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6G4SOCIETY

D4.3 EXPLOITATION REPORT V1

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Abstract	This document presents a strategic exploitation plan and sustainability strategy for the 6G4Society project, focusing on the societal and economic dimensions of 6G technology development. The report is structured to address three key areas: the identification and development of Key Exploitable Results (KERs), market analysis and commercial potential, and long-term sustainability approaches. The goal is to generate practical proposals that promote the ethical use of 6G technologies and make these technologies more useful for society, sustainable goals and stakeholders. The report analyses the market to determine the opportunities in important verticals and suggests how they may be commercially exploited. It

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emphasises the strategic collaboration with operators of the telecom systems, vertical industry partners, political representatives, and even standard-setting organisations to ensure that the outputs of the project are widely adopted. The report has a dual purpose - to direct those wishing to take part in building the socially responsible viable 6G domain and 6G - and also to provide an in-depth understanding of the societal, commercial, and regulatory elements of 6G.

Its findings will influence policy-making, standardisation, and the commercialisation of key results, ensuring that the 6G transition is both technologically and societally beneficial.

Keywords 6G, societal acceptance, sustainability, societal values, Key Value Indicators (KVIs), Key Sustainability Indicators (KSIs), Social Acceptance of Technology (SAT), Technology Acceptance Model (TAM), social impact, standardisation, policy recommendations, exploitation strategy.

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Dissemination Level		
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* R: Document, report (excluding the periodic and final reports)
DEM: Demonstrator, pilot, prototype, plan designs
DEC: Websites, patents filing, press & media actions, videos, etc.
DATA: Data sets, microdata, etc.
DMP: Data management plan
ETHICS: Deliverables related to ethics issues.
SECURITY: Deliverables related to security issues
OTHER: Software, technical diagram, algorithms, models, etc.

EXECUTIVE SUMMARY

The 6G4Society project looks at the real challenges of society and ensures the practical exploitation of the findings made, thus promoting the successful application of 6G technologies. This report represents an all-rounded roadmap for aligning 6G with the values of societal priority, environmental values, and economics of exploitation through a transparent, well-defined methodology of exploitation and a schedule of implementation. The project integrates a market-oriented approach focusing on social acceptance and sustainability with the understanding that technological innovation is not enough for either societal acceptance or market success.

The report emphasises the importance of exploiting the project's Key Exploitable Results (KERs) through industry partnerships, regulatory alignment, and stakeholder engagement. The KERs, including the Social Acceptance of Technology (SAT) framework, Key Value Indicators (KVIs), and Key Sustainability Indicators (KSIs), are designed to be adaptable across various industry verticals such as healthcare, transportation, smart cities, etc.

These outputs are structured methodologies for measuring societal impact that shall help meet the technical and social expectations of future 6G technologies. A significant part of the exploitation strategy also involves market opportunity identification and collaboration with industry leaders, policymakers, and research institutions. Hence, one of the core components of this report is the exploitation methodology put in place to ensure that the project outputs can be translated into effective real-world applications. The project acknowledges that market readiness is fundamental to deploying 6G technologies and, therefore, requires closing the gap between research and commercialisation with the engagement of operators and manufacturing equipment. The report's policy recommendations will enable the influencing of regulatory frameworks toward an assurance that ethical principles and sustainability goals.

In other words, the document highlights several market opportunities that 6G technologies can unlock. By embedding societal values and sustainability metrics into the core design of 6G, the project aims to create technologies that are not only innovative but also widely accepted and commercially viable. It also recognises the growing importance of public-private partnerships and international collaboration in shaping the global 6G landscape. It identifies potential funding sources, such as EU initiatives and national innovation programs, to support further exploitation and commercialisation of 6G technologies. It proposes the project's exploitation timeline to ensure the effective implementation of its findings, emphasising a phased approach. This includes updating the KVI/KSI metrics based on market feedback, validating key results and building partnerships, submitting policy recommendations to regulatory bodies, piloting and demonstrating the applicability of 6G solutions in real-world settings, and supporting these technologies' continued adoption and refinement beyond the project's completion. This impact shall not only be sustained in the short and medium term. The report shall propose the consultancy, training, and supporting services available to a wide spectrum of 6G development and deployment participants.

Since then, 6G4Society has given a foundation in a socially responsible 6G that is sustainable on a holistic approach to exploitation - one that resolves societal concerns through market relevance. It provides an overall roadmap for developing and exploiting socially responsible and sustainable 6G technologies. The project bridges the gap between innovation and market adoption by integrating rigorous research with practical applications and exploitation strategies, ensuring that 6G technologies make positive contributions to society and the economy. It gives the basis for the future of research, development, and commercialisation, therefore setting the road towards a new communication technology world based on high

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technical excellence and deep care for social welfare. Guided by those mentioned above, the long-term goal of the 6G4Society project is to ensure the sustainability of a framework in developing 6G that keeps moving forward well after the project's lifetime. This is foreseen to become a community of experts driving continuous research beyond the project's lifetime for lasting impacts in the future standardisation work of the 6G ecosystem.

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ABBREVIATIONS

3CLS	Convergence of Communications, Computing, Control, Localisation and Sensing
AI	Artificial Intelligence
AIE	Associazione Italiana Elettrosensibili (Italian Electrosensitive Association)
AR	Augmented Reality
ATIS	Alliance for Telecommunications Industry Solutions (USA)
CA	Consortium Agreement
CSA	Coordination and Support Action
DG CONNECT	Directorate General for Communications Networks, Content and Technology of the European Commission
DMP	Data Management Plan
DoA	Description of Action
DOI	Diffusion of Innovation
A/IS	Autonomous And Intelligent Systems
AAL	Ambient Assisted Living
AGV	Automated Guided Vehicle
AI	Artificial Intelligence
AR	Augmented Reality
B5G	Beyond 5G
CAM	Connected and Automated Mobility
CAVs	Connected and Autonomous Vehicles
CEL	CyberEthics Lab
CSA	Coordination and Support Action
CSR	Corporate Social Responsibility
CSRD	Corporate Sustainability Reporting Directive
CWA	CEN Workshop Agreement
D	Deliverable
D4P	Digital for Planet
DEP	Digital Europe Programme
DLTs	Distributed Ledger Technologies
EAD	Ethically Aligned Design

EC	European Commission
EIB	European Investment Bank
eMBB	Enhanced Mobile Broadband
EMFs	Electromagnetic Fields
ESIF	European Structural and Investment Funds
ETNO	European Telecommunications Network Operators' Association
ETSI	European Telecommunications Standards Institute
EU	European Union
FP	Framework Programme
FWA	Fixed Wireless Access
GCRF	Global Challenges Research Fund
GHz	Gigahertz
H2H	Hospital-to-Home
HBC	Human Bond Communication
HCS	Human-Centric Services
HT	Holographic Telepresence
IA	Industry Association
IEEE	Institute of Electrical and Electronics Engineers
IioT	Industrial IoT
IoE	Internet of Everything
IoT	Internet of Things
IoV	Internet of Vehicles
IPR	Intellectual Property Rights
ITU	International Telecommunication Union
KERs	Key Exploitable Results
KPIs	Key Performance Indicators
KSIs	Key Sustainability Indicators
KV	Key Value
KVIs	Key Value Indicators
LIS	Large Intelligent Surfaces
LTE	Long-Term Evolution
M2M	Machine-to-Machine
MAR	Martel Innovate

MCS	Mission Critical Services
MioT	Massive Internet of Things
ML	Machine Learning
mMTC	Massive Machine-Type Communications
MR	Mixed Reality
NGI	Next Generation Internet
NIEHS	National Institute of Environmental Health Sciences
NOMA	Non-Orthogonal Multiple Access
NORs	Non-Ontological Resources
NTN	Non-Terrestrial Networks
OECD	Organisation for Economic Co-operation and Development
ORSD	Ontology Requirements Specification Document
OTK	On-To-Knowledge
OWL	Web Ontology Language
PoC	Proof of Concept
PPDR	Public Protection & Disaster Relief
PPP	Public-Private Partnerships
PSCE	Public Safety Communication Europe
R&D	Research and Development
R&D&I	Research, Development and Innovation
R&I	Research & Innovation
RAN	Radio Access Networks
RRI	Responsible Research and Innovation
SAREF	Smart Applications REFerence Ontology
SAT	Social Acceptance of Technology
SDG	Sustainable Development Goal
SmartM2M	Smart Machine-to-Machine
SME	Small and medium-sized enterprise
SNS	Smart Networks and Services
SNS JU	Smart Networks and Services Joint Undertaking
SotA	State-of-the-art
SSNs	Self-Sustaining Networks
STEM	Science, technology, engineering and mathematics

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T	Task
TAM	Technology Acceptance Model
Telcos	Operators
THz	Terahertz
U2X	UAV-to-Everything
UAVs	Unmanned Aerial Vehicles
UC	Use Case
UN SDGs	United Nations Sustainable Development Goals
URLLC	Ultra-reliable and low-latency communications
VLC	Visible Light Communication
VR	Virtual Reality
VTF	Vertical Engagement Task Force
WG	Working Group
XR	Extended Reality
3GPPP	Third Generation Partnership Project (The Mobile Broadband Standard)
5G	Fifth generation mobile network
6G	Sixth generation mobile network
AI	Artificial Intelligence
AIE	Associazione Italiana Elettrosensibili (Italian Electrosensitive Association)
AR	Augmented Reality
ATIS	Alliance for Telecommunications Industry Solutions (USA)
CA	Consortium Agreement
CSA	Coordination and Support Action
DG CONNECT	Directorate General for Communications Networks, Content and Technology of the European Commission
DMP	Data Management Plan
DoA	Description of Action
DOI	Diffusion of Innovation
EC-GA	European Commission Grant Agreement
ELSA	Ethical, Legal and Social Aspects
EMF	Electromagnetic field

ETNO	European Telecommunications Network Operators' Association (now Connect Europe)
EU-US TCC	EU-US Trade and Technology Council
FOMO	Fear of Missing Out
GDPR	General Data Protection Regulation (EU 2016/679)
GMO	Genetic Modified Organism
GSMA	GSM Association
HCI	Human Computer interaction
IAIA	International Association for Impact Assessment
IARC	International Agency for Research on Cancer
ICNIRP	International Commission on Non-Ionizing Radiation Protection
ICT	Information and Communication Technologies
IoT	Internet of Things
ITU	International Communication Union
KPIs	Key Performance Indicators
KSIs	Key Sustainable Indicators
KVIs	Key Value Indicators
LEED	Leadership in Energy and Environmental Design
LBS	Location-based service
ML	Machine Learning
NTN	Non-terrestrial Network
OECD	Organisation for Economic Cooperation and Development
PPP	Public-private partnership
RF-EMF	Radiofrequency - Electromagnetic field
RRI	Responsible Research and Innovation
R&D	Research and Development
R&I	Research and Innovation
SAT	Social Acceptance of Technology
SDGs	Sustainable Development Goals
SNS-JU	Smart Network System - Joint Undertaking
SSH	Social Sciences and Humanities

STEM	Science, Technology, Engineering and Mathematics
STS	Science and Technology Studies
TAM	Technology Acceptance Model
TRA	Theory of Reasoned Action
TRL	Technology Readiness Level
UAM	Urban Air Mobility
UN SDGs	United Nations Sustainable Development Goals
UTAUT	Unified Theory of Acceptance and Use of Technology
UX	User Experience
VR	Virtual Reality
XR	Extended Reality

1 INTRODUCTION

The 6G4Society project addresses the dual challenge of advancing the performance of sixth-generation 6G technology while embedding societal and sustainable values into its core development. Where communication technologies enter their sixth generation, this new generation promises unparalleled innovation, connectivity, and economic growth opportunities. However, those benefits come with increasing urgency for the acceptance and design of 6G, which is socially accepted, ethically sound, and environmentally sustainable. While the new 6G technology promises to revolutionise global connectivity by empowering cutting-edge applications, such as AI native networks, semantic communications, and the Internet of Everything (IoE), it is not without its own set of complex societal challenges: privacy, trustworthiness, ethical use of AI, and environmental sustainability for next-generation networks. The 6G4Society project engages stakeholders across the Smart Networks and Services (SNS) ecosystem, from industry leaders to policymakers, civil society, and the public, ensuring broad-based input and alignment with societal expectations and sustainability goals to address these challenges.

Task T4.2 is one of the main tasks focused on ensuring that project outcomes will be exploited and sustainable in the long term. It is structured around three primary activities: KERs refinement, techno-business-societal assessment, and exploitation and sustainability strategy development. Through these, the project intends to ensure maximum exploitation and commercialisation impact of the 6G4Society outputs, particularly those concerning the SAT framework and KSIs developed during the project. These tools will help shape a value-driven 6G standard that integrates sustainability, trustworthiness, and social inclusion into the technology's design and deployment. In other words, the project contributes to building socially accepted 6G technology by integrating Responsible Research and Innovation (RRI) principles into technology design, ensuring that societal concerns are addressed early in the process.

This report details the methodology, activities, and outcomes related to T4.2 "Exploitation and Sustainability", focusing on the market potential of the project results, Intellectual Property Rights (IPR) management, and strategies for standardisation and certification. Additionally, it outlines pathways for the continuation and scalability of the project's findings through funding instruments, with a view toward creating long-term societal impact and fostering 6G development in alignment with European values and sustainability goals. It also explores vital verticals (e.g., healthcare, agriculture, transportation) to ensure that societal values are reflected in technological design and implementation, aligning with market and societal assessments, and provides a roadmap for standardisation through engagement with relevant working groups and global standard-setting bodies to enable market uptake of 6G innovations. 6G4Society aims to create an exploitation and sustainability strategy to ensure these early techno-business impacts align with market readiness and standardisation objectives. With this intention, the project consortium, through the strategic implementation of various activities, aims to provide (a) feedback to policy and operational measures based on the project's findings, ensuring that 6G is aligned with societal values, (b) consultancy services focused on technology acceptance by helping stakeholders navigate and promote broader 6G adoption, (c) consulting on sustainability indicators, ensuring that environmental goals are embedded in 6G development, and (d) on participatory design, fostering inclusive decision-making processes for technology design. These exploitation activities form a core part of the development and promotion of more informed public opinions and clear communication strategies that create a more transparent and participatory ecosystem to have smoother and broader 6G adoption with an ethical, sustainable, and societally aware approach. Updates concerning the project partners' work and related outcomes after M12 will be available in the updated version of this report, Deliverable (D) 4.4 "Exploitation Report v2", which is to be submitted in month (M) 24.

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2 DELIVERABLE STRUCTURE

This chapter summarises the deliverable's structure, providing an outline of each chapter and a brief description of its content in a clear, bullet-point format. More specifically:

- **Chapter 1 - "Introduction":** This chapter introduces the deliverable by outlining its objectives and significance in the context of 6G technology development, focusing on societal impact, sustainability, and market adoption.
- **Chapter 2 - "Deliverable Structure":** This chapter summarises the report's structure, highlighting each chapter's contents.
- **Chapter 3 - "Market Analysis and Transition from 5G to 6G":** This chapter explores the current state of 5G technology, its ecosystem, and the sectors impacted by its adoption. It also highlights the technology gaps that need to be addressed in 6G and discusses the potential benefits 6G can bring to businesses and society. This chapter further analyses funding sources, ongoing 6G activities in Europe, and the public perception of 6G technologies.
- **Chapter 4 - "Analysis of Exploitation Potential for 6G4Society Key Results":** This chapter describes the KERs identified by the project and outlines the progress achieved up to M12. It also provides insights into how the project outputs can be utilised by various stakeholders and outlines potential exploitation paths.
- **Chapter 5 – "6G4Society Key-Value and Sustainability Indicators":** This chapter discusses the framework for KVIs and KSIs, designed to assess the societal and environmental impacts of 6G technologies. This chapter emphasises the importance of aligning technological advancements with societal values and sustainability goals.
- **Chapter 6 – "Standardisation and Certification Roadmap":** This chapter overviews the current landscape of 6G standardisation and introduces the proposed ontology for 6G societal values and indicators. It outlines the methodological framework for pre-standardisation activities and details the roadmap for certification processes to ensure interoperability and compliance.
- **Chapter 7 – "Exploitation and Sustainability Strategy Plan":** This chapter outlines the project's strategy for ensuring the long-term sustainability of its results. It also reports key steps for exploitation, focusing on market adoption, stakeholder engagement, and future partnerships.
- **Chapter 8 - "Impact Assessment":** This chapter assesses the potential impact of the project's results, aligned with broader policy goals and societal needs.
- **Chapter 9 – "Conclusions":** This chapter summarises the key findings and insights of the deliverable, offering final remarks on the project's contributions to 6G development.

3 MARKET ANALYSIS AND TRANSITION FROM 5G TO 6G

Market analysis guides stakeholders through the dynamic landscape of the fifth-generation (5G) sector, offering invaluable insights into trends, opportunities, and challenges shaping its trajectory. As the world races towards ubiquitous connectivity and digital transformation, the 5G market stands at the forefront, poised to revolutionise industries, redefine consumer experiences, and unleash unprecedented innovation. By delving into key metrics, such as market size, growth projections, and adoption rates, stakeholders understand the forces driving demand, investment, and strategic decision-making in the 5G sector. This journey provides business, policy, and investment decision-makers with critical intelligence while driving cooperation and innovation to realise all the benefits of 5G technology to shape the future of connectivity. 5G differs from earlier generations of communications, particularly in its focus on enabling applications across specific vertical markets. Yet, despite the significant socio-economic value delivered by wireless technology over the generations, it is striking that none of them has ever been explicitly designed to reach this basic objective as a primary goal. In this sense, 5G is the first generation designed to drive socio-economic benefits, expecting many new capabilities explicitly. Such capabilities envisioned for 5G identified [1] include facilitating pervasive video experiences, revolutionising the concept of the smart office, aiming for ubiquitous 50Mbps connectivity, offering customisable network creation options, supporting dynamic capacity scaling, enabling connectivity in diverse transportation modes, providing a unified solution for sensor networks and IoT, ensuring ultra-reliable networks for mission-critical applications, paving the way for the tactile internet, and delivering efficient broadcast services.

While 5G was heralded as a revolutionary step in telecommunications, one explicitly targeted at bringing socio-economic benefits and new capabilities, market rollout and adoption were plagued by several issues that tempered initial optimism [2]. These lessons are important to frame the future trajectory of 6G and point to the need for caution and pragmatism. While 5G was sometimes sold with hyped forecasts, the development and marketing of 6G must be built on credibility and neutrality. Technological innovation has to go hand in hand with realistic timelines, while strong stakeholder collaboration must be assured, and predictions must be based on clear insight into societal and market readiness. By reflecting on the limitations of 5G, the 6G community can avoid repeating past missteps, fostering a development trajectory that is both ambitious and attainable.

Thus, this chapter offers a comprehensive exploration of key aspects shaping the landscape of 5G and beyond, employing a rigorous market analysis methodology to provide insights into current trends, challenges, and future trajectories. Starting with an overview of the 5G ecosystem and its intrinsic values, the chapter delves into the diverse industry sectors impacting 5G adoption, shedding light on their unique roles and contributions. Further, the chapter explores the gaps in 5G technology to identify areas for improvement and innovation. Turning the focus to the realm of 6G technology, the book explores emerging trends, concerns, and opportunities; this includes deep insights into 6G European Smart Networks and Services Joint Undertaking (SNS JU) and its implications. A techno-business-societal assessment determines the potential impacts of 6G and highlights key findings and recommendations to drive strategic decision-making in the next-generation telecommunications environment.

