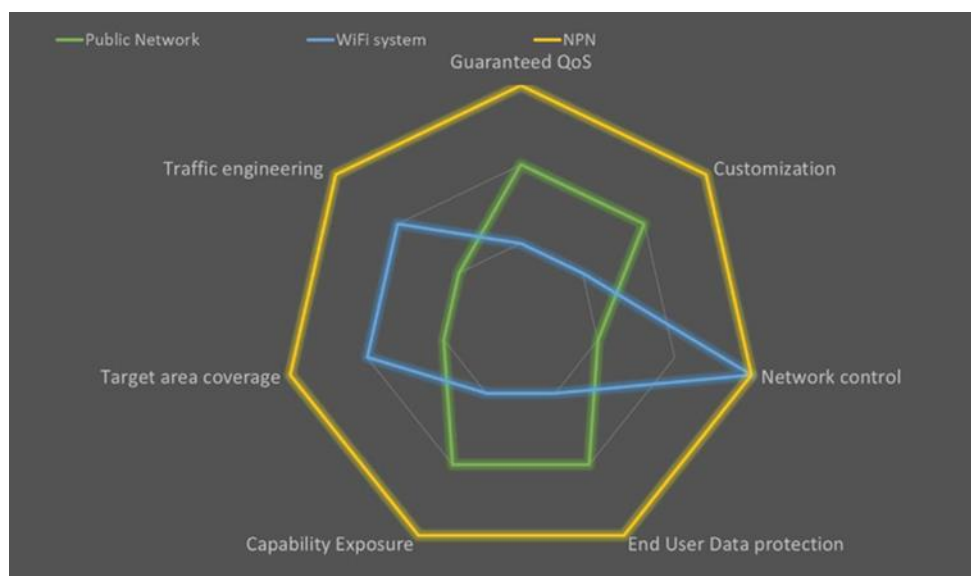


Figure 11: Technological Choices to meet the use case demands

Acknowledging that there are many possible configurations of NPNs [26], 3GPP defines two major categories of NPNs:

- Standalone Non-Public Network (SNPN), operated by an NPN operator and not relying on network functions provided by a Public Land Mobile Network (PLMN) and
- Public network integrated NPN (PNI-NPN), a non-public network deployed with the support of a PLMN.

Evidently being isolated, the SNPN provides autonomy, data privacy, low latency, fully controlled local 5G operations with in-house networks and devices, but it also poses the challenges of operation and maintenance, capacity planning and efficient use of spectrum available, QoS monitoring, security & privacy protection measures and overall technology expertise. Key parameters on planning for the appropriate NPN solution are:

- Spectrum Availability: In Europe, the approach for the spectrum bands and bandwidth to be used for the 5G private network rollouts is different among the Member States: The German regulator BNetzA has reserved 100 MHz of spectrum on the 3700 – 3800 MHz band for NPNs; in the UK, Ofcom has made available through local licenses the spectrum in the 3.8–4.2 GHz band and in addition the 24.25–26.5 GHz band for indoor use; in Finland, the 3.5 GHz licensees are obliged to either offer services to verticals in local areas or sub-license their spectrum to verticals.
- 5G ownership and maintenance: The willingness and ability of an organization to host, manage and maintain the network itself or through strategic partnerships and/or outsourcing, the need for local processing, single or multi-factory deployments, device subscription management (in factory only or in public or both) are decisive factors in shaping the appropriate solution.

- Service Level Agreements: Requirements on close monitoring of the network performance, maintenance of end-to-end SLAs across all network sections (including multiple technologies and owners) as well as the negotiation of the KPIs in respect to network QoS requirements are shaping not only the appropriate NTN category selection but features, components and APIs that must be supported.
- Security & Privacy: Depending on the industry requirements for all data to remain inside the premises for privacy and the need for role-based security and access to machines/devices or units the appropriate deployment mode can be selected.

The deployments mode foreseen for private networks include following options [27]:

- **Managed Services**: Either (option A) the industrial enterprise sets the requirements, selects the vendors, service providers & integrators to build the network and negotiates the maintenance with them, or (Option B) proceeds with an MNO-managed private network, and the industrial enterprise sets choice of spectrum, required QoS, monitoring and SLAs.
  - **Enterprise-run full service**: The enterprise installs and manages its own 5G network on premises investing in building the necessary expertise and taking over the cost of maintaining the network.
  - **Neutral Host Model**: Neutral host networks are a business model which is deployed in multiple different ownership models: developed by landlords/ owners that are willing to deploy a wireless indoor infrastructure on their premises, the enterprise itself, or by a third-party MNO. In neutral host model industrial enterprise may take advantage of two different service providers to run its networks. For example, one service provider may manage the private networks and the other provider can take care of the PNI-NPN portion of the facility.

The European Commission is attempting to monitor the private network deployments, and identify operators and vendors involved, sectors in which the private 5G networks are deployed and the spectrum band used. The list maintained by the 5G Observatory team [28], last updated September 2023 and produced based on research of publicly available information currently contains less than 100 entries.

While the roll out of private 5G networks is still in a relatively early growth phase, according to Gartner estimates [29], the private LTE and 5G network sales are expected to reach \$8.3 billion in sales by 2026, with a compound annual growth rate of 35.7 percent over the forecast period rising from \$1.7 billion in 2021. In the GSMA report on Private 5G Industrial Networks [27] published June 2023, Figure 12 is illustrating the development of the addressable market for private networks in different industry sectors over time and an estimate of the revenue opportunities [27].

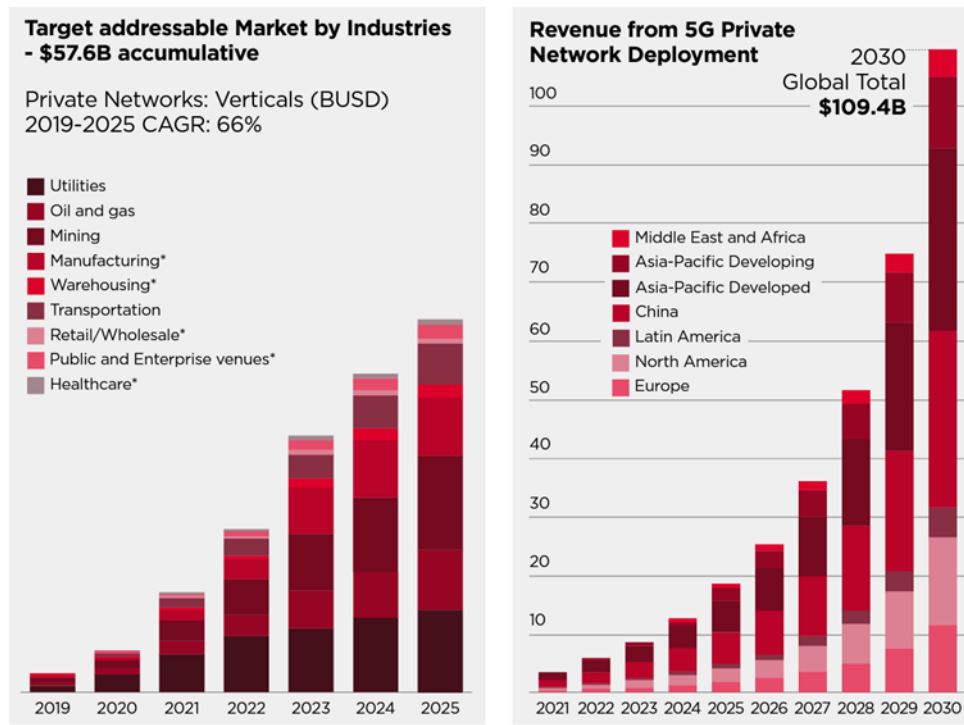


Figure 12: The addressable market and revenue opportunities for 5G private networks 5G Americas

It is therefore justified that the NPN market is quickly becoming a multi-stakeholder game, with many supplier propositions, either with worldwide offerings or regional focus, primarily including[27]:

- MNOs, as many of them already provide private network solutions to enterprise customers.
- Private vendors, such as CTS<sup>1</sup>, Boingo<sup>2</sup> that offer '5G-as-a-Service' (5GaaS).
- Equipment vendors such as Nokia, Ericsson, Huawei that have 5G SNPN network products.
- Cloud providers (hyperscalers) such as Amazon Web Services, Google Cloud Platform and Microsoft Azure are offering 5G private network (SNPN) integrated with their edge computing solutions.

In the 5GPPP State-of-the-art study for NTN [25], the 5G PPP actor role model was extended beyond the previous public-service oriented view to incorporate the non-public services. Furthermore, the concept of private networks was extended to include the integration of multiple access technologies as critical for the Industry 4.0 adoption as an integral part of the NTN E2E service delivery. This is depicted in Figure 13 and decouples the private and public roles to keep in-house management and orchestration separated from the provisioning activities executed on the PLMN. Additional roles are also provided on top of the reference 5G PPP model, to include more wireless access technologies (WAT and WAT aggregator) as well as small scale infrastructure service providers in local or cluster of local environments (DCSP).

<sup>1</sup> <https://www.cts1.com/cbrs-private-lte>

<sup>2</sup> <https://www.boingo.com/5g/>

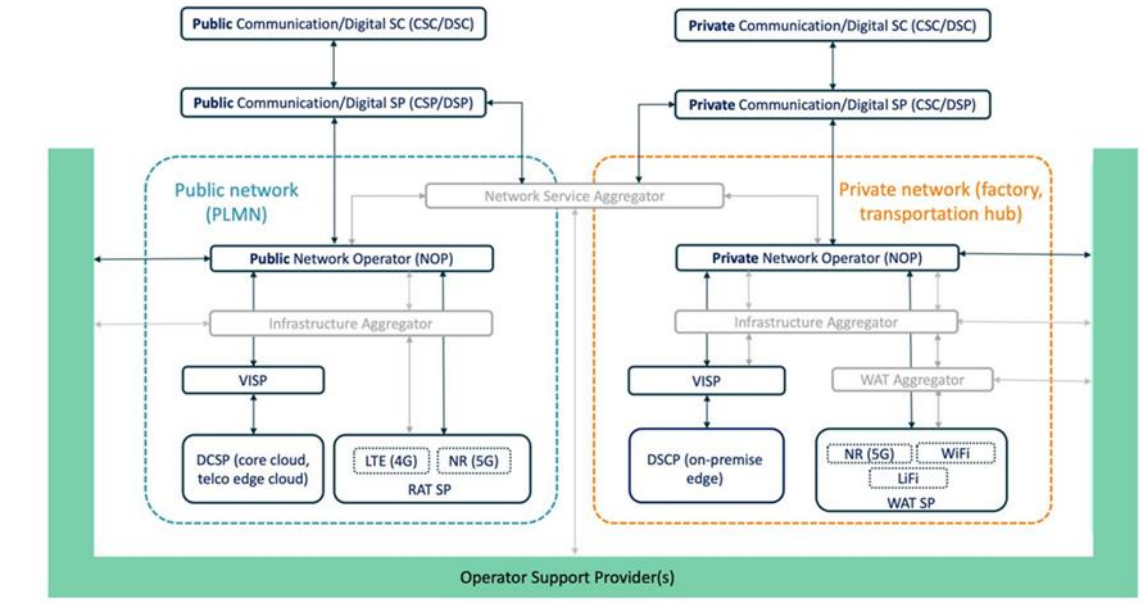


Figure 13: Extension of 5G PPP actor role model for NPN support

### 2.3.2 The private networks from the verticals' perspective

A private 5G network, alternatively referred to as a non-public network, is a mobile network established on the owner's designated premises. It allows limited access and utilizes licensed or unlicensed wireless spectrum. These networks provide enhanced control compared to traditional ones, allowing configuration for varying levels of access, and supporting continuous operations to improve service availability. The selection of network types depends on specific needs and requirements, with the possibility of combining both into a hybrid model comprising a 5G NPN and a 5G public network.