3.1 5G ECOSYSTEM AND ITS VALUES

The meaning of 5G is in its ability to revolutionise connectivity through five critical functionalities: rapid broadband, highly reliable low-latency communication, extensive machine-type communications, heightened reliability/availability, and optimised energy utilisation. These fundamental aspects are likely to transform various activities, such as manufacturing, transportation, public services, education/training, and healthcare [3]. Thus, the widespread deployment of 5G networks, as well as the need to focus on state-of-the-art (SotA) business models, hinges on collaborative efforts among all stakeholders, such as citizens, private enterprises, and government bodies, focusing the attention on the optimisation of end-user experience, service delivery, and decision-making. The 5G technology facilitates the development of new applications, drives business creativity and stimulates economic expansion. More precisely, it represents a pivotal point in the progression of mobile technology, from revolutionising personal communication to becoming a genuine game-changing technology with the potential to revolutionise industries and economies. This said, IHS Markit, an information services provider headquartered in London, projected in 2019 that by 2035, there will be a potential global (United States, China, Japan, France, Germany, United Kingdom, South Korea, rest of the world) economic value of $13.2 trillion, resulting in the creation of 22.3 million jobs solely within the 5G global value chain [4].

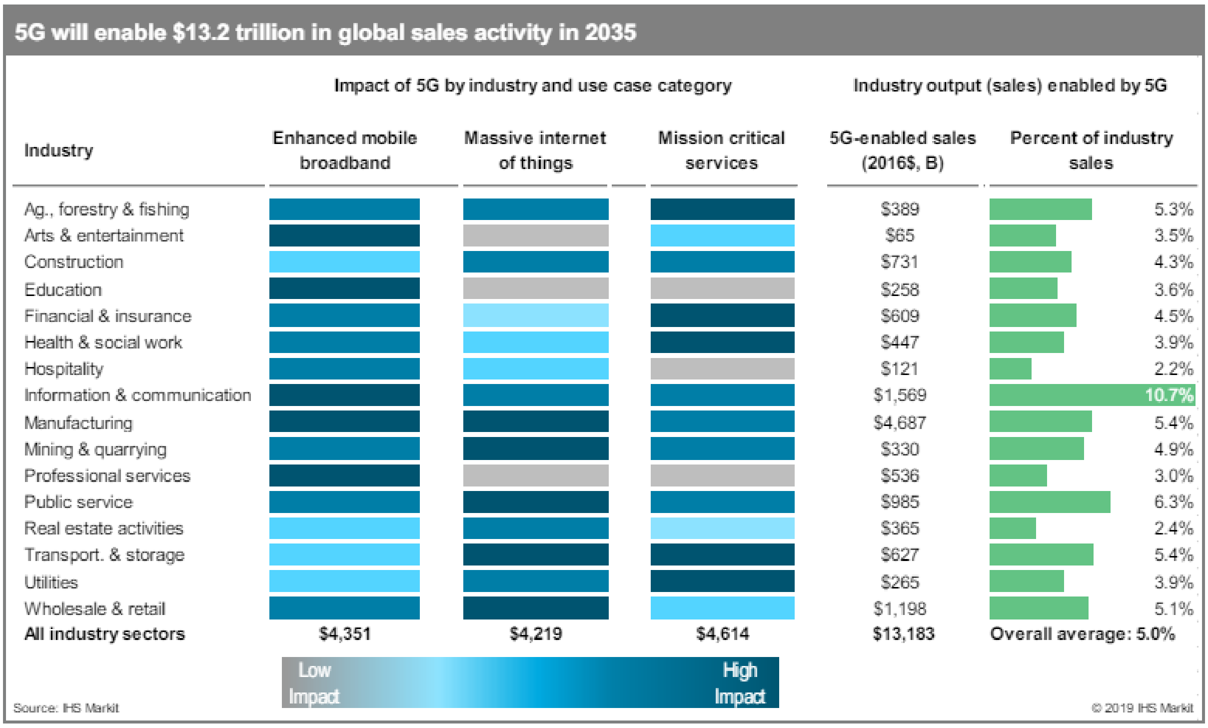


FIGURE 1: 5G GLOBAL SALES ACTIVITY IN 2035 (IHS MARKIT 2019)

Regarding use cases, the three are Enhanced Mobile Broadband (eMBB), Massive Internet of Things (MIoT), and Mission Critical Services (MCS). There are two important enablers of eMBB uptake and value creation in the 5G economy. Firstly, cellular coverage is extended into more settings: office parks, industrial estates, shopping malls, and large exhibition halls. Network capacity is further enhanced to handle many devices that process high volumes of data, primarily in thickly populated areas. These network enhancements facilitate more streamlined data transmission, reducing cost-per-bit for data transfer, thereby serving as a significant catalyst for heightened utilisation of broadband applications across mobile networks. Irrespective of their location, end users enjoy an enhanced and consistently reliable experience when using mobile broadband applications, such as:

- Improved indoor wireless broadband coverage;
- Deployment of fixed wireless broadband;
- Enhanced outdoor wireless broadband connectivity;
- Collaboration and teamwork within enterprises;

- Augmented and virtual reality experiences (AR and VR);
- Education and training;
- Expansion of mobile computing capabilities;
- Enhanced digital signage technologies.

As to what concerns MIoT, 5G enhances and expands upon previous investments made in traditional Machine-to-Machine (M2M) and Internet of Things (IoT) applications, facilitating notable advancements in economies of scale that encourage widespread adoption and utilisation across various industries. With its enhanced low-power demands, capacity to function in both licensed and unlicensed spectrum, and capability to offer broader and more adaptable coverage, 5G substantially reduces costs within Massive IoT environments. Consequently, this facilitates the scalability of massive IoT and fosters a significantly increased adoption of mobile technologies to address MIoT applications such as:

- Tracking of assets;
- Smart cities and smart agriculture;
- Monitoring of energy and utilities;
- Physical infrastructure;
- Integration of smart home technologies;
- Remote monitoring systems;
- Utilisation of beacons and connectivity for shoppers.

In summary, MCS introduces an altogether new market opportunity for wireless technology. The emerging sector of the 5G space is service applications that have ultra-high reliability requirements and ultra-low latency connectivity enabled by strong security controls and extreme availability. All these will bring to bear on wireless technology the possibility of offering ultra-reliable connections that, once supported easily, will make critical applications such as drones, smart grids, industrial automation, autonomous vehicles, and the remote control of sophisticated automation tolerable for they will not have a possibility of failure.

The President and Chief Executive Officer of Nokia once said, “Over the past decade, as 5G was first imagined, then developed, and then launched, those of us in the tech and telecommunications industries became increasingly excited by its potential. It was estimated from an early stage that 5G would make digitalisation more accessible, allowing small businesses, public services, and even individual households to reap the benefits of smart products and services. But we didn’t know exactly what those products and services would look like. Now we know” [3]. Considering this, the following Figure adds to the above-mentioned aspects and emphasises additional functional drivers of the 5G technology.

Functional driver	Description	Added value	Use cases
Enhanced mobile broadband (eMBB)	Faster connections, higher throughput and greater capacity (up to 10 Gbps)	Allows for an extension in cellular coverage into diverse structures (large venues) and the ability to handle a larger number of devices using high amounts of data	Fixed wireless access service, enhanced in-building broadband service, real-time augmented reality service, real-time virtual and mixed reality service, crowded or dense area service, enhanced digital signage, high-definition cloud gaming, public protection and disaster response services, massive content streaming services, remote surgery and examination
Ultra-reliable low latency communication (uRLLC)	Reduced time for data from device to be uploaded and reach its target (1 ms compared to 50 ms for 4G)	Enables time-sensitive connections wirelessly	Autonomous vehicles, drones and robotic applications, health monitoring systems/telehealth, smart grid and metering, intelligent transportation, factory automation, remote operation, self-driving cars, mission-critical services (security and safety), high-definition real-time gaming
Security	Robust security properties, leading to high reliability and availability	Creates an ultra-reliable connection to support applications where failure is not an option	
Massive machine-type communications (mMTC)	Increased spectral efficiency plus small cell deployment	Allows for a large number of connections to support data-intensive applications	Asset tracking and predictive maintenance, smart cities/buildings/agriculture, internet of energy/utility management, industrial automation, smart logistics (advanced telematics), smart grid and metering, smart consumer wearables, environmental management, intelligent surveillance and video analytics, smart retail
Power efficiency	Efficient power requirements for massive multiple-input, multiple-output (MIMO), small cell implementation	Leads to lower costs and enables massive internet of things	

Source: ITU, 2018.[5]

FIGURE 2: FUNCTIONAL DRIVERS OF 5G (IHS MARKIT 2019)

This is to understand the importance of the 5G Ecosystem Cycle and its components: spectrum, impact, services, devices, security, and infrastructure. In the 5G ecosystem, spectrum functions as the essential resource, akin to oil, without which neither 5G network infrastructure nor devices can function. Future networks will hinge on a blend of conventional and innovative technologies, utilising both licensed and unlicensed spectrum across various spectrum bands simultaneously. These bands encompass different characteristics: low bands offer extensive range and indoor penetration but lower capacity density. In contrast, high bands provide short-range coverage with limited indoor penetration but high-capacity density. Impact reflects the economic and societal sector, encompassing aspects such as employment (payroll), economic output, profits, and investment, as well as spanning across domains such as, amongst others, health, education, greenhouse gas levels, biodiversity, waste management, water consumption, and quality, etc. Regarding 5G services, 5G presents an opportunity for connectivity providers within the 5G ecosystem to enhance their network leadership by seizing the initiative and strategically positioning themselves to offer essential services across varied geographic regions. Nevertheless, it's necessary to revamp subscriber-based business models to facilitate digital services aligned with enterprises' strategic plans across various sectors. Engaging non-traditional stakeholders from different industries is essential in establishing partnership-oriented ecosystems and expediting the deployment of 5G networks. Devices (including sensors and smartphones) can deliver significantly enhanced performance and, thus, must come in various form factors to accommodate the emerging 5G-enabled use cases and business models. The perceived and tangible end-to-end security of 5G infrastructure, devices, and applications is a key factor for end users, enterprises, and public institutions in their decisions related to migrating their operations onto 5G. Infrastructure refers to the different elements composing the 5G network, which provide coverage, bandwidth, latency, and reliability to 5G devices. This includes base stations, mobile backhaul, edge clouds, core networks, and the end devices that utilise the 5G network.

Therefore, particular aspects influence the adoption of 5G within specific sectors. These factors encompass certification standards, especially stringent in healthcare and utilities, the incorporation of 5G into existing protocols and standards within manufacturing, and the necessity for suitable skill sets and business models, particularly in industries where wireless connectivity has been traditionally limited. The following section identifies and analyses the 5G industry sectors in depth.

3.1.1 INDUSTRY SECTORS BENEFITTING FROM 5G

Within the landscape of 5G adoption, industry sectors play a critical role in shaping the trajectory of implementation and utilisation. Each sector brings unique challenges, requirements, and opportunities, influencing the pace and extent of 5G integration. According to the World Economic Forum [5], the specific industries (see the following Figure) that significantly influence the adoption of 5G are presented, exploring the diverse factors and considerations that impact their journey toward embracing this transformative technology.

Primary industry sector (10)	Secondary industry sector (10)	Technology specialty area (11)
Manufacturing	Machinery and equipment	Internet of things
Transportation	Automotive	Mixed reality
Public services	Logistics	Autonomous driving
Health and social work	Railways	Drones
Agriculture	Education	Robotics
Energy	Info and communications	Advanced communication systems
Logistics	Semiconductors	Artificial intelligence
Media and entertainment	Urban infrastructure	Cloud
Mining and quarrying	Consumer goods	Digital twin
Professional services	Sports	Gamification
		Simulation/imaging

FIGURE 3: CREATING NEW VALUE ACROSS INDUSTRIES AND SOCIETY (IHS MARKIT 2019)

In more detail, the 5G industries that were estimated to generate most of the sales by 2035 [3] are:

Manufacturing: Stands to gain in the near-to-mid-term from improved indoor wireless broadband coverage, contributing to its adoption of 5G. Initial applications also include asset tracking-maintaining visibility into the flow of components and products within the supply chain- and industrial automation, such as providing connectivity to mobile assets including Automated Guided Vehicles (AGVs).

Information and communication: Encompass telecommunications, broadcasting, and video services. The primary initial use case revolves around providing improved outdoor wireless broadband connectivity, especially for smartphones.

Wholesale and retail: Those sectors are focusing on improving indoor wireless broadband coverage, allowing consumers to access product details, promotions, and store layouts through their smartphones, serving as a pivotal early application. Additionally, there is a utilisation of eMBB/MIoT capabilities for tracking vehicles outside the store and monitoring the condition of perishable goods during transportation.

Public service: Encompasses government operations and initiatives like smart city development and defence, a significant early focus lies on energy and utility management, exemplified by applications such as smart metering. Smart cities use the technology to optimise not only customer billing precision but also to better understand energy consumption trends at different time resolutions. Such information is invaluable to governments and utilities in forecasting demand and efficiently managing supply, from integrating alternative energy sources into the grid.

Construction: Involves the remote monitoring and control of both driver-operated and autonomous construction vehicles.

Transportation and storage: Incorporate land, water, and air transport, as well as transport via pipelines, as well as warehousing and associated transportation support activities. In the near-to-mid-term, the adoption of 5G in this sector will be propelled by asset tracking, including fleet management, and the utilisation of drones.

Financial and insurance: Initial applications will involve enterprise teamwork/collaboration and training/education. Health insurance companies explore 5G's potential in monitoring remote patient conditions at an early stage.

Health and social work: The mobile and dispersed nature of healthcare and social work professionals drives enterprise teamwork/collaboration as an early use case. Early applications include remote patient monitoring and treatment guidance from hospital-based clinicians to field workers such as nurses and paramedics.

Agriculture: In the near-to-mid-term, asset tracking (including fleet management) and drone usage propel 5G adoption in this sector. Livestock and soil monitoring via MIoT were also considered an early application. The integration of the fourth-generation (4G) of mobile phone technology Long-Term Evolution (LTE) into agricultural vehicles provides an upgrade opportunity for 5G-enabled eMBB.

Mining and quarrying: Involve the remote monitoring of high-value mining equipment to enhance efficiency and prevent downtime.

Utilities: Include smart metering for electricity, gas, and water, along with the monitoring of power and sewer infrastructure.

Education: Enterprise teamwork/collaboration and training/education, along with the utilisation of AR, particularly in research-intensive scientific disciplines.

Hospitality: Enhances the customer experience through improved indoor wireless broadband coverage.

Professional services: Among the earliest 5G use cases will be enterprise teamwork/collaboration and extending mobile computing, enabling remote access to cloud-based information and applications.

Arts and entertainment: Stadium owners' interest in eMBB 5G is fueled by the desire to provide a superior audience experience through reliable connectivity and the ability to share live video content.

3.1.1.1 5G-PPP VERTICAL SECTORS

The Infrastructure Public Private Partnership (5G-PPP), and specifically, the 5G-PPP Vertical Engagement Task Force (VTF) of the 5G Infrastructure Association (5G-IA), focuses the attention on the ways 5G empowers the vertical industries, known as automotive, manufacturing, media, energy, e-health, public safety, and smart cities [6].

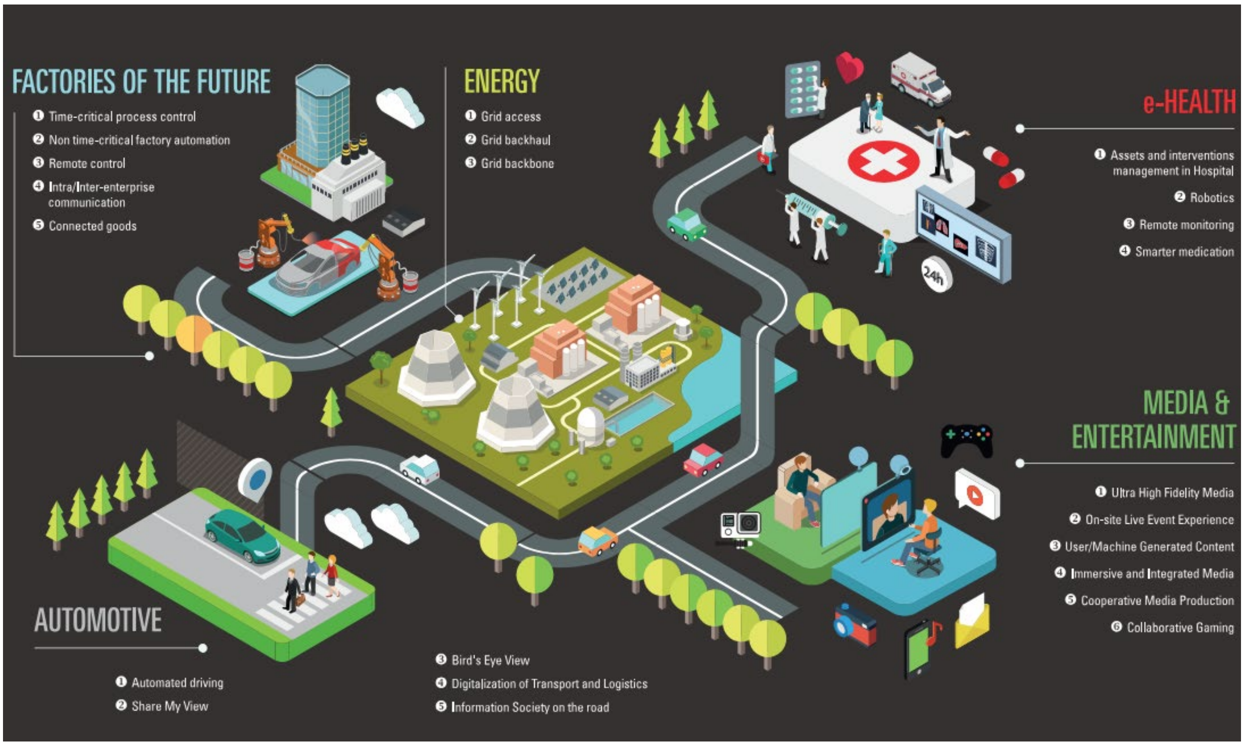


FIGURE 4: 5G-PPP VERTICAL SECTORS

Considering the Figure reported above [7], technological advancements enable vertical industries to develop new technical capabilities, which will open up new avenues for the creation of innovative products and services. In other words, 5G will further tighten the link between the telecom industry and the vertical sectors, promoting digitalisation in traditional industries to become more productive and competitive. By fostering synergies across verticals, thereby allowing the sharing of costs related to the deployment of infrastructure and operation of services, 5G bears the potential to cause radical changes in existing business models. Compatibility with past infrastructure investment ensures continuity of service, backward/forward compatibility, and thus a gradual transition from 4G to 5G deployments while addressing operational considerations. However, it is crucial to identify the particular needs of key vertical sectors, anticipate emerging trends, and seamlessly integrate them into the design of 5G technology. Therefore, close collaboration between vertical industries and 5G infrastructure providers is necessary for mutual benefit and the success of 5G.

With this intention, the White Paper of the World Economic Forum, titled “The Impact of 5G: Creating New Value Across Industries and Society” [5] emphasises the results of 40 use cases (UCs) collected, reflecting key companies, industry advancements, and 5G functional drivers. The following Figure is an example of Nokia, which, in collaboration with China Telecom and China Mobile, provides a 5G-enabled healthcare solution for hospitals.