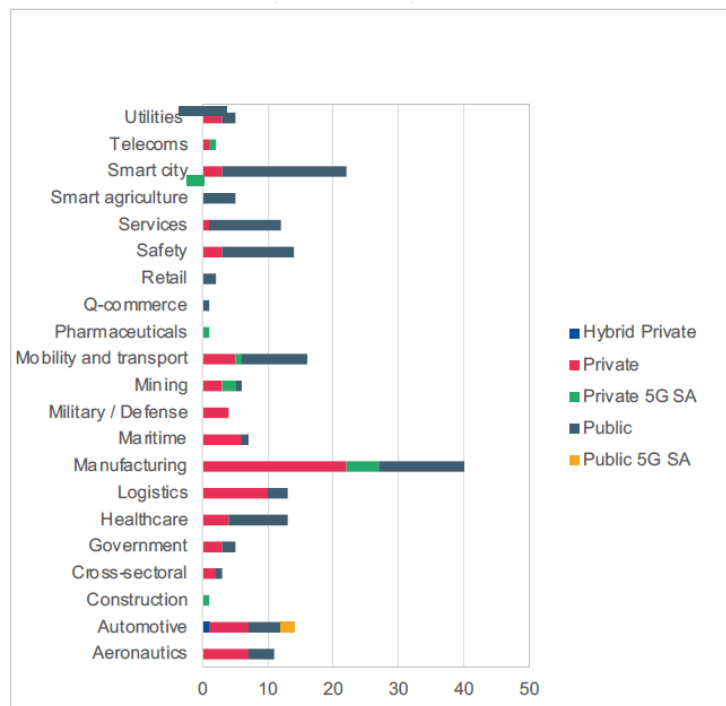
The development of a 5G NPN offers several advantages for organizations or companies, particularly in terms of security and control, achieved through robust encryption, authentication options, and network slicing. Despite the implementation of these security measures, the most notable and valuable feature of this network is its ability to operate in isolation from the provider's public network. Only devices belonging to the owner can access and leverage the capabilities of the network. With this isolated environment, external threats can be eliminated, internal ones can be addressed effectively, and even in the event of an internal issue, it can be easily managed.

Moreover, the reliability within this network is elevated, given that the placement of network components is at the discretion of the owner. This enhances coverage, facilitates better monitoring and management of connected devices, and ensures more consistent network performance. In this context, efficiency is heightened as private 5G networks leverage significantly increased network speed, higher bandwidth, and lower latency.

Private 5G networks are experiencing rapid growth and hold a significant position in global deployments. Specifically, in the USA, 5G NPNs are increasingly utilized in the military, defense, and manufacturing sectors [3]. In Korea, private 5G initiatives are flourishing across various industries, including utilities, manufacturing, and healthcare.

Turning our focus to Europe, Spain, while deploying 5G NPN, is recognized as a leader in public 5G networks implemented within the context of smart cities. In contrast, Germany is a global frontrunner in 5G initiatives for manufacturing, collaborating with key national industry leaders, particularly in the automotive sector. Italy, within the same sector, demonstrates a keen interest in the development of 5G private networks. Lastly,

France is at the forefront of the mobility and transport sector, as well as smart cities. In general, there is a discernible and active interest in the adoption and investment in 5G private networks, especially in manufacturing, smart cities, smart factories, and industries where automation plays a pivotal role [3].



Source: IDATE, *Industrial 5G deployments*, February 2023

Figure 14: The amount of 5G initiatives by sector and type of network globally

With the increasing adoption and comprehension of the functionalities of 5G NPN, vertical industries and companies are identifying a growing number of potentials and applicable use cases. Notably, in the healthcare sector, the inaugural European clinical trial of remote proctoring technology for invasive heart surgery using a private 5G network has transpired. This entails a scenario where a medical device expert, through remote proctoring, can guide the precise implantation of medical devices into the human body. This use case achieves real-time access to patient data, enabling the expert to provide surgical instructions promptly, and the doctor can interact with a 3D model to convey procedural complexities.

In this vein, Vodafone, in collaboration with Frankfurt University Hospital, is poised to deploy a cutting-edge 5G infrastructure. The objective is to facilitate telemedical diagnosis for Covid-19, conduct mobile ultrasound examinations, maintain digital health records, and optimize both internal and external processes [3]. Meanwhile, in Belgium, E-BO Enterprises and Jan Yperman Hospital are joining forces to establish a high-end 5G infrastructure. This infrastructure aims to provide remote assistance to connected emergency response vehicles, transport blood samples via drones, and offer remote classrooms for sick children unable to attend physical classrooms.

Within the framework of another EU project under the Horizon 2020 call, specifically named **5G RECORDS**, two out of three use cases have been implemented based on 5G New Production Network (NPN). This project aims to usher in a new era in the market, particularly within the content production sector, by integrating and validating innovative technologies. The primary goal is to incorporate 5G components into these use cases and assess their performance within professional content production environments.

To elaborate further, the initial use case centers around live audio production implemented in a local 5G network designed for high-quality, ultra-reliable, and low-latency audio production [30]. This network is

established based on standalone New Production Network (NPN), utilizing the design of a NR-Redcap audio device prototype. With a 5G system-based approach, the objective is to streamline current efforts related to managing remote production and spectrum access. The testbed created for this purpose will facilitate the implementation of scenarios such as live events. It will offer temporary spectrum access tailored to the specific needs of each equipment component, automate the setup of wireless equipment, and ensure a local high-quality network.

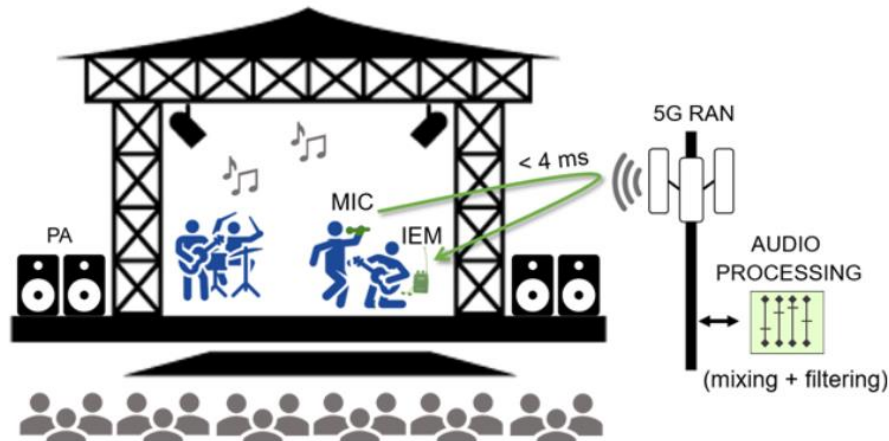


Figure 15: Use case of Live audio production

The second use case revolves around multi-camera audio and video production within a professional setting, aiming to emulate the performance and capabilities of existing technologies like COFDM radio cameras using 5G technology [30]. Additionally, it explores multi-location scenarios, encompassing production facilities local to an event and remote and distributed production models. In certain scenarios, it anticipates integrating 5G-based contribution solutions with different network configurations to establish contribution links into production centers.

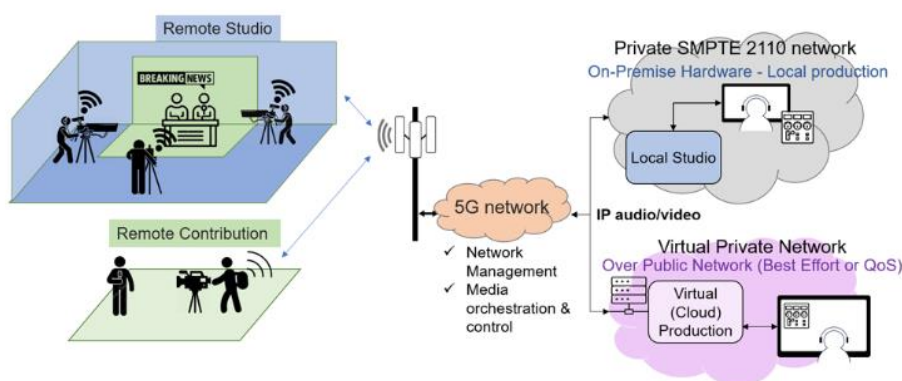


Figure 16: Use case of Multiple camera wireless studio

In this context, 5G New Production Networks (NPNs) are crucial, enabling a self-operated environment independent of the network conditions of any underlying MNO. The scenario envisions the potential for 5G-enabled equipment to seamlessly switch between NPNs and public networks during productions, maximizing interoperability between different systems and components through a common IP-based infrastructure [30].

The wider the growth of NPN networks, the greater their adoption potential, as they can cater to diverse scenarios and use cases. From a security and configuration standpoint, 5G private networks can be highly competitive compared to other network types, offering a secure and isolated environment. Generally, the deployment options for private networks are varied and should be chosen based on parameters such as spectrum availability in the region and the required spectrum bandwidth for the operational use case.

Moreover, for use cases necessitating an isolated and extremely secure environment, it is crucial to consider the worst-case scenario and plan for fallback options. In emergencies, a combination of two or more different types of NPN could prevent such situations, ensuring network stability and operational continuity. In any scenario, 5G NPN can collaborate seamlessly with other networks, establishing a secure 5G connection efficiently and enabling different types of devices to communicate and collaborate effectively.

### 3 TECHNOECONOMIC ASPECTS AND BUSINESS ANALYSIS

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In deliverable [D6.2](#), our focus centered on examining the techno-economic aspects of the EVOLVED-5G ecosystem, employing a four-step methodology encompassing Business Models and Value Networks, Business Case Viability Study, the impact of new technologies on the business case, and sensitivity analysis. Having defined and explored this approach, the current deliverable delves into a detailed exploration of the Business Model Canvas specific to the EVOLVED-5G [service package](#).

The analysis, presented in subsection 3.1, elucidates the purpose and necessity of the Business Model Canvas and provides a completed version tailored to the service package. The EVOLVED-5G service package consolidates all developments within EVOLVED-5G related to Network Applications, encompassing components such as [CAPIF](#), [NEF](#), [TSN](#), [SDK](#), and [Dummy Network App](#). Subsection 3.2 conducts a cost analysis for each component of the service package, spanning from the 5G infrastructure to SDK tools and the marketplace. An itemized breakdown of estimated costs justifies the numbers, usage, and necessity of each component.

Functioning as a SaaS, the EVOLVED-5G service package facilitates developers in initiating the development of Network Applications. Developers can interact with the Dummy Network App within this Virtual Machine (VM) to comprehend the network communication process with NEF and TSN through CAPIF. Subsection 3.3 will define SaaS, delineate its basic characteristics, and explore reasons reinforcing the openness of 5G technology.

#### 3.1 BUSINESS MODEL CANVAS

The Business Model Canvas serves as a strategic management tool that offers a straightforward method for visualizing and evaluating a business concept. It is a chart comprising nine fields that depict the value proposition, infrastructure, customers, and financial aspects of a product or service. The primary objective of this tool is to delineate how the analyzed business idea can generate profitability.

The Business Model Canvas is a versatile and customizable tool that can be adjusted to suit the specific requirements of any company, regardless of its size or industry. Furthermore, it offers a methodical framework for enterprises to investigate opportunities and experiment with fresh concepts, fostering creativity and innovation. Moreover, this visual representation of crucial business facets and all key elements of the business model offers a comprehensive perspective, aiding all team members in achieving alignment and facilitating effective collaboration.

Originally conceived by Alex Osterwalder and Yves Pigneur, the Business Model Canvas template was designed as a framework for planning and testing a company's business model. This template can be divided into two distinct sections. The right side is dedicated to external factors that can impact the product or service, focusing on the customer and the market. Meanwhile, the left section delves into internal factors, activities, and costs, aiming to best prepare the product or service for efficient customer interaction.

There are various business models that could be suitable for generating revenue from the facility.

A model that seems very well suited for the EVOLVED-5G facility is the freemium business model. A combination of the words "free" and "premium," freemium is a type of business model that offers basic features of a product or service to users at no cost and charges a premium for supplemental or advanced features. Freemium models are especially popular among software applications and internet-based businesses.

In our case, the facility could be offered to users on a complimentary basis, but there would be a cost for additional services such as:

- Hosting a 3rd party application (providing storage, processing, bandwidth).
- Offering training sessions.

- Offering premium technical support with SLA.
- Developing additional features & customizations that could be interesting to 3rd parties.

This type of business model has the advantage of acquiring a large set of initial users, especially since there is no cost associated with trying out the service. This way the consortium can build initial relationships with customers and build awareness, that could later be exploited for revenue. An additional benefit is that the customer acquisition cost is low. A disadvantage/risk of the freemium business model is that the majority of users might never convert to paying customers.

The freemium business model is included in a list of the “7 Most Successful Business Models Of The Digital Era” [31]. A different version of the freemium model is the “Razor Blade” model. Razorblade companies offer the razor handle and the first few blades super cheap and then generate cash when you go back every month to buy expensive new blades. In our case, we could perhaps offer customers the ability to develop a certain number of applications, or generate a certain number of monthly API calls, and then charge a fee for exceeding these thresholds. This “Razor Blade” model could be exploited in combination with the freemium model.

The Business Model Canvas comprises nine fundamental components. To begin, we have "Customer Segments," which pertain to the groups of individuals, companies, and markets that may express an interest in our services. This analysis can be performed by considering the diverse needs of these customers and will enable the company to tailor its approach accordingly.

The order of these steps is provided, and there are multiple alternative sequences for numbering and initiating them. In our instance, we follow the approach illustrated in the accompanying Figure 17 when completing the Business Model Canvas.

Business Model Canvas		Designed for: Startup Name	Designed by: Name1, Name2, ...	Date: DD/MM/YYYY	Version: X.Y
<b>Key Partners</b> Who are our Key Partners? Who are our key suppliers? Which Key Resources are we acquiring from partners? Which Key Activities do partners perform?  MOTIVATIONS FOR PARTNERSHIPS: Optimization and economy, Reduction of risk and uncertainty, Acquisition of particular resources and activities	<b>Key Activities</b> What Key Activities do our Value Propositions require? Our Distribution Channels? Customer Relationships? Revenue streams?  CATEGORIES: Production, Problem Solving, Platform/Network  <b>Key Resources</b> What Key Resources do our Value Propositions require? Our Distribution Channels? Customer Relationships Revenue Streams?  TYPES OF RESOURCES: Physical, Intellectual (brand patents, copyrights, data), Human, Financial	<b>Value Propositions</b> What value do we deliver to the customer? Which one of our customer's problems are we helping to solve? What bundles of products and services are we offering to each Customer Segment? Which customer needs are we satisfying?  CHARACTERISTICS: Newness, Performance, Customization, "Getting the Job Done", Design, Brand/Status, Price, Cost Reduction, Risk Reduction, Accessibility, Convenience/Usability	<b>Customer Relationships</b> What type of relationship does each of our Customer Segments expect us to establish and maintain with them? Which ones have we established? How are they integrated with the rest of our business model? How costly are they?  <b>Channels</b> Through which Channels do our Customer Segments want to be reached? How are we reaching them now? How are our Channels integrated? Which ones work best? Which ones are most cost-efficient? How are we integrating them with customer routines?	<b>Customer Segments</b> For whom are we creating value? Who are our most important customers? Is our customer base a Mass Market, Niche Market, Segmented, Diversified, Multi-sided Platform	
<b>Cost Structure</b> What are the most important costs inherent in our business model? Which Key Resources are most expensive? Which Key Activities are most expensive?  IS YOUR BUSINESS MORE: Cost Driven (leanest cost structure, low price value proposition, maximum automation, extensive outsourcing), Value Driven (focused on value creation, premium value proposition).  SAMPLE CHARACTERISTICS: Fixed Costs (salaries, rents, utilities), Variable costs, Economies of scale, Economies of scope		<b>Revenue Streams</b> For what value are our customers really willing to pay? For what do they currently pay? How are they currently paying? How would they prefer to pay? How much does each Revenue Stream contribute to overall revenues?  TYPES: Asset sale, Usage fee, Subscription Fees, Lending/Renting/Leasing, Licensing, Brokerage fees, Advertising FIXED PRICING: List Price, Product feature dependent, Customer segment dependent, Volume dependent DYNAMIC PRICING: Negotiation (bargaining), Yield Management, Real-time-Market			

Designed by: The Business Model Foundry ([www.businessmodelgeneration.com/canvas](http://www.businessmodelgeneration.com/canvas)). PowerPoint implementation by: Neos Chronos Limited (<https://neoschronos.com>). License: CC BY-SA 3.0

Figure 17: Business Model Canvas template

The "Value Proposition" segment is among the most pivotal sections within the Business Model Canvas, as it underscores the distinctiveness of the product or service and elucidates what the company can provide to its

customers. It delineates the company's unique selling point and highlights the elements that differentiate it from competitors.

The third section is "Channels," which pertains to the means by which you connect and communicate with your customer segments. Channels encompass the pathways through which customers engage with your business and become integrated into your sales process.

Next, the "Customer Relationship" section outlines the various ways through which the company can engage with these distinct customer segments. This approach can take on a more personalized form, where the company communicates directly with customers via social media, newsletters, forums, and similar avenues. On the other hand, a communal approach can also be effective, allowing the company to interact with customers who provide feedback, share opinions, or assist one another in resolving issues independently.

The "Revenue Streams" section is dedicated to exploring all the avenues through which the business can generate income. This analysis helps identify the most profitable and enduring methods, such as asset sales, subscription fees, licensing, and more. To obtain realistic insights, several questions must be addressed, including the amount customers are willing to pay and the payment methods they prefer. Additionally, a comprehensive examination of each revenue source is essential to understand its contribution to the overall revenue.

Moving on, the "Key Resources" section outlines the essential assets necessary for both the launch and sustained operation of the product or service. These assets may encompass physical locations (offices), human resources, financial resources, transportation, and more. The "Key Activities" refer to the tasks your business performs to deliver the value proposition to the customers. These activities constitute the critical actions in implementing a company's value proposition, encompassing areas such as product distribution, research and development, and strategic endeavors. They are the pivotal activities that drive the execution of a company's value proposition.

The field of "Key partners" refers to external companies or suppliers that are essential for carrying out your key activities and providing value to customers. To enhance operational efficiency and minimize business model risks, organizations often establish buyer-supplier relationships, allowing them to concentrate on their core operations. Additionally, companies may explore collaborative business partnerships, including joint ventures or strategic alliances with both competitors and non-competitors. It's crucial to map key partners to key activities for a comprehensive understanding of their roles.

Finally, the "Cost Structure" describes all the costs and expenses associated with the existing business model. This phase is significant as it aids the team in determining whether to pivot or continue with the current approach. Businesses can be categorized as either cost-driven or value-driven. A cost-driven company seeks to minimize all expenses, whereas a value-driven company places a higher emphasis on delivering exceptional customer value in terms of quality or prestige.

After establishing the purpose of the Business Model Canvas and the template used in the context of developing the service package for EVOLVED-5G, the subsequent phase involved completing the template and analyzing the provided inputs as they are depicted in Figure 18.

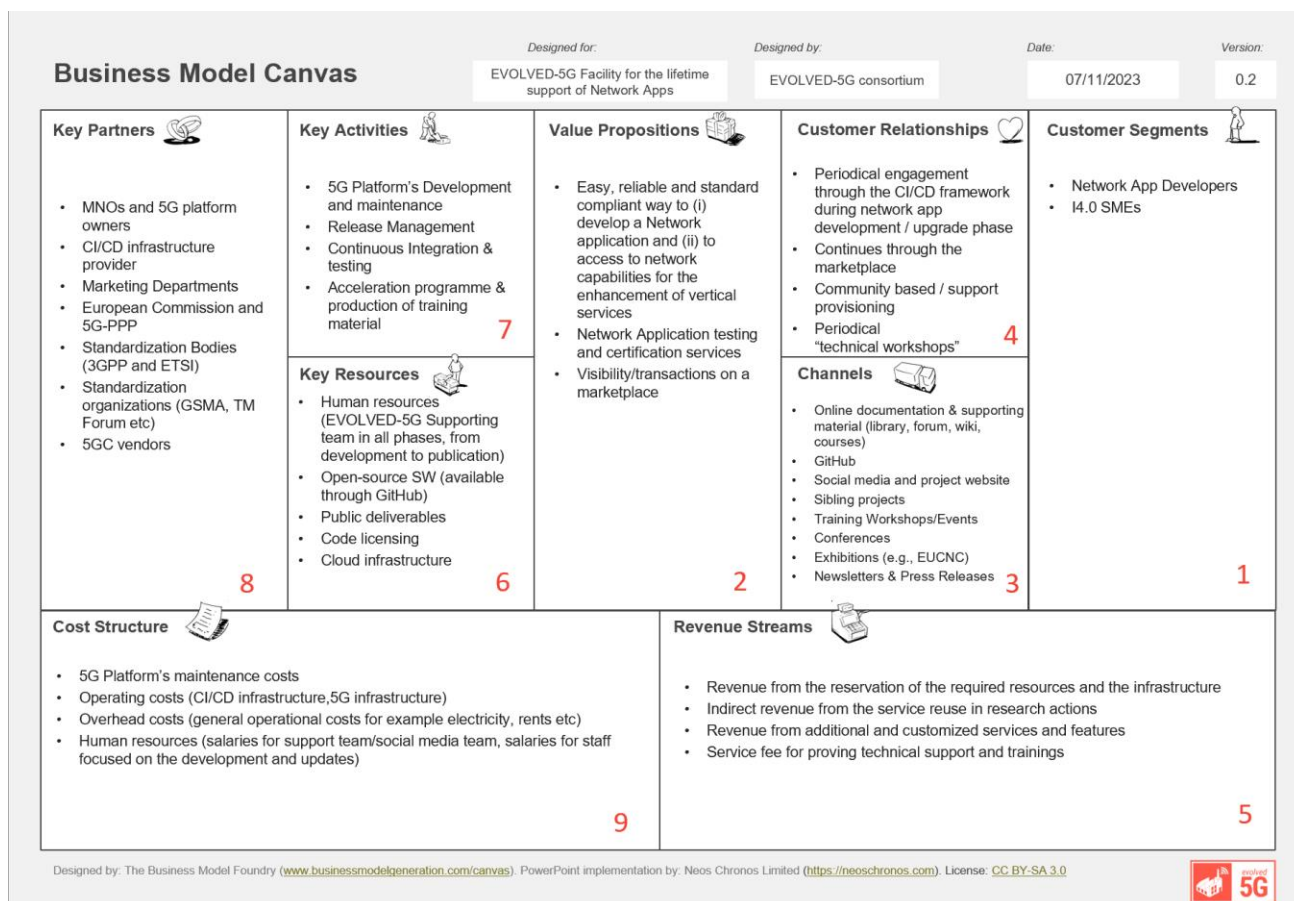


Figure 18: Business model canvas for the EVOLVED-5G service package

The customer segments that could be targeted by the EVOLVED-5G facility are Network App developers (either software developers or integrators) and SMEs that develop solutions targeting Industry 4.0. These target groups usually lack facilities for developing & testing applications, especially since in this case a 5G network is also necessary. Other target groups, such as MNOs, are not a priority as they normally have their own testing facilities.

The value proposition that the facility can offer to these groups of customers, is an easy, reliable and standards compliant way to enter the market of developing Network Apps interfacing 5G networks and serving the needs of certain industry segments. By leveraging the 5G network integration, these applications can offer enhanced services to the targeted verticals.

In addition, the facility offers Network Application testing and certification services. The facility marketplace offers visibility of the developed applications and supports transactions, so that a 3rd party could obtain an application.

The above tools and services, satisfy some common problems for developers and integrators: (i) to access a reliable development and testing environment for their applications, (ii) become exposed to a standards-based test plant that benefits from the huge global 5G ecosystem, and (iii) to obtain visibility for their products, since SMEs commonly lack marketing capabilities.

The various channels that can be leveraged in order to reach potential customers are:

- Online documentation & supporting material (including libraries, forums, wiki, courses).

- GitHub, which is used to store and manage the code, and is the most popular option for developers.
- The project's social media channels and website.
- Similar projects that also focus on Network Apps, since there have been several initiatives for collaboration between them.
- Training workshops & events.
- Conferences where consortium members have presented the results of the project.
- Exhibitions (e.g., EUCNC) where we have participated or will participate in the future.
- Newsletters and press releases either from the consortium as a whole or from individual members.

The preferred customer relationships for the identified customer groups are centered around the services offered by the facility. These include periodic engagement through the CI/CD framework during network app development, testing and upgrade cycles. Engagement carries over through using the marketplace for the developed applications. In addition, there are various opportunities for the developer's community engagement through support sessions/events and periodic technical workshops.

The key activities that need to be performed include the 5G platform continued development and maintenance, release management, and continuous integration and testing. With regards to supporting and growing our community, a major activity is the acceleration program that is being performed by the consortium and the production of training and support material. In addition, in case needed by the customers, we might need to offer dedicated support service and further development of requested facility enhancements.

The key partners that are essential for the facility are the following:

- MNOs and 5G platform owners: the facility is built either leveraging an MNO public network or a dedicated (NPN) 5G network instance.
- Provider of the CI/CD infrastructure.
- Marketing departments of the partners that are involved in the customer relationship handling.
- European Commission and 5G-PPP.
- Standardization bodies and organizations (e.g., 3GPP, GSMA, ETSI, TM Forum, Linux Foundation) since the infrastructure is built by utilizing standards-based solutions where possible.