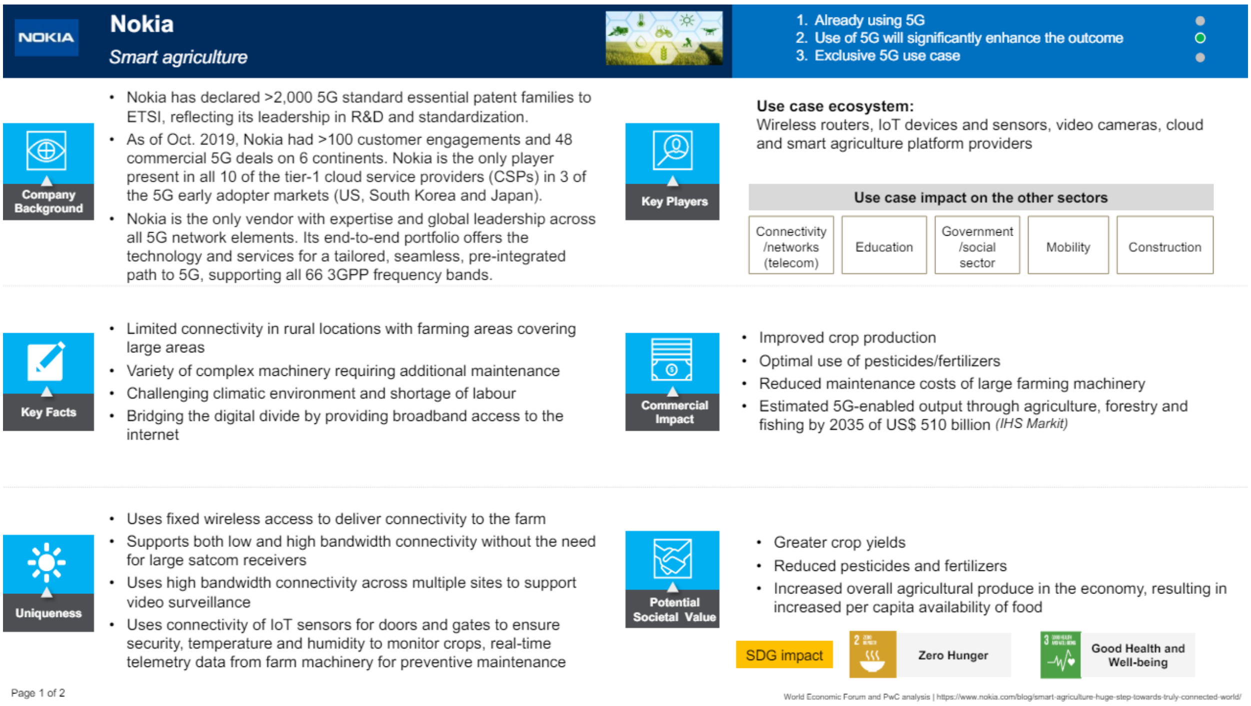
FIGURE 5: NOKIA 5G-ENABLED HEALTHCARE SOLUTION FOR HOSPITALS

In particular, pressure from improving health services in hospitals compels a need for innovations in AI and Big Data. This creates huge interest in innovative solutions applicable in the provision of both in-hospital and pre-hospital service provisions covering patient care challenges within rural areas. 5G coverage in every ward makes use of remotely controlled robots to inspect the ward promptly without a hitch. Likewise, remote diagnosis and ambulance service through applications that use 5G-enabled networks are realised. These advancements are complemented by the implementation of innovative AI and big data solutions to improve healthcare services further. Nokia collaborates with the First Affiliated Hospital of Zhengzhou

University to explore the application of 5G in healthcare and has forged a partnership with Neusoft Medical Systems in this pursuit. Such partnerships will impact other sectors such as cities/urban infrastructure, public sector (government), insurance and finance, transportation (mobility), etc., and will improve the access to healthcare services for patients residing in rural areas.

Additionally, there is the advantage of citizens accessing global expertise even in remote locations and of doctors experiencing enhanced operational efficiencies. The use of 5G technology (AI, robotics, big data, etc.) in such a domain facilitates faster internet access, enabling remote visual monitoring of patients and interconnecting hospital wards for streamlined operations. Additionally, 5G-enabled ambulance services enhance emergency response capabilities. This development brings more citizen awareness and well-being toward achieving Sustainable Development Goal (SDG) 3, Good Health and Well-being. In addition, it promotes research and innovation, meeting the requirements of Sustainable Development Goal 9: Industry, Innovation, and Infrastructure. Businesses also stand to gain, with potential revenue growth through new opportunities arising from enhanced connectivity. Moreover, the utilisation of remote monitoring can lead to a percentage of lives saved, while users may experience a reduction in healthcare costs.

Another UC example, reported by the World Economic Forum, is Smart Agriculture by Nokia (see the Figure presented below). The main challenges are limited connectivity and the need for broadband access to the internet. The farm also has a number of complex machines that require more maintenance efforts. Adverse climatic conditions and labour shortages make it difficult for the farming sector to operate smoothly. All these become crucial in bridging the digital divide and providing fair access to technology and resources for rural communities.



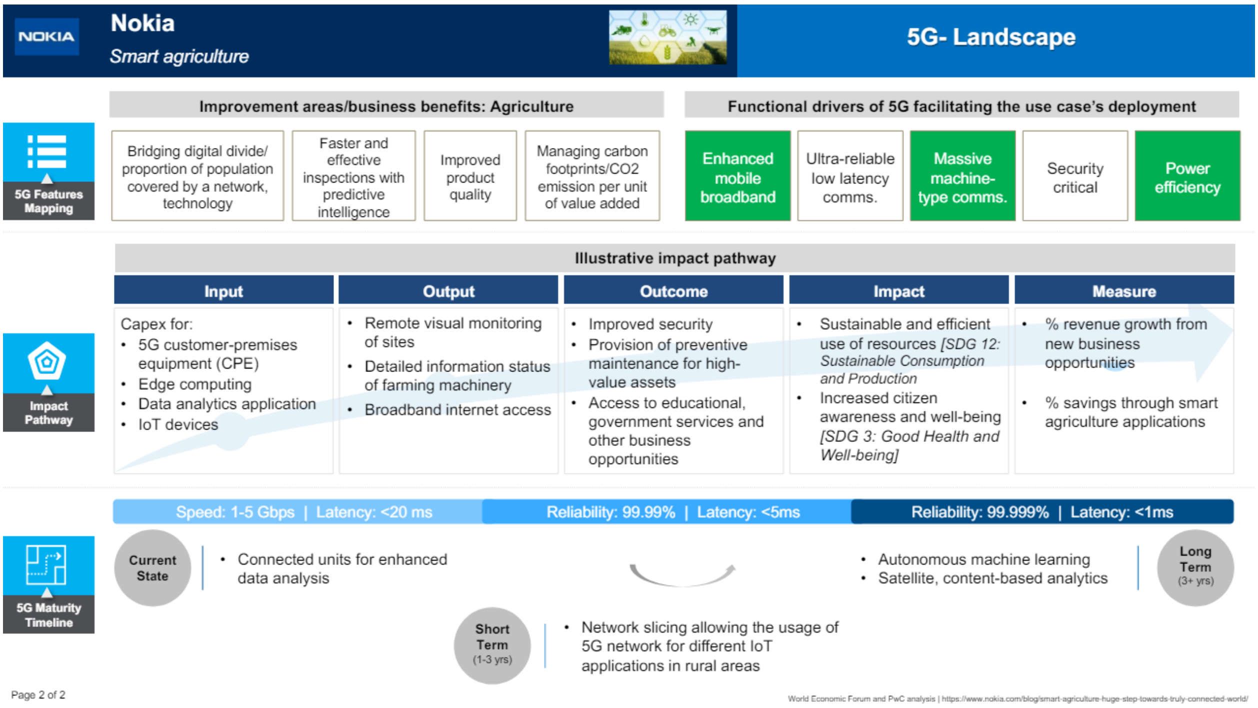


FIGURE 6: NOKIA SMART AGRICULTURE

Nokia targeted these challenges by employing fixed wireless access as a solution to provide connectivity to farms, catering to both low and high bandwidth needs without the necessity of large satellite communication receivers. This approach utilises high-bandwidth connectivity across various sites to facilitate video surveillance. It also utilises IoT sensors for the security, temperature, and humidity monitoring of crops and collects real-time telemetry data from farm machinery for preventive maintenance. Thus, this use case extends further in other industries like connectivity/networks (telecom), education, mobility, government/social sector, and construction, affecting not only improved crop yields but also optimised usage and reduction in the application of pesticides and fertilisers to contribute toward sustainable agriculture. This advancement is poised to lower the maintenance costs associated with large farming machinery. Projections indicate a significant potential for 5G-enabled output in the agriculture, forestry, and fishing sectors by 2035, estimated at US$ 510 billion by IHS Markit. Examples of outcomes are the remote visual monitoring of sites, enabling comprehensive oversight while offering detailed status updates on farming machinery. It also allows for better security and preventive maintenance of high-value assets, access to educational resources, government services, and different business opportunities, which enhance overall productivity and connectivity in rural areas. More examples can be found in the White Paper of the World Economic Forum: IoT and smart city solutions, manufacturing, robotics, etc.

3.1.1.2 5G TECHNOLOGY KEY MARKET SEGMENTATION

5G technology is going to revolutionise the global landscape of telecommunications by promising unprecedented speeds, ultra-low latency, and vast network capacity. As this transformative technology spreads further, knowing its key market segments becomes critical for stakeholders across industries. The subtlety of market segmentation in 5G brings out an ecosystem where diverse applications, verticals, and geographical considerations give way to deeper insights into which areas are truly promising and which businesses can make the most sense of this dynamic market. Dissection of such segmentation amply highlights the specific needs, challenges, and opportunities that define 5G adoptions in various sectors, shaping its trajectory of integration and driving innovation across boundaries [8].

Segmentation of the 5G technology market is thus critical to understanding its multifaceted landscape and unlocking its true potential. Its basis depends essentially on hardware, software, and services. These play a total role in 5G deployment, optimisation, and utilisation of any type of 5G network, fulfilling varying needs with their various industrial innovations. Probing deeper into these offerings will bring about a clearer and broader understanding of the 5G eco-system that reveals market dynamics, unique value propositions, and opportunities positioned by each segment in front of the entire value chain. This provides an insight into the present state of the 5G market, offering a discernible sense for future strategy decision-making in an era of accentuated connectivity and digital transformation. In addition, understanding the core sections of the 5G technology market is critical to mirroring the dynamic and rapid change driven by connectivity frontiers. One of the key aspects of the segmentation refers to the forming of the offering categories based on its connectivity- fit as it forms the crux of capability and application development of 5G networks- from enhanced mobile broadband to ultra-reliable low-latency communication through to massive machine-type communications. Basically, by connecting the connectedness of 5G to the market-for-geared analysis, we can disclose unique value propositions, use cases, and opportunities posed by this huge market. This exploration thereby offers a chance not only for stakeholders to assess diverse needs for their own and common interests but also to realise the full potential of 5G technology in the age of interconnectivity. The impact of 5G remains beyond telecommunication applications, overtaking a wide variety of industries such as healthcare and automotive, manufacturing, entertainment, etc. The application-based segmentation gives clarity on use cases, requirements, and business opportunities to drive application adoption and innovation within each sector.

Such analysis provides insight into aspects that different industries and consumers find of importance and useful targeting for stakeholders wishing to leverage 5G technology to its full extent in an interconnected world being built. The scope and impact of 5G applications extend beyond traditional telecommunications to diverse sectors like healthcare, automotive, manufacturing, entertainment, and so on. This application-based segmentation helps to identify case studies, requirements, and opportunities that would drive adoption and innovation in each sector. Such a study of the applications landscape represents the context in which we want to place 5G and how it will change industries, empower businesses, and enrich lives. The particulars of application-based segmentation allow stakeholders to pinpoint key growth bright spots and use that intelligence to deploy resources strategically to capitalise on the gigantic potential of 5G technology that is shaping the future of connectivity and digital transformation. Lastly, segmentation based on end-user categories, such as automotive, health, entertainment, manufacturing, and others, will be one of the aspects that propel the expanding efforts of adoption and innovation in response to preferences, preferences, and demands. From consumers wishing for ultra-fast mobile connectivity to enterprises leveraging their network infrastructure for industrial automation, the end-user category is vast and wide. Segmenting the market in this manner provides a window into the exact needs and challenges, as well as opportunities, facing each group of users. This exploration examines the vibrant development of 5G applications for specific sectors, illuminating how this technology is changing the way the world interacts, engages, and empowers industries. Such a grasp of the end-user segmentations not only allows stakeholders to adapt their proposition toward the needs of the segments but also sets the strategic context for decision-making to spur sustainable growth and innovation ushered in by the next generation of connectivity-5G.

Co-funded by the European Union

3.1.2 5G USE CASES

5G technology is revolutionising various industries by enabling applications that leverage its high-speed connectivity, low latency, and capacity to connect numerous devices simultaneously. Here are some notable use cases and enablers across different sectors [9] [10] [11] [12]:

1. **Enhanced Mobile Broadband (eMBB):**
   - Immersive Media: 5G facilitates AR, VR, and MR experiences, enhancing sectors like gaming, virtual tourism, and remote collaboration.
   - High-Definition Video Streaming: It supports seamless streaming of 4K and 8K videos, improving media consumption and live broadcasting experiences.
2. **Ultra-Reliable Low-Latency Communication (URLLC):**
   - Autonomous Vehicles: 5G enables real-time communication between vehicles and infrastructure, enhancing navigation and safety for self-driving cars.
   - Smart Healthcare: It allows for remote surgeries and telemedicine through real-time video and robotics, improving access to medical services.
   - Industrial Automation: 5G supports autonomous robots and real-time process control in manufacturing, boosting productivity and efficiency.
3. **Massive Machine-Type Communications (mMTC):**
   - Smart Cities: 5G connects a vast number of IoT devices, enabling intelligent infrastructure like smart lighting, waste management, and traffic optimisation.
   - Smart Agriculture: It supports precision farming with IoT sensors for soil monitoring and irrigation control, enhancing agricultural productivity.
4. **Fixed Wireless Access (FWA):**
   - Broadband Connectivity**:** 5G provides high-speed internet access in rural or underserved areas, bridging the digital divide.
5. **Network Slicing:**
   - Customised Network Services**:** 5G allows for the creation of virtual networks tailored to specific needs, such as dedicated slices for emergency services or industrial applications.
6. **Internet of Vehicles (IoV):**
   - Connected Transportation: 5G enables vehicle-to-everything communication, improving traffic management and road safety.
7. **Smart Manufacturing and Industry 4.0:**
   - Digital Twins: 5G supports real-time digital replicas of physical systems, allowing for simulation and optimisation in manufacturing processes.
8. **Smart Healthcare:**
   - Wearable Health Devices: Connected wearables monitor patient health in real-time, facilitating proactive healthcare management.
9. **Smart Homes and Consumer IoT:**
   - Home Automation: 5G connects appliances and security systems, enhancing convenience and energy efficiency in smart homes.
10. **Immersive and Augmented Reality for Enterprises:**
    - Retail and Education: 5G enables virtual showrooms and AR-powered learning experiences, transforming customer engagement and educational methods.
11. **Smart Energy and Utilities:**
    - Smart Grids: 5G facilitates real-time monitoring and management of energy distribution, improving efficiency and integrating renewable energy sources.
12. **Environmental Sustainability:**
    - Climate Monitoring: Connected sensors and drones powered by 5G monitor environmental conditions, aiding in proactive environmental management.

These use cases demonstrate 5G's potential to drive innovation and efficiency across various industries, contributing to economic growth and societal advancement.

3.2 5G TECHNOLOGY GAPS

As elaborated in the D1.1 report: "Societal aspects in 6G Technology: concerns, acceptance models and sustainability indicators" (the report will soon be available on the project website) [13] of the 6G4Society project, the advent of 5G came with significant improvements in connectivity, speed, and latency. However, largely alongside these technical achievements surfaced certain gaps that persisted to restrain broader acceptance and societal integration of technology. Alongside being technological, these loopholes encompass societal, environmental, and governance challenges. From issues related to public trust and health concerns to the need for greater sustainability and inclusive governance, the lessons learned through 5G offer a very fundamental basis to be dealt with under similar considerations while shaping the development of 6G technology. This section additionally briefly discusses some of the gaps that arise from the rollout of 5G and influence future communications technologies [14]:

1. **Public Acceptance Gaps**:
   - Lack of Trust in Technology: Similar to the public backlash against 5G, there is a vital concern that 6G may face challenges in public trust due to privacy, surveillance, and health concerns. The public needs reassurance that 6G technology addresses these concerns early to avoid similar resistance.
   - Communication and Transparency: There is a gap in how information about new technologies like 5G and 6G is communicated to the public. Lack of transparency and risk communication have been significant obstacles, with past technology deployments creating a sense of mistrust in official sources.
   - Misinformation and Disinformation: Disinformation, especially during the rollout of 5G, contributed to public fears and opposition. If 6G does not address this gap, the same cycle of misinformation could be repeated.
2. **Sustainability Gaps:**
   - Trade-offs between Performance and Sustainability: One gap identified is the conflict between technological performance goals (such as enhanced connectivity and speed) and sustainability objectives. A balance is needed to ensure that sustainability is not compromised by pursuing higher technical specifications.
   - Energy Consumption: A significant concern is how 6G will handle its energy footprint. Current projections show that the increase in connectivity could lead to higher energy consumption, creating a significant gap in achieving sustainability goals.
   - Measurable Sustainability Indicators: There is a gap in developing robust and standardised KSIs that can measure the sustainability impact of 6G technologies and ensure alignment with the United Nations Sustainable Development Goals (UN SDGs).
3. **Social and Ethical Gaps:**
   - Social Inclusion and Gender Gaps: The report highlights the importance of including diverse stakeholders, especially women, in the development process of 6G. Failure to address gender inclusivity and broader social inclusion in decision-making could result in technology that does not reflect diverse societal values.
   - Ethical Considerations of AI: AI-native networks are a key part of 6G, but there are concerns about trustworthiness, resilience, and ethical considerations of AI systems, especially regarding data privacy and the potential social impact of AI-driven technologies.
4. **Technological Gaps:**
   - Semantics and Trustworthiness: Semantic communications, which focus on transmitting the meaning of data, bring up questions about the trustworthiness of AI-based systems that interpret and generate messages. Data sovereignty and privacy concerns are identified as crucial gaps.

- Network Resilience and Reliability: There is a gap in ensuring that 6G networks are resilient, especially in disaster scenarios, where Non-Terrestrial Networks (NTNs) and energy-harvesting technologies will play a key role.

5. **Standardisation Gaps:**
   - Fragmented Approaches to Sustainability and Values: There is a gap in standardising how values and sustainability are integrated into developing 6G technology. A common framework for KVIs and KSIs across different sectors and countries is critical.
   - Interoperability and Certification: There are gaps in the interoperability of technologies and the need for a certification process to ensure that sustainability and social values are recognised across different regions and industries.
6. **Governance and Regulatory Gaps:**
   - Governance of Emerging Technologies: There is a gap in developing a governance framework for 6G that involves local communities, industry players, and policymakers. This emphasises the importance of inclusive governance that incorporates different stakeholder perspectives, particularly when addressing the democratic and ethical concerns around 6G technology.
   - Precautionary Measures and Policies: There is a gap in defining policies that adequately address public concerns, particularly regarding health risks, environmental impacts, and privacy. Precautionary principles need to be better embedded into 6G policies to prevent backlash and opposition from civil society.