5GC vendors: the vendor of the 5GC is a central partner of the facility. The APIs that interface 5GC with the external world are essential and adherence to standards, functionality and continuous development is key for the competitiveness of the facility. In addition, the 5GC vendor has an interest to expand the developer community who develop external applications for the specific 5G product. The larger the community becomes the more interesting the 5GC product becomes for prospective customers. In this sense, the consortium's relationship with the 5GC vendor has the potential to become important and could be further leveraged for common marketing events (e.g., hackathons, demonstrations) for reaching out prospective clients. If properly cultivated, this relationship could become key in the sustainability of the facility, as the 5GC vendor could become a 'sponsor' if convinced for the business value.

The facility's cost structure includes :

- Maintenance costs associated with the 5G platform.
- Operating costs related to the 5G and CI/CD infrastructure.
- General overhead costs for example, electricity, rents, etc.

Human resources cost, that includes salaries for support team, staff focusing on continuous development and updates, and social media/marketing teams.

### 3.2 COST ANALYSIS

The EVOLVED-5G facility has been developed based on three main types of components, namely a) those that refer to compute & connect infrastructure, b) those that refer to software developments during the project lifetime, and c) those that refer to integrations of open-source software and tools brought by project partners. In this section, we estimate the cost (CAPEX and OPEX) required for establishing the EVOLVED-5G facility, and we investigate various scenarios for service provisioning through the facility.

The compute & connect infrastructure refers to radio (gNBs), transport (switches), and auxiliary hardware components as well as to computational resources and orchestrators required for hosting network functions. The compute & connect infrastructure has been materialized in two experimentation platforms, i.e., in Athens and Malaga, and as such, the platform owners based on their experience provided estimations on the CAPEX and OPEX cost for every relevant component.

The software components that developed during the project lifetime are actually the ones depicted in the functional architecture of the project (see the relevant deliverable - D2.3). The CAPEX for those developments has been estimated, based on the effort allocated during the project lifetime (mainly tasks T3.1, T3.2, T3.4, and T4.1), while the OPEX is negligible since the service package is provided as open-source software under Apache 2.0 license. However, we estimated that a yearly cost of a single PM (where the PM rate can vary from 3800 to 6000 Euros) is the minimum required OPEX. Similarly, the CAPEX for the integrations of other open-source components has been estimated, based on the effort allocated during the project lifetime (mainly T3.3). Figure 19, depicts the estimated cost per component.

ESTIMATED COSTs for the ingredients of the EVOLVED-5G Facility					
list of units that compose the Facility		CAPEX			OPEX
Type	Description	Estimated Cost in Euros (MIN)	Estimated Cost in Euros (MAX)	Estimated Cost in Euros (Average)	Estimated OPEX per Year of the next 5 years
Components of the Compute and Connect Infrastructure	Cloud compute unit + Proxmox (3 servers - 12 CPUs - 376.69GB RAM)	15,000.00 €	15,000.00 €	15,000.00 €	2,000.00 €
	Cloud compute unit + Openstack (1 server - 12 vCPUs - 24GB RAM)	5,000.00 €	5,000.00 €	5,000.00 €	2,000.00 €
	Cloud Compute Unit (4 CPU + 60 GB RAM)	990.17 €	1,998.19 €	1,494.18 €	730.00 €
	5G SYSTEM (Amarisoft Classic)	25,000.00 €	25,000.00 €	25,000.00 €	2,500.00 €
	5G COTS UEs	326.00 €	1,304.00 €	815.00 €	0.00 €
	5G SA UE	500.00 €	1,500.00 €	1,000.00 €	0.00 €
	5G RAN (macro cell e.g., Nokia Airscale)	15,000.00 €	45,000.00 €	30,000.00 €	4,500.00 €
	5G Core (COTS e.g., amarisoft, athonet etc)	35,000.00 €	60,000.00 €	47,500.00 €	6,000.00 €
	5G Core ( commercial / use by operators )	150,000.00 €	250,000.00 €	200,000.00 €	20,000.00 €
	UPF for MEC	9,000.00 €	15,000.00 €	12,000.00 €	2,000.00 €
	TSN (switch)	2,156.00 €	2,156.00 €	2,156.00 €	0.00 €
	mmWave Links (Gbps)	150.00 €	750.00 €	450.00 €	0.00 €
	P2P 10G Links (Optical- SFPs)	500.00 €	1,500.00 €	1,000.00 €	0.00 €
	Access Transport incl. Backhaul	4,553.28 €	4,553.28 €	4,553.28 €	0.00 €
	P2P Optical Switch	25,000.00 €	35,000.00 €	30,000.00 €	0.00 €
	Leased Interconnections	3,000.00 €	10,000.00 €	6,500.00 €	0.00 €
	Auxiliary PC unit	988.50 €	988.50 €	988.50 €	0.00 €
	Auxiliary Laptop unit	1,382.00 €	1,382.00 €	1,382.00 €	0.00 €
	Auxiliary smartphones unit	560.00 €	560.00 €	560.00 €	0.00 €
Software components developed	Development of validation tools	117,800.00 €	186,000.00 €	151,900.00 €	4,900.00 €
	Marketplace development	53,200.00 €	84,000.00 €	68,600.00 €	
	Development of Evolved-5G SDK libraries	159,600.00 €	252,000.00 €	205,800.00 €	
	Development of Network Exposure Function (Simulator)	53,200.00 €	84,000.00 €	68,600.00 €	
	Development of Common API Framework CAPIF - (API management by CCF)	53,200.00 €	84,000.00 €	68,600.00 €	
Open source software integrated	Containerization tools (Docker)	0.00 €	0.00 €	0.00 €	4,900.00 €
	Container orchestration with OpenShift				
	Container orchestration tools (Kubernetes)				
	Open Repositories (DockerHub, AWS Code artifact, Jfrog, etc)				
	Source code editor (Visual Code, PyCharm, IntelliJ IDEA etc)				
	Version control system (GitHub)				
	CI/CD tools (Jenkins, Bitbucket Pipelines etc)				
	5G Core (opensource, e.g, Open5Gs)				
	Integration activities for the SW/HW components and the compute infrastructure	163,400.00 €	258,000.00 €	210,700.00 €	4,900.00 €

Figure 19: Estimated Costs for the components of the EVOLVED-5G facility

Based on the estimated cost per components we can study various scenarios for the services that can be offered on top of the facility. The full-fledged services are provided through the EVOLVED-5G service package; however, some of the services within the package can be offered individually. The target set of services from the EVOLVED-5G facility are as follows:

- SDK: Use of Evolved-5G SDK libraries (Development of a Network App)
- Verification: Conduct Verification tests (Robot Framework)
- Validation: Conduct Validation test (service by Platform Owner)
- Certification: Conduct Certification test (service by Evolved-5G dedicated partner)
- Publish: Hosting Network app in the Marketplace
- NEF: Use of Network Exposure Function (Simulator)
- TSN: Use of Time-Sensitive Networking capabilities
- CAPIF: Use of Common API Framework CAPIF - (API management by CCF)

Type	Component Description	Services							
		SDK	Verification	Validation	Certification	Publication	NEF	TSN	CAPIF
Components of the Compute and Connect Infrastructure	Cloud compute unit + Proxmox (3 servers - 12 CPUs - 376.69GB RAM)			○				○	
	Cloud compute unit + Openstack (1 server - 12 vCPUs - 24GB RAM)			○				○	
	Cloud Compute Unit (4 CPU + 60 GB RAM)			○				○	
	5G SYSTEM (Amarisoft Classic)			○				○	
	5G COTS UEs			○				○	
	5G SA UE			○				○	
	5G RAN (macro cell e.g., Nokia Aircscale)			○				○	
	5G Core (COTS e.g., amarisoft, athonet etc)			○			○	○	○
	5G Core ( commercial / use by operators )			○			○	○	○
	UPF for MEC			○				○	
	TSN (switch)			○				●	
	mmWave Links (Gbps)			○				○	
	P2P 10G Links (Optical- SFPs)			○				○	
	Access Transport incl. Backhaul			○				○	
	P2P Optical Switch			○				○	
	Leased Interconnections			○				○	
	Auxiliary PC unit			○				○	
	Auxiliary Laptop unit			○				○	
	Auxiliary smartphones unit			○				○	
Software components developed	Development of validation tools			●	●				
	Marketplace development					●			
	Development of Evolved-5G SDK libraries	●	●	●	●		○		○
	Development of Network Exposure Function (Simulator)	●	●	●	●		●		
	Development of Common API Framework CAPIF - (API management by CCF)	●	●	●	●				●
Open source software integrated	Containerization tools (Docker)	●	○	○	○	●	○	○	○
	Container orchestration with OpenShift	●	○	○	○		○	○	○
	Container orchestration tools (Kubernetes)	●	○	○	○		○	○	○
	Open Repositories (DockerHub, AWS Code artifact, Jfrog, etc)	○	○	○	○	●	○	○	○
	Source code editor (Visual Code, PyCharm, IntelliJ IDEA etc)	○	○	○	○		○	○	○
	Version control system (GitHub)	●	●	●	●	●	●	●	●
	CI/CD tools (Jenkins, Bitbucket Pipelines etc)	○	○	○	○		○	○	○
	5G Core (opensource, e.g, Open5Gs)			○	○		●		●
	Integration activities for the SW/HW components and the compute infrastructure	○	○	○	○		○	○	○

Figure 20: Hit-map of the components and services of the EVOLVED-5G facility

The hit-map in Figure 20 provides the dependencies between the various components and the services. Solid circles represent high dependency (the relevant components are required), while the empty circles represent dependency, but the service can be offered with partial use of the component or with alternative components. Given this mapping, three representative scenarios are studied in terms of the cost required, namely the development and verification of a CAPIF-compliant Network Application (Scenario A), the Network application certification and publishing in the EVOLVED-5G marketplace for 5 years (Scenario B), and full-fledged services over a fully functional compute & connect infrastructure for 5 years (Scenario C).

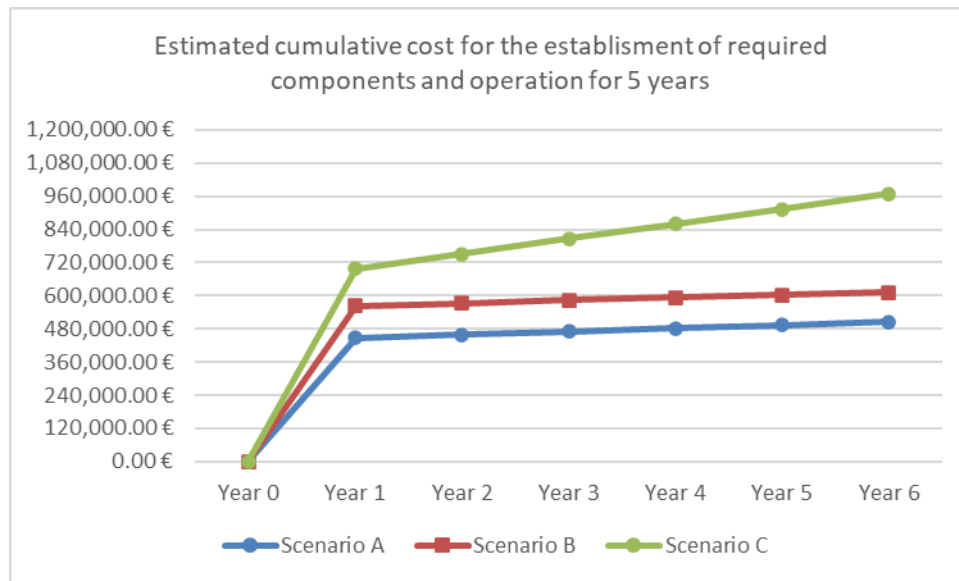


Figure 21: Estimated cumulative cost per scenario

Various scenarios can be formulated and assessed with corresponding costs tailored to the specific requirements of each case. Numerous factors may influence the configuration of each scenario, ranging from the necessity of establishing a private 5G infrastructure for either indoor or outdoor use to the implementation of a network application compliant with CAPIF specifications, facilitating connection to a 5G network and integration with a third-party application. Regardless of the scenario under consideration, the goal of cost analysis is to underscore the myriad potentials and capabilities, assess economic viability, and evaluate the feasibility and ease of adopting each scenario from both technological and economic perspectives.

### 3.3 OPEN-SOURCE SOFTWARE ENTREPRENEURSHIP

Considering the 5G openness a key enabler for technological evolution<sup>3</sup>, we have delved into various aspects and explored diverse approaches to achieve it. Numerous use cases highlight how the connectivity provided by 5G-enabled devices in everyday life can bolster the widespread adoption of 5G across various sectors. Another pivotal factor fostering this openness is the softwarization of numerous components within the 5G infrastructure. Simultaneously, deploying applications facilitates seamless connections for other vertical applications to integrate with the 5G network without requiring specific implementations and development for compatibility with different networks, such as 5G. This abstract approach, manifested in a more specified application known as Network Application, manages all necessary connection processes, enabling every application to effortlessly connect to the 5G network and enhance its capabilities. Undoubtedly, this innovative approach significantly contributes to the openness and adoption of 5G.

In the context of openness and software, our exploration has focused on open-source software—a long-standing approach embraced by numerous end users who engage with a variety of applications that follow this paradigm. Primarily, open-source software is characterized as computer software that permits anyone to utilize, study, and engage with it in multiple ways [32]. This engagement spans activities such as using the software, enhancing its features, rectifying bugs, and customizing the product according to user needs. This adaptability and collaborative interaction give rise to communities of individuals dedicated to improving the software, altering functionalities, adding features, and optimizing its overall potential. Consequently, open-

<sup>3</sup> “Technology thrives in the open, where people are free to share their ideas and build on the work of others.” Red Hat

source software emerges as a collaborative, efficient, and secure solution that caters to the needs of both users and programmers.

The utilization of open-source software offers numerous benefits, particularly from the perspective of the consumer. One primary advantage is evident for software developers who can leverage the pre-built infrastructure of open-source programs [33]. Instead of commencing projects from the ground up, developers can employ frameworks that provide full visibility into the code base. This transparency enables them to make suitable expansions and adaptations tailored to the specific needs and functionalities desired for their projects and, by extension, products.

These capabilities often come at a low or even zero cost to developers, fostering a robust community. This community serves as a valuable resource, offering assistance to developers in addressing potential bugs, problems, and security concerns. Comprising active users of the software, this community collaborates by sharing insights and providing advice. The community-oriented approach creates a familial atmosphere, with numerous experts and developers willingly offering free solutions and valuable guidance to those seeking help. This collective expertise proves to be more effective and direct compared to the support teams of closed software, as it encompasses individuals with diverse perspectives and backgrounds, allowing for a more global and holistic problem-solving approach.

From the company's standpoint, there are numerous advantages and benefits associated with open-source tools. Specifically, for companies seeking cost-effective solutions, open-source options prove advantageous as they are either free or come with very low fees [33]. From a cost and contractual perspective, open-source software eliminates the need for companies to enter into binding contracts or commit to a specific duration of use. This flexibility allows companies to adapt their toolset based on evolving needs and timelines.

Furthermore, the dynamic and engaged community surrounding open-source software enables companies to actively participate in finding answers and solutions to potential challenges. Lastly, open-source tools and software exhibit faster launches compared to closed alternatives. This expeditious initiation is attributed to the immediate access companies have to the comprehensive offerings of open source or the wealth of documentation available from numerous users involved in ongoing and mature projects.

For those individuals who have initiated open-source projects and contemplate venturing into a new Open-Source Software (OSS) startup, transitioning to offering their products as Software-as-a-Service (SaaS) may pose initial challenges [33]. The initial release of such a project is typically free, but the potential advantages and revenue opportunities are exceptionally promising. One notable benefit is the ability to foster a community-driven development approach, allowing for swift interaction and evolution within a vibrant community focused on optimizing and enhancing the product.

In contrast to closed-source software, where development is limited to an internal company team, open-source projects have the distinct advantage of engaging a broader contributor base. This inclusive approach enables anyone interested in the project to actively participate and contribute. The fact that users can access the software without an upfront payment or the need for a premium version cultivates a sense of goodwill and encourages users to give back by contributing to the product's optimization and supporting the community.

From a business perspective, this interaction with end-users and the community-based system can help the business create its own ecosystem of diverse open-source products. Such an ecosystem reinforces the ability to generate demand for products and assess it more directly, aligning with a bottom-up business model that relies on self-service to generate revenue, potentially replacing the need for a traditional sales team. This model allows a company to commence with a basic version of its product, accessible to all for free, and

subsequently offer a premium version with additional features and customized solutions at a fee, all while maintaining the open-source license structure.

Moreover, within the self-service paradigm, the community can function as a substitute for the traditional support team found in closed-source software. The open-source community, often more responsive and timelier, can address potential issues through the exchange of advice, knowledge, and solutions, facilitated by clear documentation provided by the company. This dynamic interaction contributes to the creation of an active community that develops its own open-source solutions, fostering a culture of sharing and collaboration among its members.

As outlined earlier, an open-source company can depart from traditional models used to generate social and economic value. One widely embraced model in this regard is the SaaS model, enabling a company to offer services derived from the product instead of selling the product itself. Typically, in this scenario, the software is cloud-based, with the company hosting it on its infrastructure and delivering it over the Internet. The company handles the underlying computing software and provides essential services like application hosting, regular version upgrades, and additional features that enhance overall infrastructure.



Figure 22: SaaS Model

Prominent platforms, such as GitHub, Netflix, and Zoom, exemplify the widespread adoption of the SaaS model. Its popularity can be attributed to various benefits it offers, including vertical scalability that allows customers to access more or fewer services based on their needs. The automatic updates feature streamlines performance improvements and patch management seamlessly. Additionally, the customization aspect empowers users to tailor specific features and add-ons according to their unique requirements.

The Bottom-Up Business model is an alternative approach that allows companies to broaden their market and execute extensive campaigns and strategies to attract as many customers as possible [34]. The target audience for this model is not enterprises but individual consumers, and the sales process occurs without the need for a salesperson. While the revenue per customer may be smaller, there is a larger number of customers compared to an enterprise client. Additionally, transactions are quicker since customers communicate directly with the company.

An added benefit of this approach is that innovation can occur more rapidly, as teams are empowered to be creative on their own without the need for directives from upper management, thereby boosting employee morale. Companies employing the bottom-up model can allocate resources to create a dedicated team

focused on enhancing product development for customers. This team's goal is to swiftly and effectively solve problems, maximizing customer satisfaction.

After examining what constitutes open-source software, exploring the benefits for both customers and companies, and defining some business models along with their advantages and purposes, it is crucial to address a pivotal question: How can a company in this domain generate revenue?

Although this might not be immediately evident to everyone, and revenue generation is often indirect, these companies do indeed generate income. Despite the software being freely licensed, there are dynamic methods through which a company can generate revenue. One such avenue is through consulting services. Companies can provide consulting services to enhance existing source code, adapt it for different use cases, or modify it to address specific problems. In the case of hardware companies, consulting services can involve creating customized products tailored to a client's specifications. For open-source businesses centered around content, sharing content serves as a means for creators to showcase their work. In sectors that revolve around content sharing, a showcased portfolio creates opportunities and demand for commissioned work, leading to revenue generation through projects resulting from this showcase.

Another method for a company to generate revenue involves charging for additional or supplementary services. Companies can levy fees for services such as hosting the platform, maintaining the open-source code, or providing additional features. Charging for extra features might include services like incorporating the client's company logo into the dashboard or offering additional login accounts, resembling a freemium model tailored to the client's specific needs.

The final and widely adopted revenue stream is the sale of additional proprietary products. Companies can market additional closed-source products that complement the core open-source product. In the realm of open-source hardware companies, a common revenue stream involves charging a fee based on the manufacturing cost of their open-source designs. In this scenario, anyone can download and modify the design, and the company earns revenue when the product is manufactured. Some hardware companies may also sell the necessary inputs for manufacturing their designs.

For the EVOLVED-5G project, our objective was to deliver a comprehensive, open-source implementation that allows end users to access the 5G network and connect their vertical applications to it. The connection process has been abstracted for end users, facilitated by the deployment of open-source SDK tools that encompass all necessary functions for connection and interaction with the network. Additionally, we have developed and deployed CAPIF and NEF emulators based on the containerization model, ensuring portability and easy management. All components essential for communication between the end user's vertical application and 5G are implemented following contemporary microservice programming principles and adhere to open-source practices, as the code, implementation, and documentation are publicly accessible.

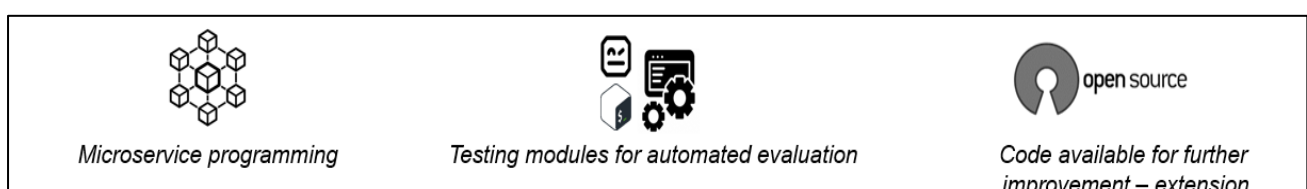


Figure 23: Contemporary principles of the EVOLVED-5G service package

## 4 ENGAGEMENT OF STAKEHOLDERS ON EVOLVED-5G

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In Deliverable 6.2, we defined the type of stakeholders that are associated with the EVOLVED-5G project or would be beneficial to do so, for themselves as well as for the growth of the project. More specifically, the stakeholders associated with the EVOLVED-5G framework encompass entities that exist independently of the EVOLVED-5G ecosystem but are considered potential candidates to play a role within it. These stakeholders are individuals or organizations pursuing goals achievable through the EVOLVED-5G framework or providing services that impact its design. Their inclusion was integral in gathering business and user requirements for the EVOLVED-5G facility. While the current set of stakeholders is not exhaustive, it can potentially expand as additional entities in the 5G ecosystem express interest in Network Apps and their development process in the future. To align with ongoing work in 5G-PPP and SNS JU, the stakeholders related to the EVOLVED-5G framework have been linked to those defined by the Vision and Societal Challenges – VSC Working Group, specifically in the sub-group Business Validation Models and Ecosystem.

Given the work in Deliverable D6.2, the next step is to approach the stakeholders via multiple and various activities with purpose to inform, to encourage and to motivate them to deepen their knowledge and understanding in the 5G technology and more specifically to the EVOLVED-5G project and its outcomes. In this deliverable, and specifically in the following sections, we define the various types of engagement adopted as well as the strategy followed. Also, a compact description is provided including the engagement activities conducted, highlighting the impact created. It is noted that the detailed list of activities is provided in [D7.5](#) and [D6.3](#) deliverables, where all the outreach & knowledge sharing activities, and the details of the EVOLVED-5G acceleration programme, i.e., a key engaging activity for SMEs in the project, are presented, respectively.

### 4.1 STRATEGY AND MATERIAL OF THE ENGAGEMENT ACTIVITIES

The fundamental concept that forms the essence of the engagement strategy in EVOLVED-5G, is purposeful engagement [35]. Practically, the goal is to effectively communicate, educate, and motivate third parties regarding 5G technology, specifically emphasizing its openness and the significant potential unlocked through the EVOLVED-5G services for the support of Network Application lifecycle.

To achieve this, a real-time engagement context and a right environment are needed. To realize the objectives of effective communication, education, and motivation in the realm of 5G technology, a multifaceted approach is imperative. Central to this approach is the concept of real-time engagement, which demands immediate and dynamic interaction with third parties. In the fast-paced landscape of technological advancements, maintaining a real-time engagement context is essential for timely responses, live interactions, and adaptive communication strategies. This ensures that the engagement activities remain agile and responsive to the evolving needs and expectations of the target audience. Simultaneously, the creation of the right environment is pivotal for the success of these activities. The "right environment" encompasses the provision of digital platforms, physical spaces, or virtual arenas that foster productive engagement. Such an environment should be thoughtfully designed to be user-friendly, ensuring accessibility to information, and cultivating a supportive atmosphere conducive to understanding and enthusiasm. By combining a real-time engagement context with the establishment of the right environment, the engagement strategy not only communicates the purpose effectively but also nurtures a space for continuous learning and motivation within the dynamic landscape of 5G technology.

Finally, a crucial element of these activities involves soliciting feedback from participants and engaging in interactive dialogue with them. While the natural flow of knowledge and information typically originates from experts and organizers of these activities, obtaining feedback from participants is invaluable both scientifically and socially. Participant feedback aids in comprehending market dynamics, pinpointing specific needs, and

enhancing the overall service package. This iterative process not only refines communication channels, making them more direct and effective but also contributes to the improvement of services and communication skills. From a broader perspective, this feedback loop establishes a connection that fosters the evolution of participants' ideas and use cases, creating a collaborative and mutually beneficial environment.