These gaps require thorough consideration to guarantee that 6G technology is open to technical advancement, social acceptance, sustainability, and ethical congruence. Detailed examples and analysis can be consulted in D1.1, to be submitted in M11. The report covers various market-oriented aspects tied to the future of 6G technology. First, it emphasises that 6G will not merely serve as a stop-gap increment over 5G but rather a larger re-engineering of perception and deployment of communication systems. Besides such technologies' uniqueness with respect to bandwidth and latency, societal values like sustainability, inclusivity, and privacy are also driving 6G. This is seen as a critical turning point in building market acceptance and creating wider useable commercial use cases for 6G across various verticals, like healthcare, energy, transportation, and education. The geopolitically competitive importance of 6G is reiterated, where regions and countries, such as the EU, China, and the United States, are competing to establish technological domination. For the EU, the development of 6G is an opportunity to regain a stronghold in telecommunications in the wake of losing out on the ground to Asia in the race for 5G. Competition among the markets will be defined by technology-oriented innovations and strategic policy-making towards such items as sustainability objectives and European values. Hence, the report also discusses how market trends, such as the increasing demand for digitisation and connectivity, are pushing for improvements to the telecommunication infrastructures. Innovations driving 6G will be capable of meeting user requirements for speed and efficiency in communication and making way for new business models and market sectors, including IoT, AI-driven services, and immersive experiences. Nevertheless, as the foregoing paragraphs have detailed, there are challenges regarding energy efficiency, privacy, and data governance that may stand in the way of increased market acceptance.

We need to explore the interests in-depth concerning what 5G once promised and what was not delivered. This gap in deployment and integration into society, technical, societal, environmental, and governance-related, should provide important lessons that are necessary and useful for the emergence of 6G. The creation of the said technologies was hailed by the industry as a major leap in the history of digital communication. This would revolutionise complete industries and lives with uninterrupted connectivity, lower latency, and better speeds and efficiencies. With the advent of 5G came innumerable challenges that hindered it from completely being accepted and integrated into society. This analysis has been able to highlight the gaps related to public trust, sustainability, inclusivity, governance, and technology resilience and has provided rich insights towards similar challenges required to be dealt with during the development of 6G. Embellishing on D1.1, this report also talks about the major issues that caused the downfall of 5G and their importance in understanding future technologies. Probably the biggest threat faced by 5G was in gaining public trust.

Thus, this report, going beyond D1.1, deliberates on the points where 5G failed and its implications for future communication technologies. Lack of public trust was one of the biggest challenges that 5G faced. Though promoted as safe and positive for huge public benefit, it was resisted at deployment by fears for health, privacy, and surveillance. Public fears for Electromagnetic Fields (EMFs) were stoked by the spread of misinformation campaigns offering conspiracy theories linking 5G to health issues and even the COVID-19 pandemic. In the words of the National Institute of Environmental Health Sciences, "…in the age of cellular telephones, wireless routers, and the Internet of things using EMF, fears continue regarding the potential connection between EMF and health effects." During the 1990s, the NIEHS stated that "additional research is needed, and continued education should be supported to inform the public on ways to reduce their exposures to EMFs" [15]. These narratives took root because of the failure of stakeholders to establish and undertake genuine transparent communication strategies because communities felt dished out and ostracised. Besides, 5G deployments essentially opened the door to practice that excluded inclusive governance: in most cases, other local voices in decision-making were not heard or consulted, which resulted in public protests and stalled infrastructure construction. This uncovered a blatant chasm in the commonly adopted way the technology made it to the public: mainly centred on technical innovations without addressing the imperative of meaningful engagement with the public for confidence building. Such created mistrust urgently calls for 6G to adhere to public transparency to engage and give an ear to public worries for acceptance to thrive.

Again, sustainability was another major promise of 5G that fell short in practice. Although presented as eco-friendly, in practice, it raised energy demand by virtue of deploying dense antenna and demanding connectivity of disparate systems to centre the connectivity paradigm. In effect, a paradox played out: optimisation inside individual system components appeared to proceed toward energy efficiency but collateral increase in system footprints grew. This disparity showed the lack of coordination between sustainability targets and realising such targets. Moreover, through 5G, countries predominantly used 4G technology and devices last as long as possible, creating a problem of e-waste management. The lack of good policies for recycling and repurposing old systems dulled some of the environmental advantages that 5G was meant to provide. Rather than help cross the digital divide, 5G sometimes exacerbated the digital inequalities it was supposed to remedy. The incredible costs associated with deploying 5G meant that urban and affluent areas had the infrastructure while the rural and neglected areas lagged far behind. In fact, such selective roll-out widened digital accessibility gaps rather than narrowing them, hence contradicting the very vision of universal connectivity. 5G adoption further highlighted global inequalities-distinct-level contrasts between developed and developing countries. The developing countries were outweighed by greater dependence on and survival rates to reap adequate benefits. 6G must embrace global inequalities and ensure its benefits reach everybody, irrespective of geographic or social considerations.

The integration of AI and IoT with 5G raised major ethical questions that were not fully addressed in its deployment. This came with privacy, ownership, and governance concerns about data, especially with connected devices and their continuous flow of huge amounts of data. Mechanisms to guarantee personal data safety were far from catching up. Thus, fears of exploitation and lynching followed closely. Besides, the social implications of 5G-enabled technologies such as automation were not duly considered: while these innovations promised efficiency and productivity, they also posed risks like the displacement of jobs and accumulation of power in technology industries. Such unintended consequences give a powerful reminder of the need to incorporate ethical considerations in the development of 6G, so as to ensure that such technology serves the interests of society and not actually promote inequality. In addition, the rollout of 5G projects left wide gaps in governance and regulation that rendered its initiatives ineffective. Slightly fragmentary approaches across regions created the ripples and delays in deployment standards that rendered a truly global vision for 5G rather helpless. In several instances, the reactive frameworks of governance fell short of addressing the health, environmental, and privacy concerns of the public, resulting in immense resistance and opposition. The absence of precautionary principles in 5G policies further brought forth this governance gap. With no social responsiveness to pre-empt actual risks, stakeholders were put on the back foot, attending to public displeasure. This sort of going with the flow brought forth a distinct demand for 6G to adopt fully functional and anticipatory governance models, wildly inclusive of diverse stakeholder positions concerning very early-on societal concerns in the technology development process.

5G had ambitious aims technologically, but certain hindrances denied its accomplishment. The barriers are logistical and financial to develop infrastructure for remote and rural areas that side-track the promise of universal connectivity. Resilience to disaster scenarios was questioned, as well, given that instances of energy-efficient, disaster-proof networks did show cracks in place. Besides, infusing AI into 5G networks prompted concerns regarding semantic communication and trust. Questions on the reliability of the AI systems' interpretive-generative aspect, alongside data sovereignty and privacy issues, were not fully settled. These gaps prompt the necessity of 6G to orient itself towards providing resilient, reliably operating, and ethically sound techno-systems. The shortcomings of 5G provide critical lessons for developing 6G, which aims to go beyond technical improvements to address societal values such as sustainability, inclusivity, and privacy. To avoid repeating 5G's mistakes, 6G must prioritise public engagement, transparency, and trust-building from the outset. It must also integrate measurable sustainability indicators, promote equitable access, and address ethical considerations in its design and deployment. By learning from 5G's unfulfilled promises, 6G has the potential to set a new standard for responsible innovation. Its development represents an opportunity to align technological advancement with societal needs, ensuring that it achieves technical excellence but also contributes to long-term social and environmental benefits.

3.2.1 GAP ANALYSIS

Before delving into the analysis of the 6G technology, summarising the outcomes of D1.1 and thus identifying the shortcomings of 5G technology across six domains: Public Acceptance, Sustainability, Social and Ethical Considerations, Technological Development, Standardisation, and Governance, is essential. As analysed in the following Table, each domain includes the identified gaps during 5G deployment and their corresponding implications for developing 6G. It also provides a structured view of these issues, enabling clear insights into how 6G can address these shortcomings.

TABLE 1: GAP ANALYSIS OF 5G AND IMPLICATIONS FOR 6G_V0.1

Domain	Identified gaps in 5G	Implications for 6G
Public acceptance	Lack of trust due to health, privacy, and surveillance concerns; insufficient public engagement.	Proactive trust-building measures; inclusive governance to align technology with societal values.
Sustainability	Energy inefficiency and lack of measurable sustainability	Focus on energy efficiency and the

	indicators; failure to address e-waste effectively.	development of robust and standardised KSIs.
Social and ethical considerations	Limited inclusivity in decision-making; inadequate consideration of AI ethics and data privacy.	Integration of diverse stakeholders in development; prioritisation of ethical AI and data governance.
Technological development	Insufficient network resilience and reliability; gaps in semantic communication trustworthiness.	Development of resilient networks; enhanced reliability for disaster scenarios and semantic communications.
Standardisation	Fragmented approaches to sustainability standards; lack of interoperability certification processes.	Creation of unified sustainability frameworks; global interoperability and certification standards.
Governance and regulation	Reactive governance; lack of policies addressing public health, privacy, and environmental concerns.	Anticipatory and inclusive governance models; proactive policies for public engagement and trust.

The above Table gives a concise summary of the main gaps identified for the deployment of 5G, discussed in the previous sections and detailed in D1.1, "Societal aspects in 6G technology: Concerns, Acceptance Models and Sustainability Indicators". These gaps refer to six critical domains: public acceptance, sustainability, social and ethical issues, technological development, standardisation, and governance. While this table provides a structured overview, it is a high-level synthesis of the in-depth discussions made in D1.1 and serves as a reference point to guide future 6G development. The identified gaps highlight lessons learned from 5G and provide actionable insights for addressing the challenges in 6G. These insights put a strong emphasis on the integration of societal values, energy efficiency, building up of public trust, and proactive governance frameworks with a view to aligning technological advancements with societal expectations. This analysis, hence, forms a very strong foundation for bridging the gaps identified in 5G and making 6G more in tune with the expectations of society, sustainability goals, and technological advancement. The GAP analysis Table offers a concise yet detailed summary, facilitating informed decision-making for future 6G developments.

3.2.2 THE HIGH COST OF 5G TECHNOLOGY DELAYS

Delays in the deployment of 5G technology have significant economic and societal repercussions. Ike Brannon's Forbes article "The Costly Delay of 5G Technology" [16] highlights several key areas impacted by these postponements. Discussing (i) economic impact, the article emphasises that postponing the 5G rollout hampers economic growth. 5G is projected to add substantial value to the global economy; for instance, PwC estimates that 5G applications in smart utility management alone could contribute $330 billion to global GDP by 2030 [17]. Delays in the deployment mean forfeiting these economic benefits, as industries cannot leverage the enhanced capabilities of 5G for improved efficiency and innovation. As for (ii) job creation, 5G deployment is expected to create millions of jobs globally. The World Economic Forum estimates that 5G may create possibly 22.3 million jobs in the global value chain by 2035 [3].

Delays in 5G implementation postpone these employment opportunities, affecting labour markets and economic development. As to what concerns (iii) technological advancements and global competitiveness, Brannon discusses how delays in the 5G rollout can lead to technological stagnation, causing countries to fall behind in international competitiveness. Other nations advancing with 5G can gain a competitive edge in various sectors, including manufacturing, healthcare, and transportation. For example, the UK has experienced slow 5G deployment, leading to concerns about its competitiveness in AI and other advanced technologies [18]. In addition, (iv) regulatory hurdles and logistical issues contribute to delays. For instance, concerns about 5G interference with aviation equipment have postponed rollouts in certain areas. Taking the UK as an example again, it is essential to highlight that complex planning laws and infrastructure deployment challenges have slowed progress [19]. Thus, such delays in 5G technology deployment have multifaceted consequences, including economic losses, missed job creation opportunities, reduced global competitiveness, and technological stagnation. Addressing regulatory and logistical challenges is crucial to expedite the 5G rollout and harness its full potential for economic and societal advancement.

To elaborate further, the European Court of Auditors' Special Report 03/2022, titled "5G Roll-out in the EU: Delays in Deployment of Networks with Security Issues Remaining Unresolved" [20], evaluates the progress of 5G network implementation in EU Member States. It highlights significant delays that threaten the EU's strategic objectives for 5G deployment by 2025 and 2030. The report reveals that, by the end of 2020, 23 Member States had launched commercial 5G services in at least one major city. However, Cyprus, Lithuania, Malta, and Portugal failed to meet this milestone. By October 2021, Lithuania and Portugal still lacked 5G services in any city, illustrating the uneven progress across the EU. Such delays compromise the Union's goals for seamless digital connectivity.

With this in mind, the EU is committed to achieving uninterrupted 5G coverage in all urban areas and major transport routes by 2025 and comprehensive 5G coverage in all populated areas by 2030. So far, only 11 Member States have been on track to meet the 2025 goal, while the remaining have considerable challenges to face, and their chances of meeting the objectives are rated as medium or low. These delays represent a serious risk to achieving the EU's digital ambitions as the national 5G strategies of the member states are not aligned with the EU's 2025 and 2030 goals. Not all member states have embedded targets into their broadband plans, leading to inconsistencies and fragmentation in 5G deployment efforts. Key reasons for the delays that have slowed down deployment are insufficient transposition of the European Electronic Communications Code into the national legislation, low demand from mobile network operators, cross-border coordination issues with countries outside the EU, scheduling disruptions due to the COVID-19 pandemic, and uncertainties as to security measures and requirements. Therefore, delays in 5G deployment threaten to undermine the EU's global competitiveness and lesser leadership in technologies. Comprehensive 5G coverage is essential to economies boosting their competitive positioning, fostering innovation, and facilitating the digital transformation of key sectors. The delays hinder such benefits and operate to exacerbate the digital divide among member states and regions. To these ends, the European Court of Auditors has made several recommendations directed at these obstacles:

- Define Quality of Service Standards: Collaborate with Member States to establish clear benchmarks for 5G network performance, including minimum speed and maximum latency requirements.

- Align National Strategies with EU Objectives: Encourage Member States to integrate the 2025 and 2030 deployment goals into their national broadband plans and 5G strategies.
- Support Spectrum Coordination: Assist Member States in resolving cross-border spectrum allocation issues, particularly with neighbouring non-EU countries, to facilitate timely deployment.

Taking the above into account, Femi Oshiga, who serves as the Vice President of Sales for Service Providers in the Middle East and Africa at CommScope [21] stated, “If you think of 5G as an improvement in efficiency, whether in the efficient use of spectrum, ease of installation, optimisation, whatever investment made now doesn’t go to waste. Specific spending on 5G radio, 5G core and 5G equipment, there’s been a slowdown, but in terms of improving efficiency, we believe that it’s a short and temporary setback...It has, in fact, highlighted where there’s demand in the network, and where there is a capacity requirement, latency reduction requirement and a need for reliability.” He continued, stating, “This delay will give us time to rethink 5G use cases monetisation and an opportunity to reduce the costs of 5G devices. As CommScope, we’re seeing that operators are starting to rethink their partnerships. Some companies have been able to differentiate themselves in terms of supply chain and diversification.”

To provide further analysis, the IEEE article "5G Implementation: Major Issues and Challenges" [22] examines the critical challenges hindering the deployment of 5G networks, emphasising the significant costs and delays involved. Speaking of the key challenges identified, the emphasis is on:

- Infrastructure Investment**:** The transition to 5G requires a massive upgrade of existing mobile networks, including the installation of new base stations and the introduction of new technologies. Such upgrades require enormous time and financial resources, adding to the delays in deployment.
- Spectrum Allocation: The process of securing the right frequency for 5G services involves a long regulatory process and coordination among stakeholders. Spectrum allocation cannot afford delay.
- Technological Integration: There are several challenges posed due to the introduction of new technologies such as Massive MIMO, network slicing, and edge computing into the existing networks. Such have implications on technical interoperability and performance, requiring extensive investigations to ensure seamless operation and performance optimisation that could prolong network deployment timelines.
- Security Concerns: Operating 5G introduces serious security vulnerabilities that must be addressed through protective measures for the safety of network integrity and user data. Developing and implementing these complex security measures may add to the timeline of deployment.

As pointed out by the European Court of Auditors in Special Report 03/2022, IEEE also stated that such delays highlighted some adverse consequences. Therefore, the most economic benefits that could be achieved through 5G are thwarted because of these delays - increased industrial automation and the growth of IoT applications, which could harm economic growth in a way. Therefore, missed expectations regarding the deployment of 5G will put countries at a disadvantage in the global market as various nations rush ahead to exploit the competitive advantages that 5G affords them. This means that delays can stifle innovation or are bound to be innovative and rich in services dependent on the characteristics of high speed and low latency that 5G offers. With delays in deploying 5G, applications dependent on low latency will have to wait longer to set up the required infrastructure. Therefore, delay-sensitive services with high latency degrade the service performance and user experience and, in turn, impede service reliability. Without timely deployments, networks have to rely on legacy infrastructures incapable of realising the optimised capabilities of 5G. With this comes inefficiencies, which increase operational costs and lower the ability of a network to provide multiple services at the same time. Building upon this, it is quite apparent that delayed deployment leads to dependence on 4G or other interim solutions, which do not have the reliability and robustness to support modern applications. Prolonged dependence on decrepit 4G infrastructures spikes maintenance costs and power consumption by a wider ratio, basically compounding an ever-widening digital divide between the haves and have-nots. Healthcare and critical infrastructure are some of the sectors most vulnerable to interruptions from less than optimal network capability. This is compounded by operators having a challenging time satisfying demand on a network with less bandwidth and capability. The deployment delays hinder scalability to sustain the expected growth of connected devices and applications, impeding innovation and delaying the adoption of new business models based on 5G. Extensively, deployment strategies should contemplate infrastructure, spectrum, and technological necessities. Focus should also be put on cooperation between governments, industry stakeholders, and regulatory bodies to simplify processes and share best practices. In addition, another key area is the allocation of resources directed toward advancing technologies and solutions that facilitate expeditious 5G implementation [22].

Kalvin Bahia, Principal Economist at GSMA Intelligence, strongly cautioned The Parliament regarding the progress of Europe’s 5G rollout. “Europe is far from reaching Digital Decade connectivity targets and is now painfully behind other advanced regions in digital connectivity and digital offerings for businesses and consumers” [23]. This statement highlights the economic repercussions of Europe's sluggish 5G deployment, emphasising substantial financial losses due to acceptance failures. Europe's share of early adopters for successive mobile technologies has significantly decreased:

- 3G Era: Europe led with the majority of early users.
- 4G Era: Only 11% of the first 500 million users were from the EU.
- 5G Era: A mere 4% of the initial 500 million users are from the EU, while China accounts for 71%.

This trend points toward a continued decline in Europe's influence over global mobile technology adoption, yielding missed socio-economic opportunities and reduced market share. Because of the diminishing innovation spectrum, Europe must depend heavily on non-European manufacturers for critical 5G technology. This makes Europe vulnerable to dependence on technological sovereignty and continues to drain revenue out from the MNOs back into respect to foreign technology providers in the local economy. To explore in-depth, the "State of the Digital Decade" report by the European Commission shows that 65% of populated rural areas in Europe do not have 5G coverage. The sluggish rollout of 5G threatens the competitive future of European industries, considering the increasing reliance of traffic management and medical technology on 5G connectivity. Late compliance with such adoption may lead to immense losses for industries since organisations could lose efficiency and innovation benefits brought in by 5G. This shortfall inhibits the EU's goal of full 5G coverage by the year 2030; hence, economic growth and innovation, especially in rural regions, would be at a standstill. Elaborating on this, other authors [24] reported that out of 114 European network operators, only 10 have implemented standalone 5G networks. Europe aims for 100% of its population to be covered by 5G by 2030, yet only 80% coverage has been achieved thus far. There is a €174 billion funding gap, according to the European Telecommunications Network Operators' Association (ETNO), which could leave 45 million EU citizens without broadband by 2030. Slow progress in rolling out 5G leaves Europe vulnerable to the fear of becoming a "technological colony" relative to global competitors like China, South Korea, and the U.S.

Co-funded by the European Union

This trend indicates a sharp decline in Europe's influence over global mobile technology adoption, leading to missed economic opportunities and reduced market share. Due to limited innovation capacity, Europe relies heavily on non-European companies for critical 5G technology. This dependency affects Europe's technological sovereignty and results in financial outflows to foreign technology providers, impacting the local economy. To analyse further, The European Commission's "State of the Digital Decade" report reveals that 65% of populated rural areas in Europe lack 5G coverage. The slow 5G rollout threatens Europe's industrial competitiveness, as sectors like traffic management and medical technology increasingly depend on 5G connectivity. Delays in adoption can lead to significant financial losses across various industries, as businesses miss out on the efficiencies and innovations that 5G enables. This shortfall hampers the EU's goal of achieving full 5G coverage by 2030, potentially stalling economic growth and innovation, especially in rural regions. To elaborate further, other authors [24] reported that only 10 out of 114 European network operators have implemented standalone 5G networks. Europe aims for 100% 5G population coverage by 2030, but current coverage stands at 80%, indicating significant delays. The European Telecommunications Network Operators' Association (ETNO) identifies a €174 billion funding gap that could leave 45 million EU citizens without broadband access by 2030. Europe's slow progress in 5G deployment risks relegating it to a "technological colony" compared to global competitors like China, South Korea, and the U.S. For example, in the year 2023, the fibre optic coverage in China was about 93%, while that of Europe was 65%. Also, according to D1.1, any delay in 5G deployment has immediate economic implications as it slows down technological development and the adoption of applications that depend on low latency and high reliability. Public resistance against 5G infrastructure, especially in the form of local opposition in Europe, leads to increased costs of re-strategising the plan for its deployment and the pacification of the public. This is also partly because of the lack of alignment between local governance of citizen concerns and national or EU-level 5G goals. Besides, ineffective communication by industry and policymakers has resulted in slower public buy-in and missed opportunities to capitalise on early 5G adoption. We are aware that the issues encountered in the rollout of 5G will provide lessons for 6G, especially with regard to technical development and societal and environmental sustainability.

3.3 5G BENEFITTING BUSINESS AND TECHNOLOGY

Europe faces significant challenges in its digital infrastructure sector, including insufficient fiber optic coverage and delays in deploying 5G standalone networks [25]. These deficits leave the EU behind global leaders like South Korea and Japan. Investment shortfalls and fragmented regulatory frameworks exacerbate these challenges, hindering progress toward a cohesive digital infrastructure. The technological landscape is also evolving rapidly, driven by network virtualisation, cloudification, and edge computing, which require integrated systems capable of handling complex and data-intensive use cases, such as autonomous vehicles, real-time health monitoring, and smart grids. To overcome these challenges, the report calls for policy measures that address Europe's connectivity gaps and fragmented digital market. It emphasises the need for coordinated investments in network infrastructure, a harmonised regulatory environment, and targeted public-private partnerships to foster innovation and scale. This includes securing and making resilience in critical digital systems possible, also considering geopolitical tensions and cybersecurity threats. The EU will have to increase its technological leadership in critical areas like quantum computing, edge computing, and advanced cloud solutions and, at the same time, increase the sustainability of such technologies with energy-efficient and low-carbon network technologies. Speaking of innovation and economic growth across Europe, from a business perspective, 5G allows for the development of new markets and business models through unprecedented connectivity and data processing capabilities. It supports industries in real-time data analysis, predictive maintenance, and automation, which reduce operational costs while improving efficiency.

Manufacturing, logistics, and transportation companies would gain much from higher operation performance that could make supply chains and industrial systems smarter. On the technological front, 5G is instrumental in the development of advanced applications, particularly in fields requiring ultra-reliable, low-latency communication. These include autonomous vehicles, remote healthcare services, and smart energy management. Its ability to connect a vast number of devices simultaneously supports the growth of the IIoT, driving innovation in vertical sectors like transport, energy, and agriculture. Furthermore, 5G's capabilities in handling massive amounts of data at high speeds create opportunities for applications like augmented and virtual reality, poised to transform industries such as entertainment, education, and retail.

Therefore, even though there were delays, challenges, and gaps concerning the 5G deployment and adoption, as already explained in the above chapters/sections, 5G unlocks significant business value companies must address. 5G's transformative capabilities directly translate into significant business value by driving efficiency, innovation, and enhanced customer experiences. Companies that strategically deploy 5G can unlock new revenue streams, optimise processes, and stay competitive in the growing digital economy. Enterprises across industries must proactively implement 5G into their operations to unlock these opportunities. This said, the European Commission's report "Identification and Quantification of Key Socio-Economic Data to Support Strategic Planning for the Introduction of 5G in Europe" [26] is a comprehensive study of the expected socio-economic benefits of the 5G technology in several verticals and environments, such as automotive, health, transport, utilities, etc. It was thus estimated that, by 2025, 5G is projected to generate approximately €62.5 billion annually across four key verticals: automotive, healthcare, transport, and utilities. Additionally, it is expected to contribute €50.6 billion per year within four specific environments: smart cities, non-urban areas, smart homes, and smart workplaces. Its distribution is expected at 63% business and 37% consumers and society, meaning the impact is still positive at the business level. The estimated cost of deployment of 5G infrastructure is around €56.6 billion, which also underscores its massive investment for extensive rollout. These benefits, therefore, underline the very substantial economic benefits that 5G can provide for enterprises by driving more effective processes, improved customer experiences, and the development of new business models. The next Figure sums up how such benefits are categorised into three major kinds of benefits: strategic, operational, and user benefits.

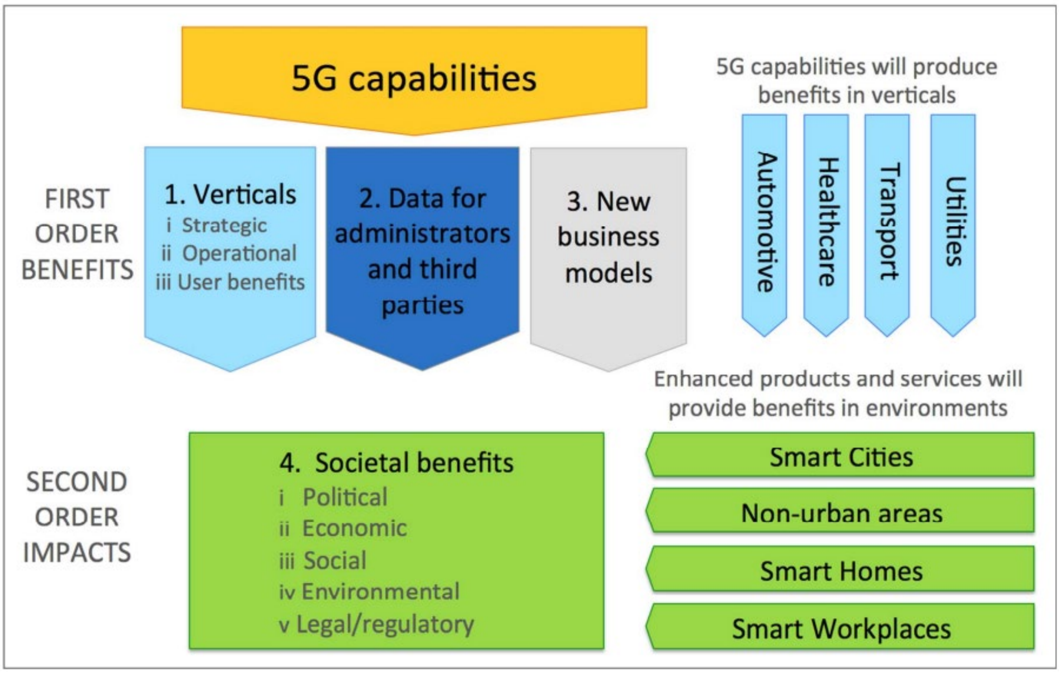


FIGURE 7: KEY BENEFITS OF 5G CAPABILITIES

The former covers long-term strategic benefits to industries, including enhanced decision-making capabilities, differentiation, and new innovation opportunities. In contrast, operational benefits refer to enhancements in operational efficiency, cost reduction, and improvements in productivity realised via real-time access to data, automation, and seamless connectivity. These beneficiaries, including consumers and businesses, would benefit from improved services, better reliability, and access to new technologies that improve the quality of life and work efficiency. Further, robust data from 5G will enable administrators and third parties to make use of real-time data to make decisions, develop policies, and optimise services. Another critical dimension of first-order benefits involves the capability to support new and disruptive business models, thereby allowing firms to reach untapped markets and revenues. Beyond the direct benefits, 5G was expected to bring wider societal benefits across several domains:

- Political: Enhanced digital infrastructure to support more effective governance, policy implementation, and public engagement.
- Economic: 5G's transformative effects to stimulate economic growth by fostering new industries, improving efficiency, and reducing costs.
- Social: The technology to bridge digital divides, improve quality of life, and enable inclusivity by offering reliable connectivity in underserved areas.
- Environmental: By enabling smart grids, energy-efficient systems, and reduced emissions through improved traffic management, 5G was expected to support environmental sustainability.
- Legal/Regulatory: New frameworks are needed to address data privacy, security, and governance challenges that arise from increased digital interconnectivity. These second-order impacts plan to manifest in enhanced environments, such as smarter cities, more connected rural areas, intelligent homes, and workplaces, driving innovation and societal well-being.

In addition to the above, it is vital to acknowledge that we need a comprehensive framework for understanding the evolution of **business models** in the era of 5G [27]. Shifting from traditional linear value chains to ecosystem-based models that focus on collaboration among diverse actors to deliver complex value propositions is important. This transformation is driven by technological advancements such as, as already analysed, eMBB, URLLC, and mIoT, which enable new market opportunities and innovative service delivery frameworks. One of the foundational changes introduced by 5G is the transition from linear value chains, where individual vendors deliver products or services directly to operators, to dynamic, ecosystem-based value networks. The following Figure visually represents this shift, illustrating how ecosystem approaches foster collaboration among multiple actors, including network operators, hardware providers, software developers, and integrators. Unlike traditional models, ecosystems rely on shared resources, interoperable technologies, and real-time data exchange, enabling more robust and scalable service delivery.

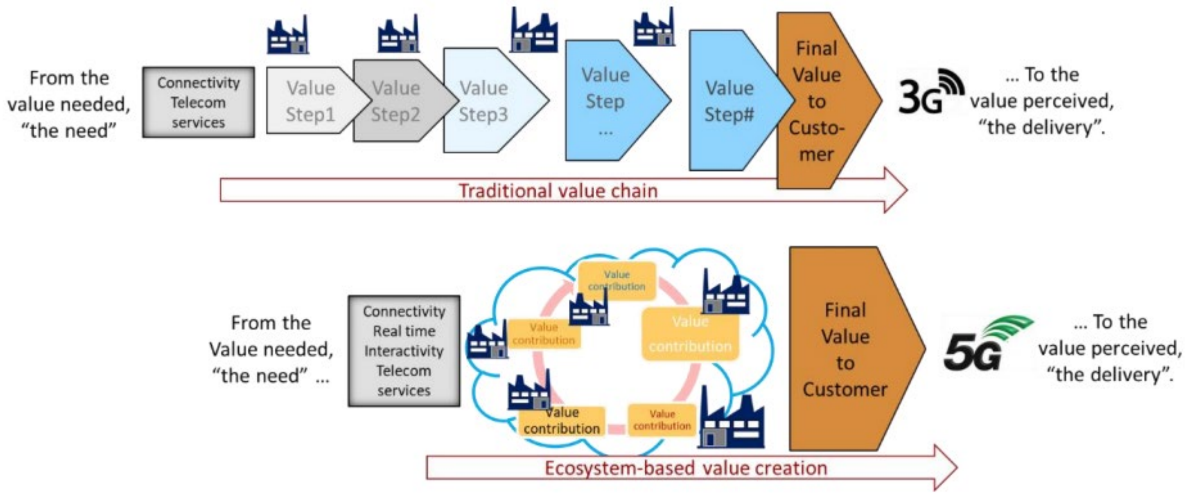


FIGURE 8: TRANSITION FROM LINEAR VALUE CHAIN TO ECOSYSTEM-BASED VALUE CREATION

The segmentation of the 5G ecosystem into two primary components is essential at this stage. For instance, the (a) provisioning ecosystem focuses on the development and delivery of 5G services, with key actors including network operators, service providers, and technology integrators who work together to ensure seamless service deployment. The (b) vertical ecosystem, though, combines 5G services with other technologies to deliver industry-specific applications. This includes integrating 5G with IoT, cloud computing, and edge technologies to address sectoral needs in healthcare, automotive, logistics, and more. Therefore, to develop and refine ecosystem-based business models, a five-step iterative methodology is proposed [27]. The following are the steps:

1. Expand: Identifies potential ecosystem participants and maps their roles and relationships. Figure 10 below demonstrates how the number of possible ecosystem configurations increases with the number of actors, emphasising the complexity and opportunities in ecosystem design.
2. Focus: Prioritises specific roles and value propositions for enterprises, aligning with strategic objectives.
3. Design: Utilises tools like the Flourishing Business Canvas to compare and refine business models based on sustainability and economic feasibility.
4. Develop Business Cases: Creates detailed revenue and cost models for each actor, ensuring alignment with long-term sustainability goals.
5. Iterate: Continuously adapts business models to reflect market feedback, technological advancements, and evolving ecosystem dynamics.

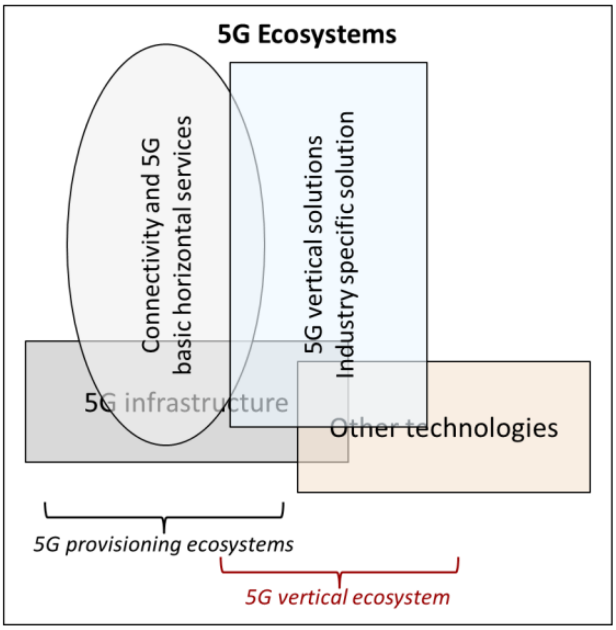


FIGURE 9: ECOSYSTEM AND ITS COMPONENTS

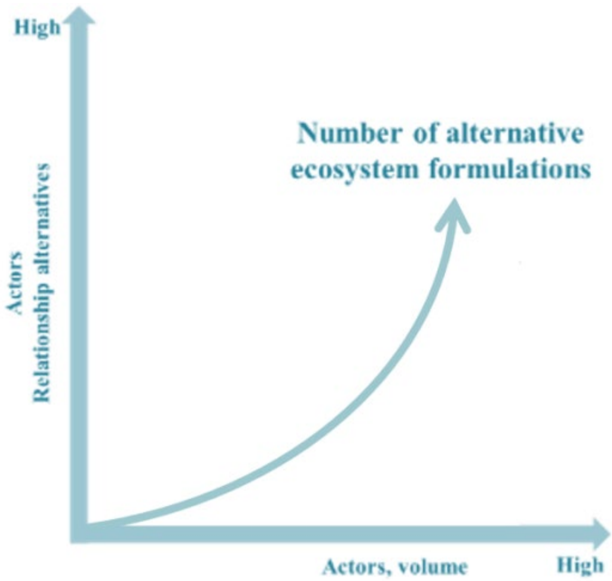


FIGURE 10: 5G ECOSYSTEM FORMULATIONS AND PARTICIPATING ACTORS

It is, therefore, important to examine how these principles are implemented through practical applications in 5G PPP projects. To elaborate:

- 5G-SMART[1]: This project integrates 5G into industrial environments, particularly manufacturing. By enabling real-time monitoring, predictive maintenance, and

[1] https://5gsmart.eu/

automation, it highlights the role of vertical ecosystems in enhancing operational efficiency and creating new revenue streams.
- 5G-TOURS[2]: This project applies 5G technologies in tourism, healthcare, and transport. It demonstrates how ecosystem collaboration can deliver innovative services like augmented reality-guided tours and remote medical consultations, leveraging 5G's low-latency and high-reliability capabilities.
- 5GENESIS[3]: Focused on testing and validating 5G technologies, 5GENESIS employs ecosystem modelling to assess network configurations. Its iterative approach ensures adaptability to diverse market conditions, aligning with the expand and iterate steps of the framework.
- 5G-SOLUTIONS[4]: This project showcases the application of 5G in smart cities, agriculture, and logistics. For example, precision farming enabled by IoT and real-time analytics demonstrates how 5G ecosystems address societal challenges like energy efficiency and resource optimisation.

Visual representations, such as illustrated in the following figures, provide detailed insights into ecosystem dynamics. More specifically, Figure 11 emphasises how iterative refinements lead to stable ecosystems, while Figure 12 maps the value network of a small-cell ecosystem, showcasing interactions among network operators, hardware providers, and service integrators. These figures highlight the importance of collaboration, resource sharing, and role alignment in ecosystem development.

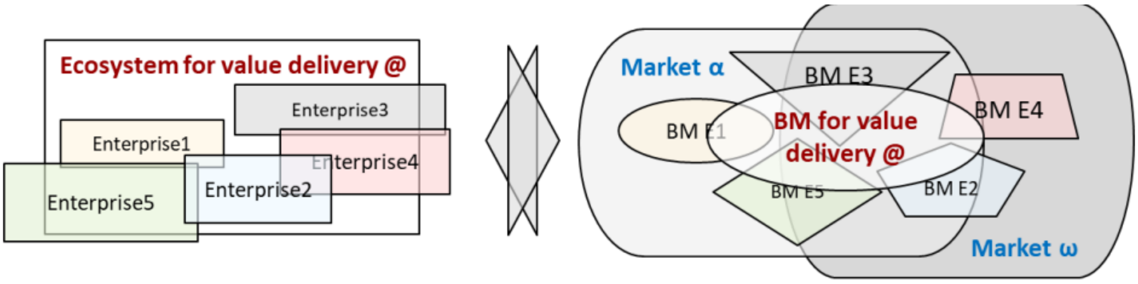


FIGURE 11: EVOLVING ENTERPRISE BUSINESS MODELS TOWARDS A STABLE ECOSYSTEM

2 https://5gtours.eu/

3 https://5genesis.eu/

4 https://5gsolutionsproject.eu/

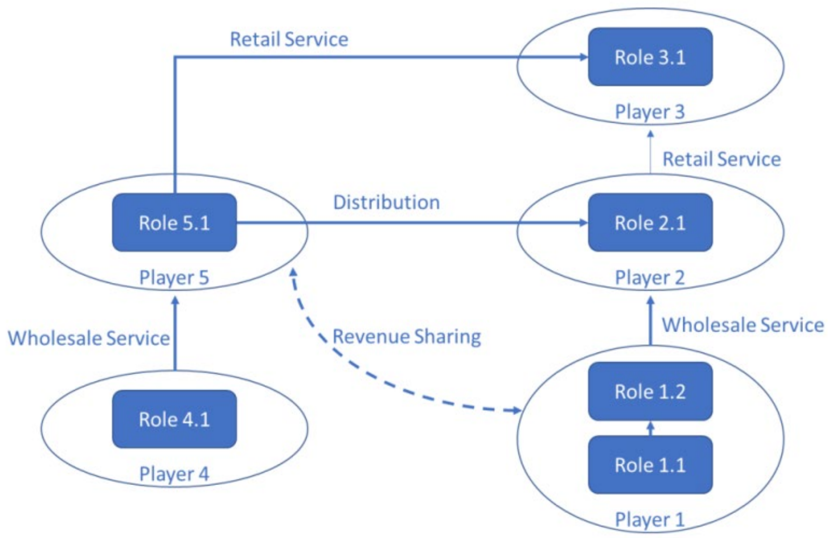


FIGURE 12: REPRESENTATION OF A VALUE NETWORK IN A SMALL CELL ECOSYSTEM

Analysing business and technological benefits, the White Paper [27] underscores the significant benefits of 5G for both businesses and technology. From a business perspective, 5G enables companies to explore new markets, optimise processes, and reduce costs. Industries such as manufacturing, logistics, and healthcare stand to gain from real-time data analytics, automation, and improved customer experiences. On the technological front, 5G's advanced capabilities—including ultra-reliable, low-latency communication and massive device connectivity—facilitate innovations like autonomous vehicles, smart energy management, and precision agriculture. These applications not only drive economic growth but also address broader societal challenges such as sustainability and inclusivity. With this in mind, it provides a robust framework for understanding and navigating the complexities of 5G ecosystem business modelling. By leveraging iterative methodologies, advanced tools, and practical insights from 5GPPP projects, enterprises can position themselves effectively within these ecosystems. Examples and figures presented in the report underscore the potential for 5G to bring transformation in terms of innovation, sustainability, and economic growth in various sectors. As businesses move along this changing ecosystem, they open new doors to survive and thrive in this new digital economy.