With the foundational aspects of the strategy and the context of engagement activities in place, the subsequent phase involves the development and production of pertinent materials for use during these activities. Presentations emerge as a fundamental method in the majority of these activities, serving as a primary vehicle to communicate the objectives and convey essential information. Furthermore, for certain instances such as physical meetings, the creation of visually impactful materials like posters and stickers becomes imperative and beneficial. Harnessing the power of images in these tangible forms proves to be a potent and direct means of reinforcing key messages and enhancing the overall effectiveness of the engagement efforts.

## 4.2 TYPE OF ENGAGEMENT ACTIVITIES AND LEVEL OF ENGAGEMENT

Throughout the lifecycle of the EVOLVED-5G project, a diverse range of engagement activities was undertaken to connect with different target groups and foster their understanding of the project's purpose. Given the varied nature of these target groups, a multitude of activities were adopted to effectively attract diverse third parties. Beyond the project's core activities and its specific field, the overarching goal of these engagement efforts was to inspire, promote, motivate, and educate individuals interested in the realm of 5G technology. We define three levels of engagement, which (from the lowest to the highest level of engagement) refer to a) knowledge sharing activities, b) educational activities, and c) interactive activities.

The knowledge sharing activities refer to a light indirect engagement with the concepts that the project conveys through presentations in workshops, general audience publications (e.g., press releases), and the project communication channels. To this end the EVOLVED-5G project often organized, or participated in trials, showcases, and events like workshops, seminars, and webinars as listed in the project [website](#). The trials and showcases, predominantly executed by project partners, aim to connect with the market and individuals interested in exploring specific 5G contexts. These focused activities offer concise and beneficial insights for those interested in the scientific field. Participants can deepen their understanding, concentrating on specific aspects and potentially adopting the solutions developed by project partners. Similarly, workshops and seminars serve similar purposes to trials and showcases. Simultaneously, they emphasize the EVOLVED-5G facility, and its capabilities tailored to each participant's use case. Participants can benefit from expert guidance provided by the consortium team, enhancing their comprehension and engagement with the project.

The educational activities refer to a unidirectional knowledge flow from the project to third parties, which include structured content that is available on demand and targets stakeholders that are interested to learn and potentially become future contributors to the Network application ecosystem. For this level of engagement (through educational activities), we consider the on-line courses (hosted in the [UPV\[X\] platform](#)) and the scientific [publications](#) that was prepared from the project partners. The project's insights and expertise are slated to become integral components of upcoming graduate and postgraduate courses, enhancing the curricula of partner universities. This initiative aims to have a substantial impact, particularly on M.Sc. and Ph.D. students, fostering the education of a new generation of European researchers and engineers specializing in the fields addressed by EVOLVED-5G project, and supporting a growing and diverse market. EVOLVED-5G makes coordinated contributions that are showcased in prestigious international conferences and disseminated through peer-reviewed publications and magazines. The consortium actively submits articles to high-impact conferences and journals, emphasizing the intersection of 5G and security. Notable outlets include IEEE Security and Privacy Magazine, IEEE Transactions on Vehicular Technology, IEEE Journal on Selected Areas in Communications, IEEE Network Magazine, IEEE Transactions on Dependable and

Secure Computing, IEEE Communications Magazine, IEEE Internet of Things Journal, ACM Computer and Communications Security (CCS), Usenix Security, IEEE GLOBECOM, and IEEE International Conference on Communications (ICC).

The higher engagement though, is conducted with interactive activities where the stakeholders are using the EVOLVED-5G concepts and have bidirectional transfer of knowledge with the project partners. We include in this category the [EVOLVED-5G Acceleration program](#), the collaboration with other projects under the 5GPPP umbrella, as well as the [EVOLVED-5G forum](#) interaction with potential Network App developers. Key role in this effort was played by the 5GPPP and the related Work Groups, where active integration and knowledge sharing conducted with other projects. Though the 5GPPP channels the EVOLVED-5G gain visibility to other associations and initiatives outside the 5G research community.

Considering who was the driver of the engagement activity, two main categories are defined. The first one is about activities which took place in the context of the project itself, such as the Acceleration program, a comprehensive five-month blended learning support initiative aimed at fostering the growth of SMEs, entrepreneurs, and developers in the 5G sector. This program encompasses immersive training, entrepreneurship master classes, live case studies, workshops on business model innovation, financial guidance, and networking opportunities. Participants will also benefit from virtual mentorship, coaching, and access to online forums for idea exchange. The program is designed to equip SMEs, entrepreneurs, and developers in the 5G industry with essential training, resources, guidance, and support for their success. Networking with other industry players and experts is a key element of the Acceleration Program, enhancing participants' connectivity within the 5G ecosystem. The second one pertains to the willingness of each partner to actively engage in or organize activities and events aimed at promoting awareness of the EVOLVED-5G project. This involves communicating the project's use cases and, more broadly, involving interested third parties seeking to adopt 5G technology. The objective is transfer of knowledge and guidance from experts to those who may need support in navigating the intricacies of 5G adoption.

## 4.3 ENGAGEMENT ACTIVITIES CONDUCTED

### 4.3.1 Knowledge sharing activities

Within the framework of knowledge-sharing activities in the EVOLVED-5G project, a total of 48 presentations were conducted across both online and physical events, alongside 8 workshops and special sessions. The dissemination and promotion of EVOLVED-5G materials primarily rely on presentations, serving as a key means to reach a diverse audience. Some of these presentations occurred within events where the consortium actively participated, offering insights into various facets of the project. Approximately 38 such events took place, with a significant presence in prestigious conferences like IEEE International Conference, EuCNC, InfoCom World, among others. These targeted initiatives provide a succinct and valuable exploration for individuals keen on the field, enabling participants to delve into specific aspects and consider potential adoption of solutions crafted by project partners. Workshops and seminars, resembling trials and showcases, serve analogous purposes in this comprehensive engagement. The emphasis on the customized capabilities of the EVOLVED-5G facility for each participant's use case underscores the practicality of these activities. Moreover, participants stand to benefit from expert guidance offered by the consortium team, thereby elevating their understanding and active involvement in the project. The integrated approach ensured a holistic and enriching experience for all participants, fostering a deeper connection with the project's objectives and outcomes.



Figure 24: EVOLVED-5G in EuCNC and 6G SUMMIT 2023

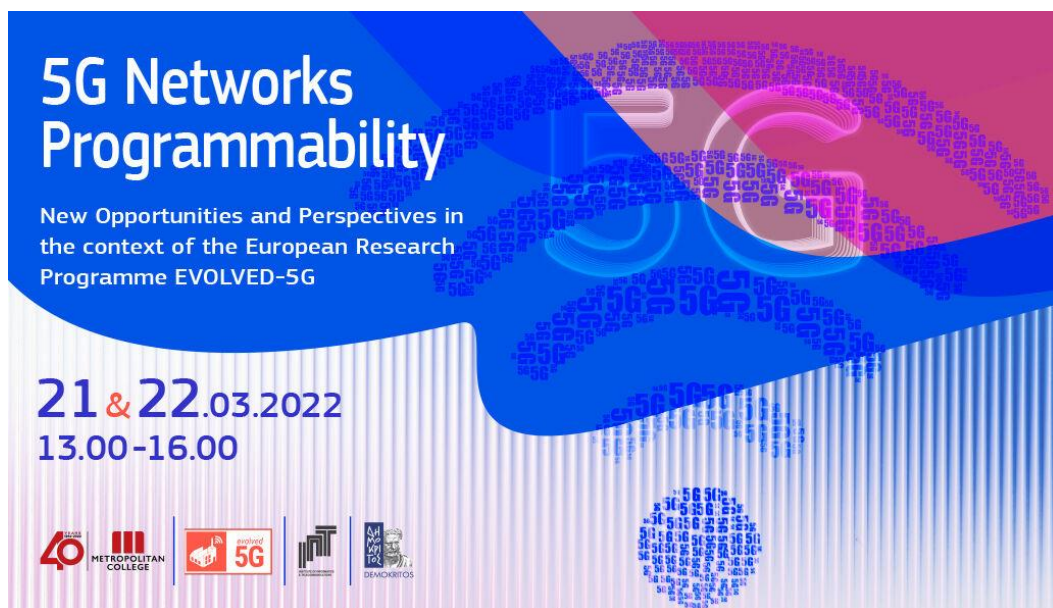
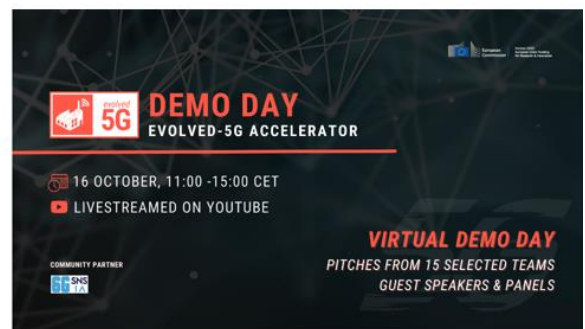
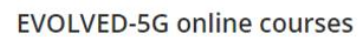


Figure 25: 5G Networks Programmability

#### 4.3.2 Educational initiatives

In the realm of educational initiatives, five courses have been developed and are accessible through [UPV\[X\] platform](#). These courses aim to introduce the fundamental components of the EVOLVED-5G facility, outlining the architecture and functionality of the EVOLVED-5G service package. Serving as training modules, these courses cater to individuals seeking a deeper understanding of the EVOLVED-5G service package, assessing their knowledge through post-course questions. Upon completion, participants can undergo a final

[illegible]

COURSE	DESCRIPTION	AUTHORS
1) EVOLVED-5G Network Apps	Network App concept	NCSRD
2) EVOLVED-5G Network App Development	Development of Network Apps: – Network App development process – Software tools for Network App development	NCSRD, ATOS, MAG, INF, UPV
3) EVOLVED-5G Network App Verification	Verification of Network Apps	ATOS, UPV, TID, INTRA
4) EVOLVED-5G Marketplace	Use of Network App Marketplace	MAG, NCSRD
5) CAPIF	What is CAPIF and CAPIF API Services	FOGUS

48

Given the inherently specialized audience of these activities, primarily consisting of programmers and developers, master classes, training sessions, and workshops have been organized. In a training workshop, experts lead sessions on technical aspects of EVOLVED-5G, fostering collaborative learning and problem-solving among participants. These workshops may concentrate on specific technical domains, such as Network App development. Developer meetups for training, serve as gatherings for individuals seeking deeper knowledge in specific technical aspects of the EVOLVED-5G project. These events facilitate the exchange of information and insights among developers and experts, covering technical skills and innovative approaches to development processes. Additionally, webinars (Internet-based seminars) and similar events are considered EVOLVED-5G developer-oriented if their primary audience comprises developers rather than academic or university audiences. The key criterion for such events is a dedicated focus on training in EVOLVED-5G technical topics, including the project's vision, framework, and developments.

Furthermore, seminars tailored for academia and university students were organized as part of the EVOLVED-5G training initiative. Seminars serve as the primary event format in academic settings, offering a platform to communicate the EVOLVED-5G vision, objectives, and technical developments to students specializing in technical fields. These seminars centered around technical topics related to EVOLVED-5G, function as dedicated classes within universities that are not restricted to any specific subject. They provide students with a comprehensive exploration of a particular topic, encompassing both theoretical concepts and practical applications. In addition to seminars, various other event formats are under consideration, including webinars (online seminars conducted exclusively over the Internet without a physical or hybrid format), university workshops, or lectures integrated into specific subjects. These events aim to introduce technical topics and elements from EVOLVED-5G to university students, enhancing their knowledge and comprehension of the project's objectives and technical advancements.