3.4 6G TECHNOLOGY

As seen in the above-mentioned paragraphs, significant transformations in technology and business landscapes are foreseen by 2030 [28], anticipating a shift towards a data-driven, highly digitalised, and intelligent environment. This forthcoming revolution will introduce fresh technological demands, necessitating enhancements to existing communication networks. The 6G mobile communication network is poised to address these needs, providing essential capabilities such as connection speed, reliability, coverage, and infrastructure support. Envisioned as a comprehensive wireless ecosystem, 6G is expected to facilitate a wide range of industrial functions, including sensing, communication, computation, and more, with intelligence akin to human decision-making. This evolution marks a transition towards human/machine-centric communication, accommodating various biometric-based applications and significantly improving energy efficiency.

In other words, 6G is expected to emerge as the upcoming frontier in wireless technology, transcending mere speed enhancements to fundamentally transform people's interactions with technology. At the heart of this advancement lies the allocation and utilisation of the 6G spectrum, encompassing a spectrum of electromagnetic frequencies employed for transmitting wireless signals. The term "6G spectrum" [29] denotes the novel and untapped frequency bands under consideration for the next iteration of wireless communication technology. Unlike its predecessors, 6G is expected to explore higher frequency bands, including sub-terahertz (sub-THz) bands. These are the frequencies at which ultra-high speeds and minimal latency are expected from 6G networks. However, it should be noted that different frequencies have different properties, with lower frequencies offering better penetration through materials. It is thus essential to understand that the primary distinction between 5G and 6G spectrums (see Figure 13) lies in their operating frequency bands. While 5G predominantly utilises frequencies below six gigahertz (GHz) and extends into millimetre-wave bands (up to approximately 40 GHz), 6G aims to push this boundary further, potentially incorporating frequencies in the terahertz range. This transition to higher frequencies enables 6G networks to accommodate even more data-intensive applications, albeit posing challenges in terms of signal range and penetration.

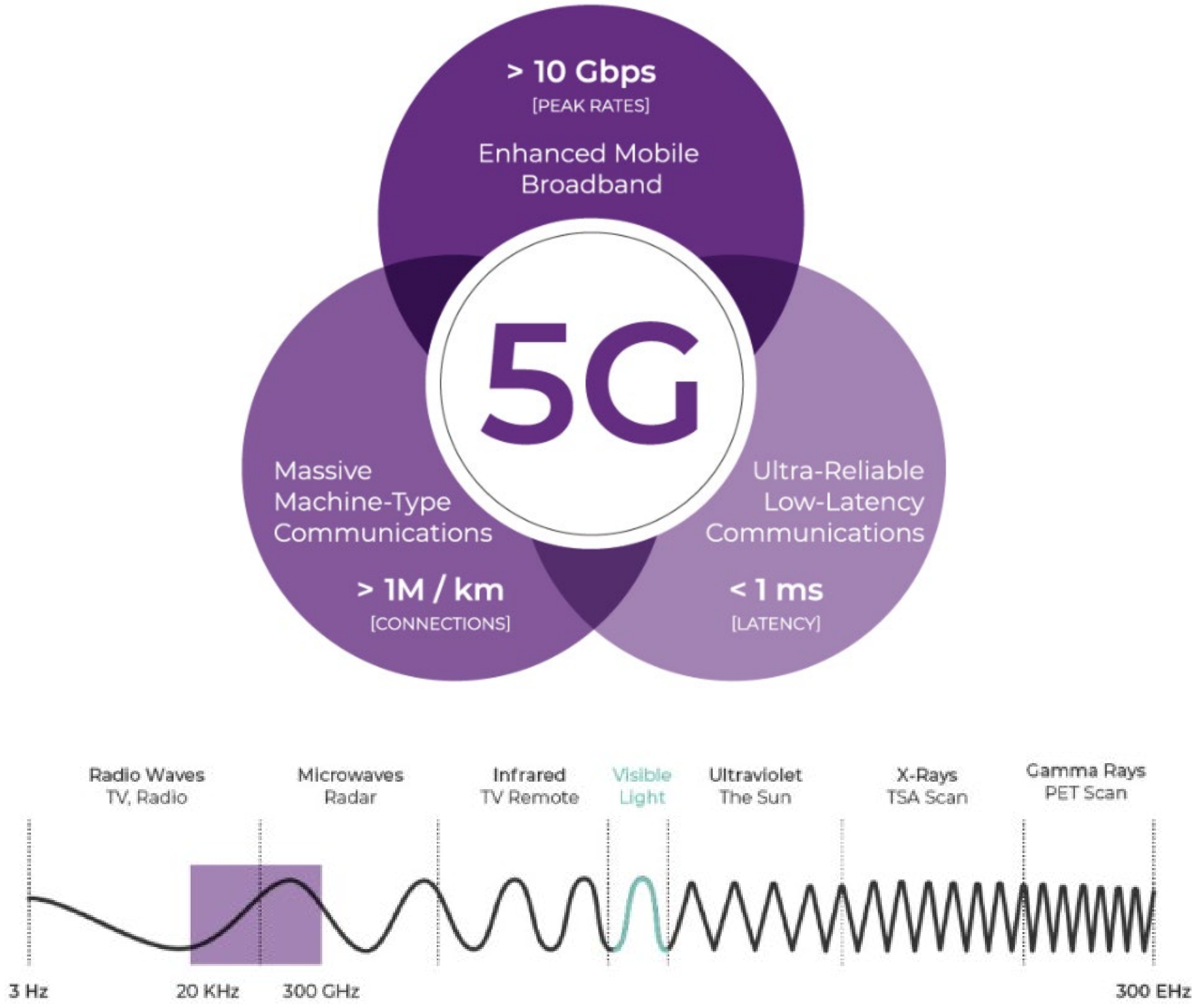


FIGURE 13: 5G & 6G SPECTRUM FUNCTIONALITIES

The anticipated 6G spectrum is anticipated to encompass a broad range of frequencies, extending beyond the conventional cellular frequencies prevalent today. Specifically, this spectrum is projected to include mid-band frequencies spanning from 7 to 15 GHz, featuring distinct bands such as 7.125-8.5 GHz, 10.7-13.25 GHz, and 14-15.35 GHz. These mid-band frequencies are selected for their ability to strike a balance between capacity and coverage, which are essential for establishing a resilient and efficient 6G network. Furthermore, ongoing research is exploring the potential of the sub-THz spectrum, which holds promise for applications requiring ultra-precise sensing and positioning. This frequency band is extremely high; therefore, one can perceive that 6G is aspiring to the zenith levels in terms of speed, precision, and connectivity. Therefore, spectrum utilisation via 6G would open several windows for prospects, including:

- Ultra-fast internet speeds;
- Enhanced VR and AR experiences;
- Advanced IoT connectivity;
- Improved healthcare capabilities;
- Smart cities;
- Advancements in self-driving vehicle technology;
- High-fidelity holographic communications;
- Global connectivity;
- Greater energy efficiency in network operations;
- Enhanced emergency response systems.

Figure 14 presents the main priorities of SNS-JU and 6G-IA towards meeting the IMT-2030 targets based on four scenarios: immersive communication, hyper-reliable and low-latency communication, massive communication, and integrated AI and communication [30]. This shall be enabled by pillars such as sustainability, ubiquitous intelligence, security and privacy resilience, and connecting the unconnected. The key breakthroughs in enabling technologies include integrated sensing and communication for better applications in smart cities and environmental monitoring, AI-driven networks that realise real-time decision-making and energy efficiency. Moreover, it connects the unconnected through resilient, scalable networks, ensuring ubiquitous connectivity to bridge the digital divide. Further, immersive communication enables innovation such as virtual reality and holographic telepresence. Moreover, hyper-reliable and low-latency communication and massive communication improve robustness, energy efficiency, and critical applications such as autonomous vehicles and IoT. This gives the implementation framework for an inclusive and sustainable 6G ecosystem, developed as a balanced combination of technological innovation with societal and environmental objectives.

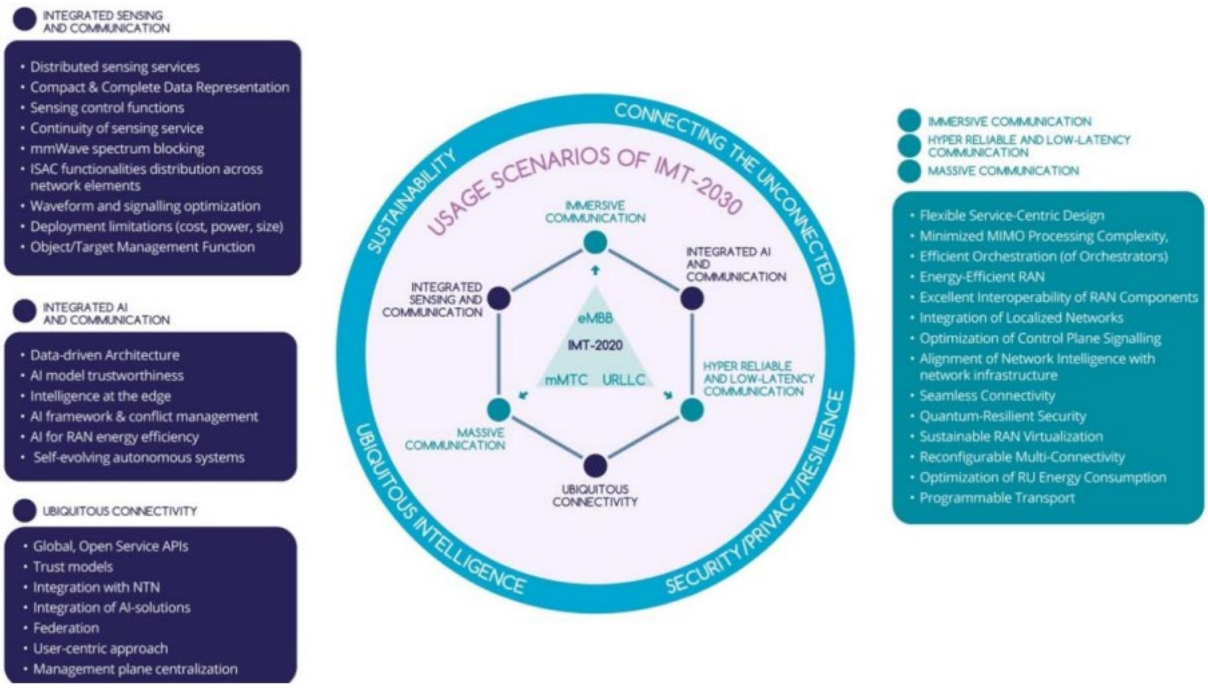


FIGURE 14: WORK ITEMS FOR SNS JU AND 6G-IA TO FULFILL THE IMT-2030 GOALS

Based on the above-mentioned, it is important to note that many companies are in the preparatory stages for the advent of 6G. Development efforts are focused on creating infrastructure and devices capable of harnessing the higher frequency bands expected in 6G networks. Nokia estimates the first 6G specifications will appear in Third Generation Partnership Project (3GPP) Release 21, which is planned for launch in the last half of 2028. This means that companies will work their way up gradually in the last years of this decade toward developing their capabilities to support 6G technology.

3.4.1 6G SNS JU

The European Smart Networks and Services Joint Undertaking (SNS JU) is a Public-Private Partnership to develop and build industrial leadership in Europe within 5G and 6G networks and services. Through funding initiatives, the SNS JU supports projects that delineate a robust research and innovation (R&I) roadmap and deployment strategy, fostering collaboration among a diverse array of European stakeholders and promoting international cooperation across various 6G initiatives. Based on this, below are presented the SNS JU's principal missions [31]:

1. Cultivating Europe's technological sovereignty in 6G by executing pertinent R&I programs aimed at conceptualising and standardising by approximately 2025. It advocates for early market readiness of 6G technologies by the decade's end, emphasising the mobilisation of a wide spectrum of stakeholders to address strategic aspects of the networks and services value chain. This encompasses the provisioning of services based on edge and cloud computing, as well as exploring market opportunities in novel components and devices beyond conventional smartphones.
2. Accelerating the deployment of 5G technology across Europe to foster the development of digital lead markets and facilitate the digital and green transition of the economy and society. To achieve this, the SNS JU provides strategic guidance for

relevant programs under the Connecting Europe Facility, particularly focusing on initiatives such as 5G Corridors. Additionally, it aids in the coordination of national programs, including those under the Recovery and Resilience Facility, alongside other European programs and facilities such as the Digital Europe Programme (DEP) and InvestEU.

Since the SNS JU initiative respects Europe's Strategic Priorities [32], the attention is on new applications, security, and technological sovereignty, while also emphasising the societal impact of the 6G technology, reinforcing industrial leadership, and enabling sustainable development (Figure 15).

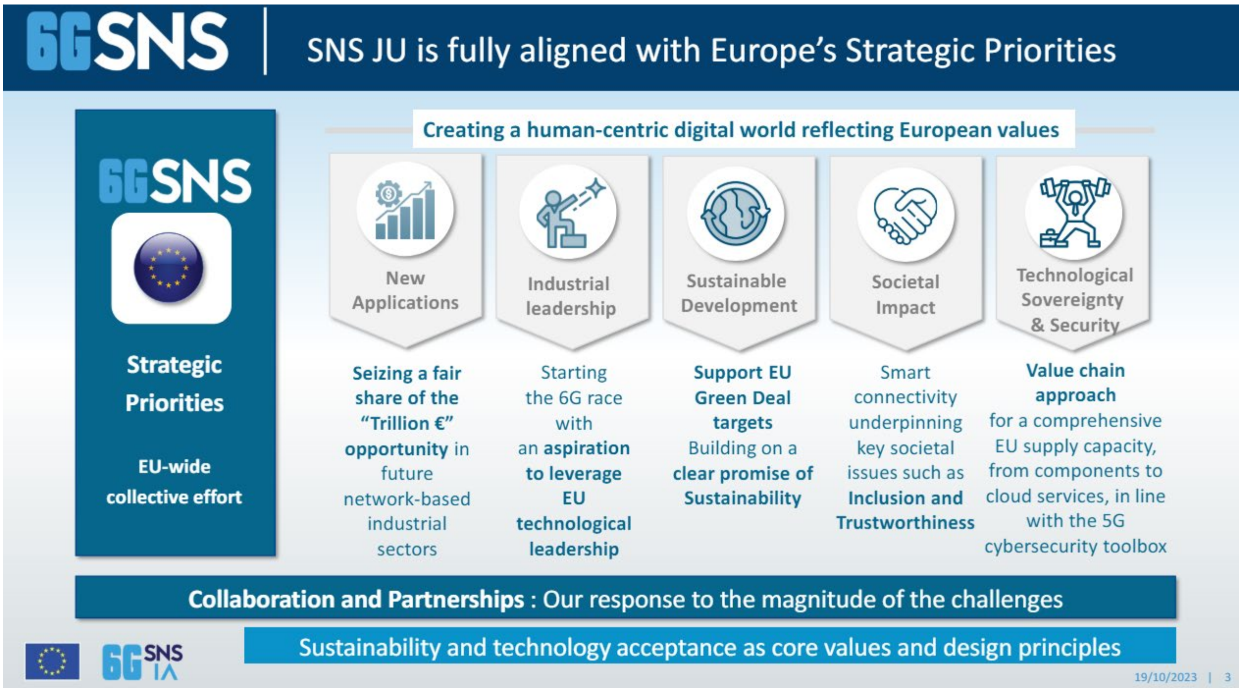


FIGURE 15: SNS JU - EUROPE'S STRATEGIC PRIORITIES

The SNS JU finances projects aimed at crafting a robust R&I roadmap and deployment agenda. It achieves this by mobilising a substantial number of European stakeholders and fostering international collaboration across diverse 6G initiatives. These efforts are facilitated through the support of 35 projects categorised into four streams, along with a support actions component [33]. More specifically, the SNS JU consists of three Phases: SNS JU Phase 1 focuses on the evolution of 5G and the exploration of 6G technology, relevant concepts, and definitions, SNS JU Phase 2 focuses on a 6G-detailed design and system optimisation, and SNS JU Phase 3 focuses on pre-commercialising 6G systems.