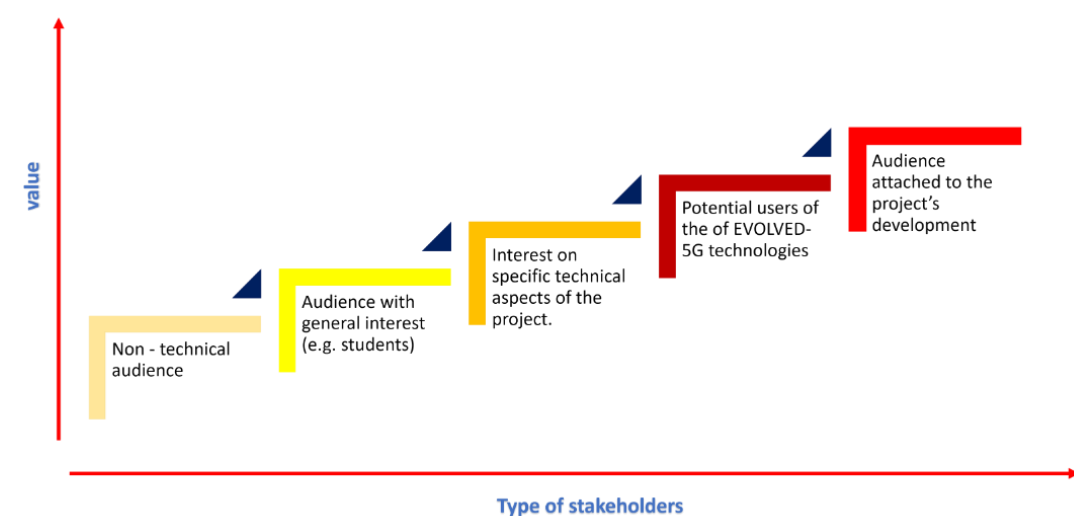


Figure 28: Interaction among users and EVOLVED-5G project

Throughout the project's lifecycle, five courses, eleven training events, and seven hands-on training demos have been developed and made available. The diverse audience, encompassing undergraduate and postgraduate students, professionals, developers, and programmers, among others, along with a range of engagement activities, facilitated a comprehensive approach to communication and promotion. This holistic strategy enabled interaction with individuals from diverse backgrounds, allowing each activity to emphasize different aspects of the EVOLVED-5G facility and service package. Figure 28 depicts the interaction between the different types of audience and the EVOLVED-5G project.

Regarding targeted activities for a specific audience within the EVOLVED 5G project, a total of 33 publications have been produced. To be more precise, four of these are journal papers, including publications in esteemed journals such as IEEE Access and IEEE Network Magazine. Additionally, 13 publications are in the form of conference papers, and three have been published as book chapters. Notably, 13 white papers have been accepted and published within renowned platforms such as 5GPPP, 6G-IA, and Immersion.

#### 4.3.3 Interactive activities

In the advanced engagement phase, the EVOLVED-5G project incorporates an Accelerator program and collaborates with other projects under the 5GPPP umbrella. The EVOLVED-5G Accelerator aims to guide innovative SMEs across Europe in adopting and implementing 5G technology through a hands-on methodology based on lean startup principles and experiential learning. The program provides holistic support, covering business innovation essentials and technical aspects of 5G technology adoption. An online Info Day hosted by Envolve/IEA attracted over 40 participants, disseminating information about the open call and opportunities in the Acceleration program.

A total of 76 applicants responded to the call, with 25 deemed eligible for the EVOLVED-5G Accelerator. The selected teams, spanning 13 countries and operating in diverse sectors, underwent a rigorous evaluation process based on criteria such as business potential and evaluation scores. The original goal was to admit 20 SMEs, but 25 teams were eventually chosen due to ties in grading and business potential. The participants engaged in Entrepreneurship Masterclass, Introduction to 5G Networks & Network Applications, Industry & Case Studies, and Virtual Venture Support & Business Coaching. The most active and advanced 15 teams pitched their business ideas to a judging committee, with 11 teams advancing to the final chapter of the Acceleration Program. The Demo Day, broadcasted live on YouTube and attended by 56 participants in a Zoom meeting, showcased the progress of the participating SMEs and garnered significant online engagement. Throughout the program, all 25 participants had the opportunity for one-to-one mentoring and feedback workshops, totaling 12 hours, with the management of Envolve Entrepreneurship/IEA, partners of the EVOLVED-5G Network, and ecosystem stakeholders.



Figure 29: EVOLVED-5G Accelerator

The EVOLVED-5G Accelerator engaged with associations and clusters such as 6G-AI, AI Cluster, 5G Ventures V.C. (Phaistos V.C.) engaging with and directly connecting with the cohort and their ventures. The Accelerator workshops and Demo Day hosted 15 facilitators and over 20 speakers, amongst which 8 EVOLVED-5G Partners

(Immersion, Infolytis, NCSR Demokritos, Cosmote, Fogus Innovations & services P.C., Internet Institute, Telefonica) were engaged as well as stakeholders and members of the ecosystem, including 5G-IANA, Bespot, 6G-IA, IQUADRAT, AI Catalyst, 5G Ventures (Phaistos), Allcancode, Venture Friends, ICCS, TU Delft, UN Autonomous Systems, GMI Aero.

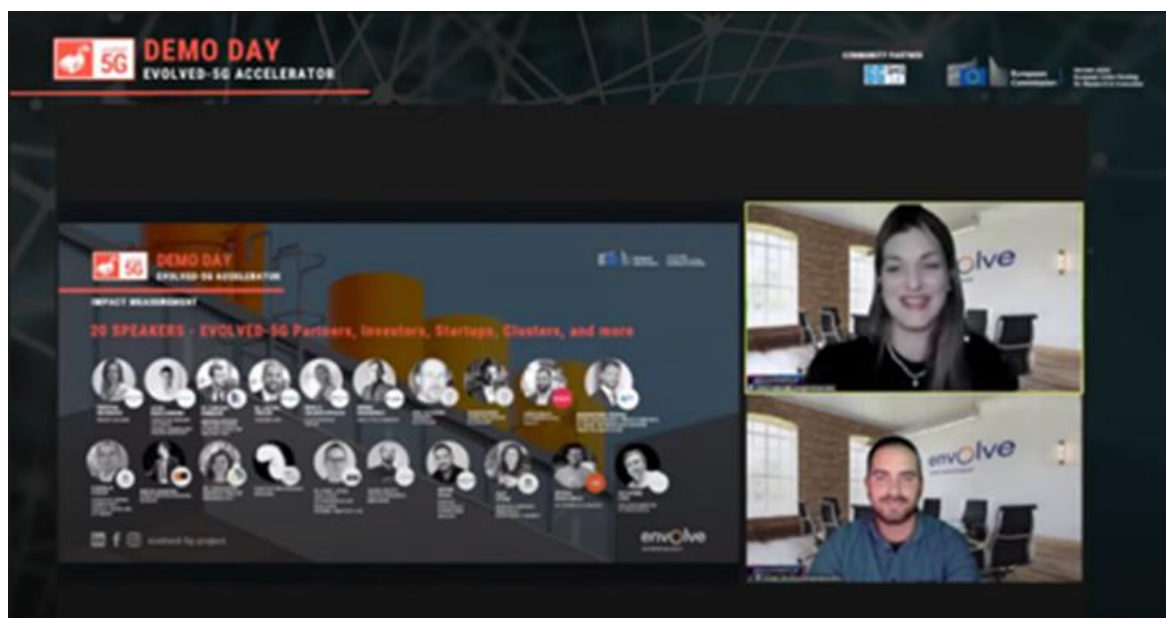


Figure 30: EVOLVED-5G Demo day

Also, in the context of the promotion and communication project partners interacted with the extensive startup and SMEs network across various countries, including Greece, Italy, Finland, Spain, Ukraine, UK, Bulgaria, and more. They presented information about the EVOLVED-5G Project, the EVOLVED-5G Accelerator & Library, and the broader 5G & beyond ecosystem. This engagement took place through participation in workshops, DeepTech conferences, and policy forums.

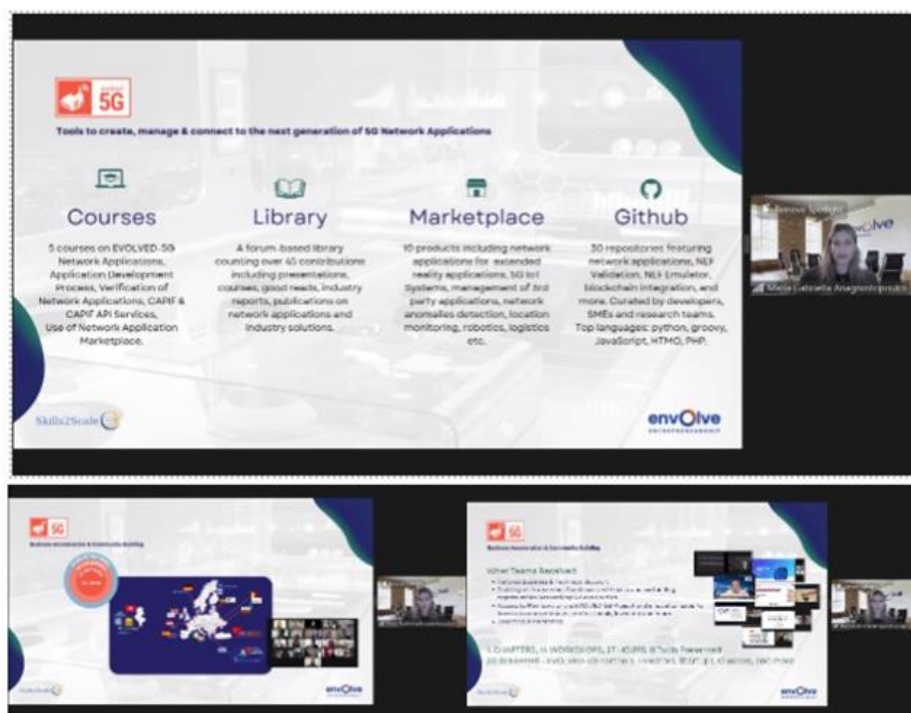


Figure 31: EVOLVED-5G Ecosystem mapping

The engagement process facilitated by tools produced by the Project presenting the EVOLVED-5G IP Commercialization Blueprint to the SMEs cohort of the EVOLVED-5G Accelerator, whilst also introducing them to the EVOLVED-5G marketplace and GitHub featuring the Network Applications and the respective code directories.



Figure 32: EVOLVED-5G IP commercialization blueprint

Particularly for engaging SMEs and Start Ups, the partners of the EVOLVED-5G Project and the cohort of the EVOLVED-5G Accelerator, organized four (4) technology transfer workshops. For these workshops, IEA/ENVOLVE collaborated with the Hellenic Industrial Property Organization and DLA Piper.



Figure 33: Workshops conducted with Hellenic Industrial Property Organization

Specifically, IEA/ENVOLVE worked in synergy with UN Autonomous Systems (SME partner of the EVOLVED-5G Project) in two (2) workshops testing and validating the EVOLVED-5G IP Commercialization Blueprint, which was also featured in the EVOLVED-5G YouTube channel to communicate this activity to the broader network.

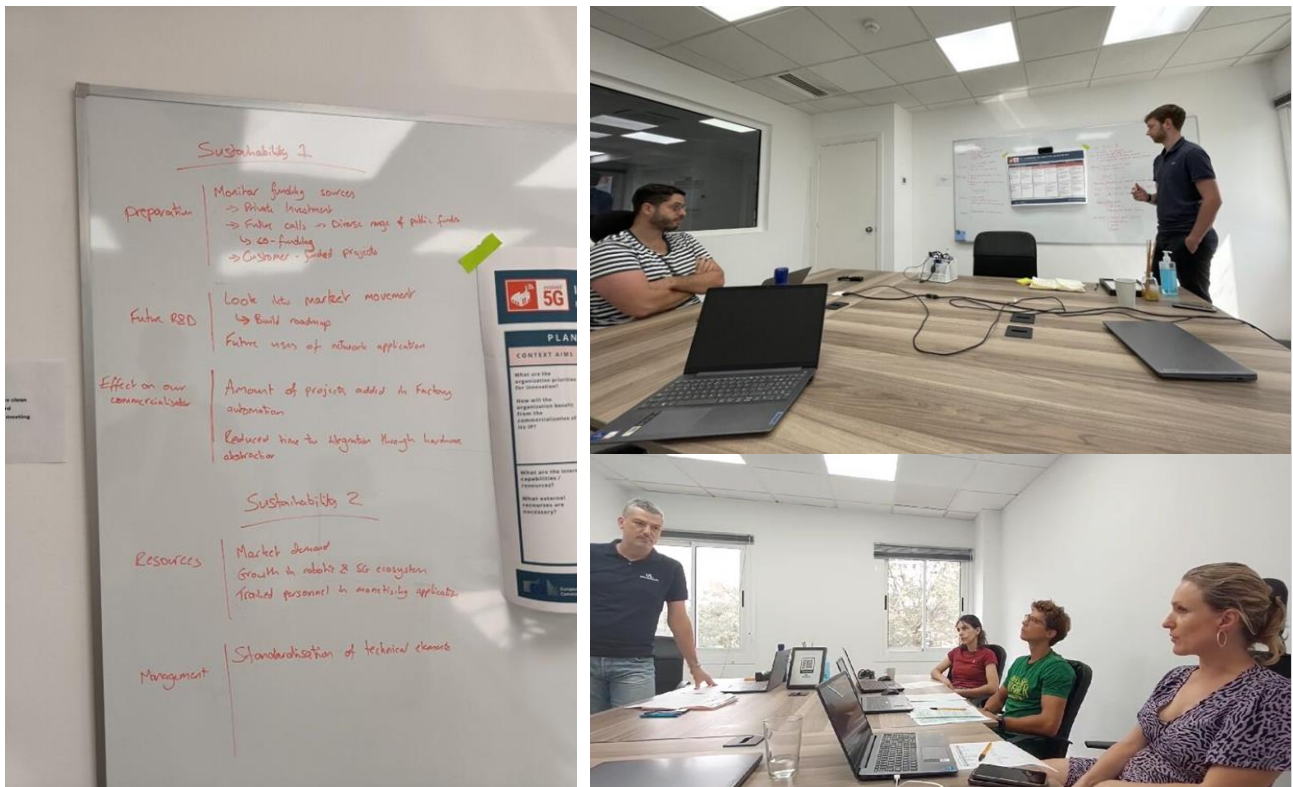


Figure 34: IP commercialization blueprint workshop

The EVOLVED-5G project has made significant contributions to 5G-PPP through various activities. This includes valuable inputs to whitepapers, active participation in presentations within 5G-PPP Working Groups, and collaborative efforts in organizing events with other projects. The crafting of whitepapers demonstrates a commitment to advancing collective knowledge, while participation in working groups and presentations underscores the project's dedication to sharing expertise and fostering collaborative discussions. Additionally, joint events with other projects highlight a collaborative spirit and synergistic impact. Furthermore, EVOLVED-5G has actively contributed to surveys, facilitating the production of whitepapers, brochures, and key achievement initiatives. Overall, these multifaceted activities showcase the impactful engagement of the EVOLVED-5G project within the 5G-PPP framework.

EVOLVED-5G actively engaged in several significant events, including a special session at 5G FORUM titled "EVOLVED-5G & 5G USE CASES INNOVATION". This session provided an opportunity to interact with other projects, fostering an exchange of perspectives on the verticals' ecosystem and use cases derived from network programmability. The project also played a prominent role in the EuCNC & 6G Summit, where it showcased network core openness by exposing functions like NEF and TSN through standardized API managers. Demonstrations emphasized the programmability features of EVOLVED-5G, highlighting DevOps and the CI/CD framework, along with exhibiting performance improvements in Industry 4.0 applications.

In collaboration with [5G-IANA](#), EVOLVED-5G engaged in joint activities, including participation in the EVOLVED-5G Accelerator Info Day, subsequent meetings to define joint activities, and presentations of 5G-IANA tools at the EVOLVED-5G Accelerator Cohort. This collaboration led to SMEs/start-ups applying to the 5G-IANA open call. Joint activities in June 2023 explored the use of the NEF emulator in 5G-IANA network applications. Notably, the 5G-IANA project coordinator participated in the EVOLVED-5G virtual demo day in October 2023, solidifying collaboration through shared communication channels.

Furthermore, EVOLVED-5G actively contributed to the initiative by 5GASP for closer collaboration among ICT-41 projects. This involvement resulted in the proposal of a workshop on "Next-Generation Business Model for 6G Network Applications" at the EUCNC 2023, showcasing the commitment to sharing experiences and best practices across projects in the ICT-41 realm.

In summary, the conducted activities served as an excellent opportunity to effectively convey the purpose, the EVOLVED-5G facility, and its service package, showcasing their potential and capabilities. These engagements not only facilitated interaction and idea exchange between the consortium and the audience but also proved mutually beneficial. The diverse array of activities allowed for the highlighting of various aspects of the project, contributing to the academic community through publications. The diverse backgrounds of the audience necessitated creativity in organizing different communication methods and events, catering to various knowledge levels. The win-win approach adopted throughout these activities proved highly advantageous, enriching both participants and organizers in terms of knowledge and social experiences.

## 5 REFERENCES

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- [1] "5gobservatory.eu," 19 October 2023. [Online]. Available: [https://5gobservatory.eu/wp-content/uploads/2023/10/BR-19\\_October-2023\\_Final-clean.pdf](https://5gobservatory.eu/wp-content/uploads/2023/10/BR-19_October-2023_Final-clean.pdf). [Accessed November 10 2023].
- [2] GSA, "gsacom.com," July 2023. [Online]. Available: <https://gsacom.com/paper/5g-standalone-july-2023-member-report/>. [Accessed 20 November 2023].
- [3] "connectivity-eu," [Online]. Available: <https://connectivity-eu.b2match.io/page-1651>. [Accessed 12 November 2023].
- [4] European Court of Auditors, "op.europa.eu," 2022. [Online]. Available: <https://op.europa.eu/en/publication-detail/-/publication/5e6042b9-d58b-11ec-a95f-01aa75ed71a1/language-en>. [Accessed 20 October 2023].
- [5] F. Grijpink, A. Ménard, H. Sigurdsson and N. Vucevic, "mckinsey.com," [Online]. Available: <https://www.mckinsey.com/~media/McKinsey/Industries/Technology%20Media%20and%20Telecommunications/Telecommunications/Our%20Insights/The%20road%20to%205G%20The%20inevitable%20growth%20of%20infrastructure%20cost/The-road-to-5G-The-inevitable-growth-of-infr>. [Accessed 25 October 2023].
- [6] B. Klayman and S. Nellis, "reuters.com," 3 February 2023. [Online]. Available: <https://www.reuters.com/business/autos-transportation/fords-pain-underscores-uneven-impact-two-year-auto-chip-shortage-2023-02-03/>. [Accessed October 25 2023].
- [7] S. Kechiche, "ookla.com," 23 February 2022. [Online]. Available: <https://www.ookla.com/articles/5g-europe-mapping-the-future-q1-2022>. [Accessed 27 October 2023].
- [8] European Commission, "ec.europa.eu," 8 February 2022. [Online]. Available: [https://ec.europa.eu/commission/presscorner/detail/en/IP\\_22\\_729](https://ec.europa.eu/commission/presscorner/detail/en/IP_22_729). [Accessed 27 October 2023].
- [9] I. Beveridge, "entrust.com," 6 October 2023. [Online]. Available: <https://www.entrust.com/blog/2023/10/5g-security/>. [Accessed 29 October 2023].
- [10] Nokia, "nokia.com," [Online]. Available: <https://www.nokia.com/thought-leadership/articles/privacy-challenges-security-solutions-5g-networks/>. [Accessed 30 October 2023].
- [11] S. Farhang, Y. Hayel and Q. Zhu, "ieeexplore.ieee.org," 7 December 2015. [Online]. Available: <https://ieeexplore.ieee.org/document/7346836>. [Accessed 30 October 2023].
- [12] C. QUINTIN, "eff.org," 28 January 2019. [Online]. Available: <https://www.eff.org/deeplinks/2019/01/5g-protocol-may-still-be-vulnerable-imsi-catchers>. [Accessed 1 November 2023].
- [13] Reuters, "reuters.com," 7 June 2023. [Online]. Available: <https://www.reuters.com/business/media-telecom/eu-considers-mandatory-ban-using-huawei-build-5g-ft-2023-06-07/>. [Accessed 1 November 2023].
- [14] Z. Zhang, L. Scola and A. Schulman, "cseweb.ucsd.edu," [Online]. Available: [https://cseweb.ucsd.edu/~zez003/ICT4S23\\_Base\\_station.pdf](https://cseweb.ucsd.edu/~zez003/ICT4S23_Base_station.pdf). [Accessed 1 November 2023].
- [15] H. Maluleke, A. Bagula, O. Ajayi and L. Chiaraviglio, "An Economic Feasibility Model for Sustainable 5G Networks in," *sustainability*, pp. 1-24, 26 September 2022.

- [16] I. P. Chochliouros, M.-A. Kourtis, A. S. Spiliopoulou, P. Lazaridis, Z. Zaharis, C. Zarakovitis and A. Kourtis, "Energy Efficiency Concerns and Trends in Future 5G Network Infrastructures," *energies*, pp. 1-14, 30 August 2021.
- [17] X. Cheng, Y. Hu and L. Varga, "5G network deployment and the associated energy consumption in the UK: A complex systems' exploration," *ELSEVIER*, pp. 1-24, 2 April 2022.
- [18] E. Oughton and S. K. A. Kumar, "Techno-economic assessment of 5G infrastructure sharing business models in rural areas," *frontiers*, 20 October 2023.
- [19] L.-C. Wang and S. Rangapillai, "e-tarjome.com," [Online]. Available: [https://e-tarjome.com/storage/uploaded\\_media/2022-10-01/1664601523\\_F1967-English-e-tarjome.pdf](https://e-tarjome.com/storage/uploaded_media/2022-10-01/1664601523_F1967-English-e-tarjome.pdf). [Accessed 3 November 2023].
- [20] A. M. CAVALCANTE, M. V. MARQUEZINI, L. MENDES and C. S. MORENO, "5G for Remote Areas: Challenges, Opportunities and Business Modeling for Brazil," *IEEE Access*, January 2021.
- [21] P. Pavon-Marino, F.-J. Moreno-Muro, M. Garrich, M. Quagliotti, E. Riccardi, A. Rafel and A. Lord, "Techno-Economic Impact of Filterless Data Plane and Agile Control Plane in the 5G Optical Metro," *Journal of Lightwave Technology*, March 2020.
- [22] K. W. Shah and G. Huseien, "Potential Applications of 5G Network Technology for Climate Change Control: A Scoping Review of Singapore," *sustainability*, 30 August 2021.
- [23] S. Popli, R. Kumar Jha and S. Jain, "A comprehensive survey on Green ICT with 5G-NB-IoT: Towards sustainable planet," *ELSEVIER*, 9 November 2021.
- [24] "5gobservatory.eu," 2022. [Online]. Available: [https://5gobservatory.eu/wp-content/uploads/2022/04/5.11\\_QR-15.pdf](https://5gobservatory.eu/wp-content/uploads/2022/04/5.11_QR-15.pdf). [Accessed 15 November 2023].
- [25] "5g-ppp.eu," 5G PPP Technology Board, 17 November 2022. [Online]. Available: [https://5g-ppp.eu/wp-content/uploads/2022/11/WhitePaperNPN\\_MasterCopy\\_V1.pdf](https://5g-ppp.eu/wp-content/uploads/2022/11/WhitePaperNPN_MasterCopy_V1.pdf).
- [26] D. Chandramouli and W. I. Rapporteur, "3gpp.org," 13 May 2020. [Online]. Available: <https://www.3gpp.org/technologies/tsn-v-lan>.
- [27] GSMA Head Office, "gsma.com," June 2023. [Online]. Available: [https://www.gsma.com/iot/wp-content/uploads/2023/09/GSMA-Private-5G-Industrial-Networks-Report\\_June-23-.pdf](https://www.gsma.com/iot/wp-content/uploads/2023/09/GSMA-Private-5G-Industrial-Networks-Report_June-23-.pdf).
- [28] "5gobservatory.eu," [Online]. Available: <https://5gobservatory.eu/5g-private-networks/>.
- [29] RCR Wireless News, "What are non-public networks in 3GPP parlance?," 11 April 2022.
- [30] "5g-records.eu," [Online]. Available: <https://www.5g-records.eu/index.php/use-cases>. [Accessed 20 November 2023].
- [31] B. Marr, "forbes.com," Forbes, 14 March 2023. [Online]. Available: <https://www.forbes.com/sites/bernardmarr/2023/03/14/the-7-most-successful-business-models-of-the-digital-era/>. [Accessed 16 November 2023].
- [32] Indeed Editorial Team, "indeed.com," 24 August 2023. [Online]. Available: <https://www.indeed.com/career-advice/career-development/open-source-software-definition>. [Accessed 27 November 2023].

- [33] A. Park, "heavybit.com," 20 October 2022. [Online]. Available: <https://www.heavybit.com/library/article/open-source-software-benefits-advantages>. [Accessed 27 November 2023].
- [34] P. Manjunatha, "saastitute.com," 26 March 2022. [Online]. Available: <https://www.saastitute.com/blog/bottom-up-saas-the-go-to-model-for-businesses#:~:text=What%20is%20Bottom%2DUp%20Business,SaaS%20product%20before%20purchasing%20it>. [Accessed 30 November 2023].
- [35] "i.forbesimg.com," [Online]. Available: [https://i.forbesimg.com/forbesinsights/pega/new\\_rules\\_of\\_customer\\_engagement.pdf](https://i.forbesimg.com/forbesinsights/pega/new_rules_of_customer_engagement.pdf). [Accessed 30 November 2023].