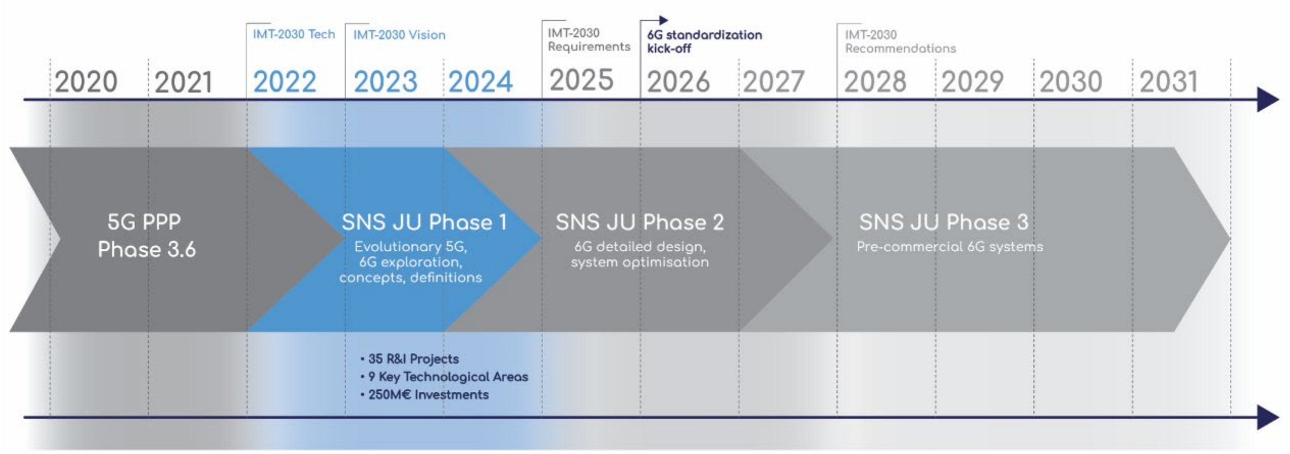


FIGURE 16: SNS JU PHASES

As to what concerns the SNS JU streams, Stream A, "Smart Communication Components, Systems and Networks For 5G Mid-Term Evolution Systems" consists of nine projects[5]. Research topics encompass a wide array of areas, spanning from energy-efficient radio networks and adaptive Open Radio Access Networks (RAN) to integrated 5G-NTN, AI-based edge platforms, and intelligent resource management, all aimed at ensuring trustworthiness, privacy, and security. Stream B, "Research for Revolutionary Technology Advancement Towards 6G" reflects nineteen projects[6], of which research topics span a broad spectrum, encompassing novel 6G system architectures, advancements in wireless and optical communication technologies, innovations in NTN, and the secure development of URLLC applications. Stream C, "SNS Experimental Infrastructures" consists of three projects[7], and focuses on the development of EU-wide experimentation platforms capable of integrating promising technical 6G enablers for subsequent validation. Critical considerations for these projects include ensuring the reusability and adaptability of the experimental platforms throughout the duration of the SNS program. Additionally, emphasis is placed on accessibility and openness, with well-defined and thoroughly documented technological and business interfaces regarded as essential assets of the infrastructures under development. Concerning Stream D, "Large-Scale SNS Trials and Pilots", which consists of four projects[8], the aim is to investigate and showcase the capabilities of 5G/6G technologies, advanced applications, and services across various vertical sectors, including energy, manufacturing, automotive, construction, media, culture, and e-health. Furthermore, these extensive trials aspire to stimulate the development of sustainable business ecosystems. Stream D projects integrate technologies pivotal for 6G networks, such as AI and Machine Learning (ML), cloud/edge computing, advanced IoT solutions, and cybersecurity, among others. In addition, part of the SNS JU system is the "Coordination and Support Actions (CSAs)". In more detail, the emphasis is on two CSAs, specifically, the SNS OPS and SNS ICE[9], which concentrate on internal operational functions within the SNS Partnership. Additionally, they aim to foster dialogues

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5 https://smart-networks.europa.eu/stream-a-smart-communication-components-systems-and-networks-for-5g-mid-term-evolution-systems/

6 https://smart-networks.europa.eu/stream-b-research-for-revolutionary-technology-advancement-towards-6g/

7 https://smart-networks.europa.eu/stream-c-sns-experimental-infrastructures/

8 https://smart-networks.europa.eu/stream-d-large-scale-sns-trials-and-pilots/

9 https://smart-networks.europa.eu/csa-s/#SNS-OPS

with EU initiatives, including national initiatives and related partnerships. Moreover, these projects seek to promote the results and accomplishments of the SNS Partnership on a global scale while striving toward the establishment of global standards. Organisations and individuals benefiting from the actions of the SNS JU [32] are key stakeholders (Figure 17) engaged in the SNS initiative, including policymakers from EU institutions such as the European Commission (EC), European Parliament, Council of the EC, and Committee of the Regions, along with representatives from individual Member States including relevant government officials and permanent representations, as well as municipalities and regional authorities. SNS JU is a governance structure that is composed of various stakeholders, including the 6G Industry Association (IA), EC, Member States, and technical experts. Therefore, several key stakeholders will be engaged in this initiative, comprising present and future beneficiaries, financial actors such as investors, and the general public.

FIGURE 17: SNS JU ECOSYSTEM

SNS JU, to meet its mission and objectives and to facilitate and ensure industrial leadership in Europe for 6G networks and services by 2030, the emphasis is on the following vertical sectors in which the European Union (EU) invests its funding (around 900 million euros) for the years 2021 to 2027:

- Gaming and Metaverse;
- Media and Entertainment;
- Industrial IoT;
- Automotive;
- Energy;
- Smart Cities;
- Tourism and Culture;
- E-Health;
- Smart Farming;
- Connected and Automated Mobility (CAM) and Transportation;
- Security, safety, and Public Protection & Disaster Relief (PPDR).

Co-funded by the European Union

In more detail, the SNS-JU acts as a focal point that ensures Europe remains at the forefront of the 6G ecosystem, enabling research, innovation, and standardisation. This shall be achieved by its mission to contribute to the achievement of a sustainable, inclusive, and globally competitive 6G network ecosystem in Europe, in line with the European vision set out in the White Paper: “European Vision for the 6G Network Ecosystem” [30]. This document underlines the main strategic priorities for 6G development, namely advanced connectivity, digital inclusiveness, sustainability, and ethical integration of AI, thereby providing a sound basis for the activities of the SNS-JU. Emphasising collaborative research and exploiting the diversity of Europe's industrial landscape is how SNS-JU intends to address the complex societal, economic, and environmental challenges linked to the transition to 6G. The White Paper further underlines that collaboration among industry, academia, and policymakers is essential to keeping Europe ahead of the wave of next-generation network innovation.

It is noteworthy that 6GSNS-IA shared with the public some practical examples of the 5G/6G activities taking place in various countries across Europe. To elaborate, “6G Bridge” [34] is a program developed and funded (130 million euros) by Business Finland between January 2023 and the end of 2026 to increase collaboration in R&I for 5G-Advanced (5GA) and 6G technologies, enrich the development of new business ecosystems in 5GA/6G, attract international investors, strengthen capabilities, as well as foster experimentation and testing facilities in 6G. Another example is “Digitalization for the Society – Towards 6G”. In more detail, in 2021, the frequency regulatory body of Germany, BnetzA, initiated the funding program with a budget of 176 million euros over three years. This program, operating under the label GAIA-X, aimed to catalyse the formation of consortia within the ecosystem to foster a digital ecosystem in Europe. Out of the 131 proposals submitted, 16 were selected, with the first set of 11 projects commencing activities in 2022. Additionally, other initiatives under the same program were launched to promote the widespread adoption of AI and enhance cybersecurity within the telecommunications domain. These initiatives include a "Roadmap towards Standardization of AI" and an "Introduction to the Blockchain”. More information about funding sources in 5G/6G is available in Chapter 3.

3.4.2 KEY FINDINGS

From envisioning unprecedented levels of connectivity to redefining the boundaries of human-machine interaction, the contours of 6G are taking shape against a backdrop of rapid innovation and transformative potential. Therefore, in the following paragraphs, challenges, needs, and key trends [35] that are poised to define the narrative of 6G and offer insights into the emerging paradigms, technological advancements, and societal implications that promise to shape the future of communication and connectivity are presented:

1. **Expansion of IoT towards IoE:** The proliferation of IoT towards the IoE is predicated on the construction of a hyper-connected system of people, things, and information to improve different domains of human and industrial life. The total IoE market is forecast to reach 24 billion euros by 2030 and USD 1.5 trillion in total by 2030, with the number of IoT devices on the market set to reach 24 billion. This transition poses challenges, such as the integration of AI and ML technologies in mobile communication networks for efficient and effective data processing from the huge amount of data. Furthermore, data security and privacy and breaking down the current limitations of the network infrastructure are also critical. For security and scalability improvements, answers to the problem are suggested as distributed Artificial Intelligence and distributed Ledger Technologies (DLTs), including blockchain. In addition, emerging technologies such as Non-Orthogonal Multiple Access (NOMA) and cognitive satellite-UAV system are expected to be equipped in communication networks in future for seamless connectivity of IoE devices. In general, the trend towards IoE means the development of

interconnected ecosystems and the demand for new solutions to deal with the newly emerging issues and opportunities.

2. **Massive availability of Small Data:** Small Data" is the idea of restricted datasets concentrating on a narrow scope, as opposed to the massive datasets of past Big Data. Little Data is needed to sustain the use of millions of IoT devices, particularly for real-time or statistical use cases, across industries such as industrial IoT (IIoT) and retail analytics. Nevertheless, available mobile networks are limited in their ability to effectively process such data, because of their inability at the cloud and edge computing. This is achieved by the need to build Edge AI infrastructure capable of efficient Small Data execution. Future networks will be required to balance energy efficiency for offloading data to the edge with minimising transmission overheads. Further, novel methods with new ML techniques are demanded to optimise network functions for future services.
3. **Self-sustained networks:** Self-Sustaining Networks (SSNs) autonomously manage network resources to maintain Key Performance Indicators (KPIs) by adapting operations based on real-time analysis of environmental factors, usage patterns, and energy constraints, facilitated by ML techniques. However, current mobile networks lack this capability, necessitating novel architectures for SSNs. These networks should enable seamless access to emerging applications and promote energy self-sustainability at both infrastructure and device levels. Energy harvesting in network infrastructure is vital for extending range and standby times, requiring future networks to be designed with energy-awareness. SSNs must handle massive IoT device numbers efficiently, relying on context-aware operation to minimise energy consumption per bit for diverse communication requirements.
4. **3CLS:** Future communication networks are anticipated to converge computing resources, controlling architecture, and infrastructure for precise localisation and sensing, essential for highly personalised and time-critical applications. This convergence, known as 3CLS (Convergence of Communications, Computing, Control, Localisation, and Sensing), is crucial for facilitating efficient communication and real-time processing of data streams, particularly for Human-Centric Services (HCS). However, existing 5G technologies have not fully explored the interdependence between these elements. Developing 3CLS services requires future networks to possess collective network intelligence at the edge to run AI and ML algorithms in real time. Additionally, the network architecture should be open, scalable, and elastic to support an AI-orchestrated end-to-end 3CLS design. Precise localisation and sensing must coexist with communication networks, sharing network resources to facilitate emerging applications such as extended reality (XR), connected robotics, autonomous vehicles, sensing, and three-dimensional (3D) mapping.
5. **Zero Energy IoT:** Zero energy IoT devices have the potential to harvest energy from the environment, such as Radio Frequency (RF) waves, enabling maintenance-free operation and extending network lifetimes. This technology is crucial for connecting the vast number of objects in the real world efficiently. However, current network infrastructures, including 5G, lack support for energy harvesting and efficient energy conversion. Future communication networks must enable ultra-low-power communication and efficient energy harvesting to accommodate zero-energy IoT devices. This requires advancements in electronic circuitry to support energy harvesting and wireless power transfer, optimising data communication stacks for energy efficiency.
6. **Advancements in communication:** The recent advancements in mobile communication technologies, such as electromagnetically active Large Intelligent Surfaces (LIS) and novel channel access schemes like NOMA, are shaping the future of communication networks. These technologies, along with advancements in THz frequency bands for uninterrupted connectivity, highlight the need for a shift from existing 5G networks. Future networks must support high-frequency bands and denser

network deployments, necessitating new architectural designs and multi-mode base stations. Additionally, integrating technologies like LISs as transceivers and AI-powered network functionalities will require a paradigm shift in mobile communication networks to accommodate these advancements not realised in 5G.

7. **Gadget-free communication:** Users accessing digital services without physical devices emerging is a significant trend driven by the integration of digital interfaces and sensors into the environment. This shift towards user-centric communication relies on ubiquitous smart digital surroundings, enabling users to access services without personal devices or wearables. However, current 5G networks face limitations in supporting this trend, emphasising the need for future networks to be highly automated, adaptable, and secure. These networks must provide high availability, performance, and energy efficiency while accommodating extreme data rates and reliability for advanced applications like holographic communication. Improving network security and privacy measures is also essential for seamless, gadget-free communication.
8. **Elderly population:** The elderly population is growing rapidly, posing challenges for healthcare monitoring. Technologies like wearables and sensors are vital for real-time health tracking. Concepts like Human Bond Communication (HBC) and Ambient Assisted Living (AAL) aim to enhance remote monitoring. However, existing networks struggle to support these needs. Future healthcare demands high data rates, reliability, and low latency, requiring advanced edge intelligence. Integration of technologies like Visible Light Communication (VLC) and Hospital-to-Home (H2H) services demands seamless connectivity and robust data security, driving the need for new mobile communication networks.

In addition to the above, several 6G emerging technologies and applications aim to address the limitations of 5G and meet the requirements of a hyper-connected world by 2030 [35]. Some key technologies and applications emerging in the 6G landscape (Figure 18) include:

1. **Internet of Everything (IoE):** The IoE extends the concept of IoT by integrating people, data, things, and processes to create a highly interconnected ecosystem. It envisions a world where sensors monitor various parameters across industries such as healthcare, smart cities, and traffic systems. IoE will rely on 6G's ability to handle massive device connectivity, real-time data transmission, and ultra-low latency communication to function effectively.
2. **Smart Grid 2.0:** Incorporates intelligent decision-making systems to monitor and control energy consumption more efficiently. As energy demand grows, 6G's capabilities, such as ultra-reliable communication and edge computing, are expected to enable real-time monitoring, CO2 emission tracking, and renewable energy integration, addressing the limitations of current communication systems in managing large-scale energy infrastructures.
3. **Holographic Telepresence (HT):** HT represents one of the most futuristic applications of 6G, where users can project realistic, real-time 3D images of distant people and objects for applications like immersive virtual meetings, education, and entertainment. 6G's high data rates (in the range of terabits per second) and extremely low latency are necessary to provide the seamless, high-quality experience that HT demands.
4. **Unmanned Aerial Vehicles (UAVs)**: UAVs, or drones, are expected to become increasingly important in 6G networks for applications such as disaster relief, traffic monitoring, and even aerial passenger taxis. The introduction of UAV-to-Everything (U2X) networks will enable these devices to operate autonomously in real-time, supporting both communication and sensing functions. 6G's enhanced mobility and low-latency communication will allow for improved UAV trajectory design and operational efficiency.
5. **Extended Reality (XR):** XR encompasses technologies such as VR, AR, and MR, all of which will rely on the high-speed, low-latency capabilities of 6G to provide immersive

user experiences. Applications in education, healthcare, and entertainment will be revolutionised by XR, where real-time interaction and data processing are critical.

6. **Connected and Autonomous Vehicles (CAVs):** CAVs are a key component of smart transportation systems, which will require 6G to enable autonomous driving, smart platooning, and cooperative vehicle networks. These systems will depend on 6G's extreme reliability, ultra-low latency, and real-time data processing to ensure safety and efficiency in vehicular communication.
7. **Industry 5.0:** Industry 5.0 will focus on human-machine collaboration, with robots working alongside humans to add a personal touch to automated processes. This next generation of industry will rely on 6G to provide the communication, computing, and control capabilities necessary for seamless collaboration between humans and machines, particularly in areas such as tele-surgery, manufacturing, and smart production.

FIGURE 18: EMERGING 6G APPLICATIONS

It is thus understood that 6G technologies such as THz communication, edge AI, blockchain, and quantum networks will support these emerging applications, which are expected to redefine industries and human interaction by 2030. The move from 5G to 6G is not only about improving connectivity but also about addressing societal needs, including sustainability, energy efficiency, and intelligent infrastructure. Briefly, the key findings from D1.1 emphasise that embedding societal challenges and values within 6G innovation activities is an open challenge. The integration requires value deliberation, strategic guidance, self-awareness and self-reflection among developers, and practices that make abstract values tangible. This issue is crucial because it affects societal acceptance of new technologies. KVIs and KSIs are viewed as tools to align 6G technological innovation with environmental, social, and economic priorities. These indicators support decision-making processes, help measure the impact of technology, and can ensure that technological development is societally responsible. Moreover, the report also highlights the need for transparent and standardised frameworks to evaluate the sustainability of 6G technology. Such frameworks must involve stakeholders and prioritise diverse values such as energy efficiency, inclusivity, and accessibility. It also stresses that the transformative nature of 6G technology will impact not only connectivity but also societal norms, leading to changes in communication, privacy, and social policies. The concept of hyperconnectivity is highlighted as one that may lead to both positive and negative social consequences, requiring further study. It identifies a significant gap in the critical analysis of how 6G technologies might negatively impact the human and social spheres, meaning that while technological benefits are often highlighted (as per our market analysis and descriptions derived from the industry), the risks and losses, such as deskilling, loss of intimacy, and exclusion, are less frequently addressed. Engaging a diverse range of stakeholders, including the public, industry experts, and policymakers, is identified as crucial to ensuring that the values embedded in 6G technologies are reflective of societal needs and ethical standards. This engagement is vital to creating acceptance and minimising resistance to new technologies. The potential of 6G to support immersive communications and other advanced applications, fundamentally altering how individuals interact with technology and information, is also identified. These advancements will drive new business models and societal interactions and bring ethical and practical challenges that need addressing. Therefore, these findings highlight the multi-dimensional challenges and opportunities of integrating societal values into the technological evolution of 6G and underscore the importance of developing frameworks like KVIs and KSIs to guide ethical and sustainable innovation.

3.4.3 6G USE CASES

The Hexa-X-II project is Europe's flagship initiative under the SNS JU, dedicated to advancing 6G technology. Building upon the groundwork laid by its predecessor, Hexa-X, the project focuses on developing an end-to-end system design and an enabling platform for next-generation wireless networks. It also aims to create a sustainable, inclusive, and trustworthy 6G platform that addresses future societal and business needs. The project transitions from research to systemisation analysis, early validation, and proof of concept, enhancing technology readiness by validating key modules, protocols, interfaces, and data [36].

With the above in mind, the project has identified six pivotal 6G use case families (Figure 19), each emphasising sustainability across environmental, social, and economic dimensions [37]:

1. **Seamless Immersive Reality:** Facilitates real-time interaction in mixed reality environments, enabling users to engage with both physical and virtual elements seamlessly. This advancement supports remote collaboration, virtual education, and enriched cultural experiences, enhancing quality of life and work flexibility.
   End-users identified:
- Remote Workers: Individuals engaging in virtual collaboration and telepresence.
- Students and Educators: Participants in virtual classrooms and training sessions.
- Cultural Enthusiasts: Users experiencing augmented reality in museums or virtual events.
2. **Cooperating Mobile Robots:** This field focuses on networks where machines are primary users, emphasising task-specific local connectivity. Applications include autonomous robots in manufacturing and logistics, which enhance efficiency and adaptability in dynamic environments.
   End-users identified:
- Manufacturing Personnel: Operators overseeing autonomous robots in production lines.
- Logistics Managers: Supervisors coordinating robotic systems in warehouses.
3. **Network-Assisted Mobility:** Leverages beyond-communication capabilities like sensing and positioning to gather 3D data about physical scenarios. This enhances efficiency and safety in applications such as autonomous driving and smart city infrastructure management.

End-users identified:

- Autonomous Vehicle Operators: Entities managing fleets of self-driving cars.
- Urban Planners: Authorities implementing smart city infrastructure.

4. **Real-Time Digital Twins:** Creates digital counterparts of real-world entities for interaction, control, and maintenance. Applicable in sectors like manufacturing and urban planning, enabling real-time monitoring and optimisation of processes and systems.
End-users identified:

- Industrial Engineers: Professionals utilising digital replicas for system optimisation.
- Facility Managers: Individuals monitoring building operations through digital twins.

5. **Ubiquitous Connectivity:** Aims to provide seamless and universal network access, ensuring consistent service quality across diverse geographies. This supports applications requiring reliable connectivity, such as remote healthcare and education, bridging digital divides.
End-users identified:

- Residents in Remote Areas: Individuals accessing high-speed internet in underserved regions.
- Travelers: Users requiring consistent connectivity across various geographies.

6. **Secure and Private Communication:** This focus is on establishing networks that prioritise user privacy and data security. It is essential for applications involving sensitive information, such as financial transactions and personal health data, and fosters trust in digital services.
End-users identified:

- Healthcare Patients: Individuals whose medical data requires secure transmission.
- Financial Service Clients: Users engaging in secure online banking and transactions.

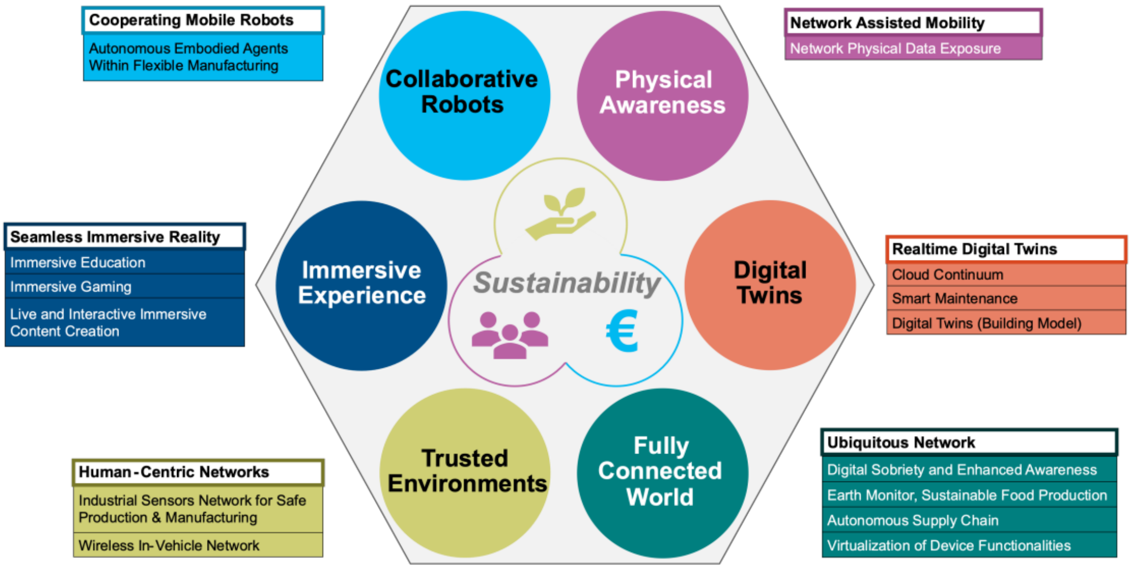

FIGURE 19: HEXA-X-II RESPECTIVE USE CASES

The 6G-IA Working Group (WG) elaborated on the analysis of HEXA-X-II use cases and their respective KPIs. The following Figure [38] illustrates how 6G use cases will vary significantly in terms of data rates, latency, reliability, mobility, and precision requirements. While immersive experiences and digital twins require ultra-low latency and high positioning accuracy, ubiquitous networks prioritise coverage and resilience. Advanced sensing and AI/ML capabilities are critical for most use cases except for ubiquitous networks.

	Seamless Immersive Reality	Cooperating Mobile Robots	Network Assisted 3D Mobility	Realtime DTs	Ubiquitous and Resilient Networks	Human-Centric Networks
User experience data rate [Mb/s]	< 250	< 10	< 100	< 100	DL: 0.1 - 25 Mbps | UL: 2 Mbps	-
Mobility [km/h]	Pedestrian, up-to vehicular speeds	<20	<300	<100	<120	Pedestrian, slow vehicular
E2E latency [ms]	< 10 ms for split rendering | < 50 ms for voice | < 150 ms for collaboration	< 0.8	1-20	< 1	10-100	< 250 ms for AGV and care robots | < 1000 ms for initiating an intervention
Reliability [%]	99.9 - 99.999 %	99.999-99.99999 %	99.99 %	99.999 - 99.99999 %	99.9 - 99.999 %	99.99 - 99.999 %
Connection density [devices/m²]	-	< 0.1-1	0.01 d/m² 0.01 d/m³)	1-10 d/m³	0.1	1-10 indoor | <0.001 outdoor
Area Traffic Capacity [Mb/s/m²]	< 250 Mbps/m2 for Indoor, per floor | <20 Mbps/m2 for wide area/outdoor	-	-	-	-	-
Service Availability	-	-	99.99 %	-	98.5 %	-
Coverage	-	-	99.9 %	99.99 %	Up to 10-15 kms range (cell radius) | 99.9% area coverage with integrated networks	-
Positioning Accuracy [m]	<= 0.1, horizontal & vertical	< 0.1 fine, <1 coarse | 99.9% availability	1 (3D) precision with 99.9% reliability within 99.9% of service space (0.1)	<= 0.1	< 10 | 99% of availability	< 10 location accuracy | <0.3 - <1 positioning accuracy | <0.1 relative positioning accuracy
Sensing-Related Capabilities	YES / Required	YES / Required	YES / Required	YES / Required	NO	YES / Required
AI/ML-Related Capabilities	YES / Required	YES / Required	YES / Required	YES / Required	NO	YES / Required

FIGURE 20: 6G USE CASES KPIS

As explained, the European Vision for the 6G Network Ecosystem outlines a comprehensive strategy for developing and deploying 6G networks by 2030, emphasising technological innovation, sustainability, and societal impact. 6G enablers (Figure 21) collectively represent the pillars of 6G innovation, addressing performance, flexibility, security, and sustainability challenges. Their development will ensure that 6G networks can meet the growing demands of future applications while supporting societal and environmental goals. In more detail, each enabler represents a critical technological advancement that will drive 6G capabilities forward:

FIGURE 21: 6G ECOSYSTEM AND ITS ENABLERS

1. Energy Efficiency Technology: Innovations focused on minimising power consumption, contributing to sustainable network operations.
2. Network & Service Security: Enhancing privacy and security mechanisms to ensure trusted communication and data protection.
3. Deterministic Networking: Providing highly predictable and reliable network performance, essential for mission-critical applications.
4. Radio & Signal Processing: Advanced radio access technologies and signal optimisation to support ultra-high data rates and connectivity.
5. New Access & Flexible Topology: Enabling versatile and adaptive network architectures to meet diverse application requirements.
6. Edge-Cloud Continuum: Integrating edge and cloud computing to ensure seamless, low-latency service delivery.
7. Network Softwarisation and Disaggregation: Decoupling hardware and software to allow flexible, modular network configurations.
8. Network Intelligence: Incorporating AI and machine learning for automated network management and optimisation.
9. Photonics: Leveraging optical technologies for ultra-fast data transmission and efficient connectivity.
10. Digital Twins: Creating virtual representations of real-world systems for real-time monitoring, analysis, and optimisation.
11. Hardware: Designing energy-efficient, scalable, and high-performance hardware solutions for 6G systems.

The European Vision for the 6G Network Ecosystem White Paper, published by the 5G Infrastructure Association in June 2021 [39], outlines Europe's strategic perspective on developing 6G technologies and their anticipated societal impact. In more detail, 6G is envisioned to integrate advanced technologies such as AI, robotics, and cloud computing, transitioning from a human-centric to a combined human- and machine-centric ecosystem. This evolution aims to provide near-instantaneous and unrestricted wireless connectivity, supporting applications like holographic telepresence and immersive communication. Aligned with the UN SDGs, 6G seeks to address pressing societal needs by promoting sustainability, privacy, security, transparency, and inclusiveness. The convergence of 6G with operational technologies is expected to decouple the location of industrial activities from human operators, potentially reversing urbanisation trends and redefining urban and rural dynamics. Key features of 6G refer to:

- Intelligent Management and Control: Enhanced network performance through AI-driven management.
- Programmability: Flexible network configurations to meet diverse application requirements.
- Integrated Sensing and Communication: Combining communication with sensing capabilities for advanced applications.
- Energy Efficiency: Reducing the energy footprint to support environmental sustainability.
- Trustworthy Infrastructure: Ensuring security and reliability in network operations.
- Scalability and Affordability: Providing widespread and cost-effective access to 6G services.

Considering architectural considerations, the 6G architecture is expected to be a flexible "network of networks," integrating terrestrial and non-terrestrial communications, joint communication and sensing, and AI-powered enablers. The principle of "AI everywhere" will enhance network performance and enable AI-as-a-Service in a federated network. Additionally, advancements in radio technologies, optical transport connectivity, photonic integration, and modern security paradigms will drive the core development of 6G. Expanding network capacity to approach or surpass current technological limits will be essential, as well as developing Europe-based 6G infrastructures and solutions for securing European sovereignty in critical technologies and systems.

3.4.4 5G AND BEYOND 5G AND 6G ACTIVITIES IN EUROPE

The presentation titled "5G, Beyond 5G, and 6G Activities Promoted by Member States" [34] offers a comprehensive overview of national initiatives across Europe aimed at advancing 5G and future communication technologies. Compiled by the 6G Infrastructure Association (6G-IA), it highlights the collaborative efforts of various countries in fostering research, development, and deployment of next-generation networks. The document details activities stimulated by national and regional ministries, public agencies, regulatory bodies, and cities, focusing on the deployment and evolution of 5G towards beyond 5G (B5G) and 6G networks. A diverse group of rapporteurs from countries including Austria, Belgium, Finland, France, Germany, Greece, Italy, Luxembourg, Netherlands, Norway, Poland, Portugal, Romania, Serbia, Spain, Sweden, Turkey, and the UK have contributed to this comprehensive overview.

The presentation showcases various national projects and funding programs, such as Austria's 5G GigaApp initiative, Belgium's 5G Radio Spectrum Auction, and Finland's 6G Flagship Program. These initiatives drive innovation, address regional challenges, and promote digitisation across urban and rural areas. The primary goal is to report on activities relevant to the deployment of 5G communication networks and their evolution towards B5G and 6G, emphasising the importance of national and regional efforts in shaping the future of communication technologies. Since 5G case studies were explored in the previous paragraphs (e.g., Chapter 3), this section emphasises 6G case studies, programs, etc. For instance, Figure

22 shows how the 6G Bridge Program aims to create new value by leveraging 5G Advanced and 6G technologies to support sustainable industries and societies. Its focus includes smart cities, smart energy systems, smart ports, and smart factories by fostering collaboration among diverse ecosystem players. The program's key goals are (i) promoting ecosystem-driven research and innovation for 5G/6G, (ii) building future business ecosystems in 5G/6G while attracting international investments, (iii) enhancing critical capabilities and expertise related to 5G/6G technologies, and (iv) supporting testing and experimentation of 6G solutions. With a planned budget of EUR 130 million, the program runs from January 2023 until the end of 2026. It is overseen by Business Finland, which coordinates the initiative and facilitates its implementation.

FIGURE 22: 6G BRIDGE PROGRAMME

Another initiative to consider is 6G Finland. A coalition of Finnish research and development (R&D) organisations aimed at promoting Finland's 6G expertise on a global scale. The initiative builds international partnerships and strengthens national 6G development efforts to create a sustainable, data-driven society. Enabled by seamless and unlimited wireless connectivity, the coalition supports technological progress toward 6G adoption. Serving as Finland's national contact point for 6G knowledge, the coalition actively contributes to discussions at both national and international levels. It operates as an open network, welcoming new members based on their contributions and expertise. Public bodies in charge of this initiative include a non-profit coalition of national R&D organisations working in collaboration with Business Finland and the Academy of Finland. The founding members consist of leading Finnish institutions and organisations such as Aalto University, Nokia Bell Labs, University of Oulu, Tampere University, and others, reflecting strong national collaboration.

6G Finland

- Description: 6G Finland is a coalition of Finnish 6G R&D organizations to advance the impact of Finnish 6G expertise globally, build new international partnerships, and intensify national 6G development efforts towards sustainable and data-driven society enabled by instant and unlimited wireless connectivity. 6G Finland is a national contact point of Finnish 6G know-how, and actively participates in 6G discussion both nationally and internationally. 6G Finland operates as a network to which new members are invited on a content basis.
- Public bodies in charge:
  - Non-profit coalition of national R&D organizations in collaboration with Business Finland and Academy of Finland
  - Founding members: Aalto University, BusinessOulu, Finnish Defence Research Agency, LUT University, Nokia Bell Labs, Oulu University of Applied Sciences, University of Helsinki, University of Oulu, Tampere University, VTT.
- Further information: 6G Finland website

FIGURE 23: 6G FINLAND

It is understood that Finland is a good example when examining new 6G initiatives and strategies. Another essential example is the 6G Flagship program, a national research initiative from 2018 to 2026 with a total funding of €250 million. Led by the University of Oulu, it involves 400 researchers from 50 nationalities and collaborates with over 400 companies across more than 300 research projects. The program has played a pivotal role in defining early 6G visions, producing 13 White Papers (downloaded over 1 million times), over 2500 peer-reviewed papers, and 85 doctoral theses. The flagship's research focuses on four strategic research areas: (i) Wireless connectivity solutions, (ii) Device and circuit technologies, (iii) Distributed intelligent wireless computing, and (iv) Sustainable human-centric services and applications. The 6G Flagship Vision for 2030 emphasises building a data-driven, sustainable future society enabled by near-instant and unlimited wireless connectivity. This is why key goals include advancing 6G technology enablers, developing 6G vertical applications, and promoting opinion leadership and fostering innovation. The flagship drives global collaboration, contributing to initiatives like 6G Test Networks (6GTN) and training 6G experts to influence future standards. Public bodies supporting this initiative include the Academy of Finland and the University of Oulu.

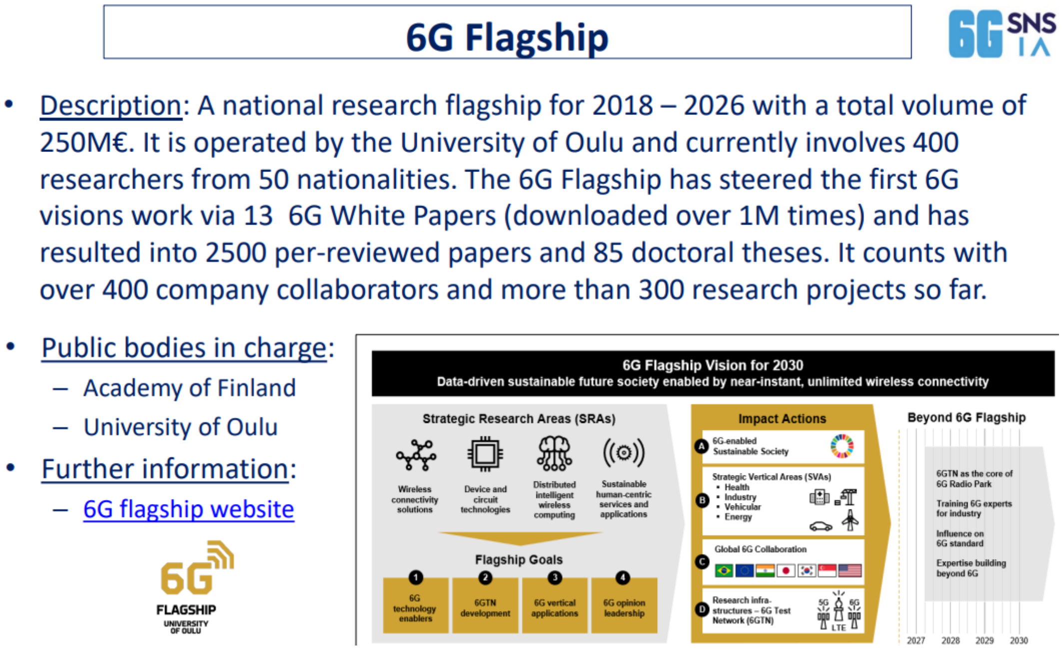

FIGURE 24: 6G FLAGSHIP

The RESTART Program is a large-scale research initiative with a budget of €116 million from January 2023 to February 2026. It is a joint effort involving universities, research centres, companies, and public administrations, aiming to advance technologies in 5G/6G networks, high-capacity fixed infrastructures, IoT, edge/core-cloud, and a range of applications and services across various verticals. The program is organised into seven key missions: (i) Research, (ii) Labs, Proof of Concepts (PoC), and Demonstrators, (iii) Innovation and Technology Transfer, (iv) Start-ups and Spin-offs, (v) Education and PhD Programs. (vi) Communication, and (vii) Standardisation and Open-Source. As part of its research mission, RESTART encompasses 14 structural projects (large-scale initiatives) and 18 focused projects aimed at addressing specific gaps, particularly in industrial sectors. Public bodies in charge include the RESTART Foundation and the Ministerio della Università e della Ricerca in Italy.

FIGURE 25: THE RESTART PROGRAM

Additional initiatives and programs refer to the 6G Platform Germany initiative, funded by the Federal Ministry of Education and Research in Germany. This initiative focuses on developing 6G technologies through research hubs and collaborative projects. Another example is the Dutch Digitalisation Strategy (Netherlands), which emphasises the importance of digital infrastructure, including 5G and future technologies, to support economic growth and societal well-being. The 5G Roadmap of France focuses on accelerating 5G deployment, fostering innovation, and ensuring security, with a commitment to allocate frequencies and support industrial 5G applications. Another example is Austria, the 5G GigaApp initiative, which funds the development of innovative digital applications and services based on gigabit-capable 5G infrastructure, focusing on regional challenges to drive digitisation in rural areas. We thus understand that European countries are employing varied strategies tailored to their unique needs and priorities, encompassing spectrum allocation, funding research and development, and fostering innovation ecosystems. There is a strong emphasis on collaboration among governments, industry players, and research institutions to drive the advancement of communication technologies, as many initiatives aim to leverage 5G and future technologies to support innovation across various sectors, including industry, healthcare, transport, and energy. The deployment of advanced communication networks is seen as a catalyst for economic growth, digital transformation, and societal well-being. Several initiatives highlight the importance of ensuring that new technologies are secure and resilient and contribute to sustainable development goals.

However, the 6G technology is expected to become commercially available in the 2030s, building upon the advancements and high-end capabilities introduced by 5G networks [40]. It aims to contribute to a more innovative, sustainable, and efficient society by merging digital and physical worlds. This integration is anticipated to enable new applications such as multisensory extended realities, precision healthcare, smart agricultural robotics, and intelligent autonomous systems. Notably, North America currently holds the largest market share in the 6G market, attributed to substantial investments in advanced technology deployments. The United States, in particular, is a leading innovator and investor in both 5G and 6G markets, whilst Asia-Pacific is identified as the fastest-growing market, with significant developments and investments anticipated in countries like China, Japan, and South Korea. Examples of key companies operating in the 6G market include AT&T, Broadcom, Cisco, Ericsson, and Google. These industry leaders actively invest in R&D to advance 6G technologies and infrastructure.

3.4.5 PUBLIC PERCEPTION OF 6G TECHNOLOGY

Opinions about 6G technology are diverse and evolving, reflecting excitement and caution. Many view 6G as a transformative leap forward, promising unprecedented advancements in connectivity, speed, and real-time integration of AI-powered systems [41]. People are particularly intrigued by its potential to revolutionise healthcare, transportation, and smart cities while fostering sustainability through optimised resource management and reduced carbon footprints. Overall, public opinion about 6G technology balances optimism about its potential to drive innovation and improve quality of life by recognising the challenges that must be addressed to ensure responsible and equitable development [42]. On the other hand, some express concerns regarding the environmental impact of increased data consumption, potential privacy risks, and the socioeconomic divide that could arise from unequal access to such advanced technology. Questions about the feasibility and practicality of deploying 6G infrastructure globally also fuel scepticism. For instance, someone shared their opinion about the technological transition from 5G to 6G in an e-news article in 2023 [42]. It was stated that "With 5G networks still being deployed around the world and many areas of the globe still using 4G and even 3G networks, it seems a bit early to throw around the term 6G. After all, what use do we have for 6G networks when relatively few people can even use a 5G network?". Using this statement as an example, the author of the article elaborated by reporting that future advancements may not be labelled "6G" but could instead take on names like "5G Enhanced" or eliminate naming conventions, focusing on the experience of being perpetually connected. With future technologies, data transmission could become so instantaneous that terms like "6G" or "7G" may become obsolete as connectivity reaches a point where speed and access are no longer noticeable limitations. Additional statements by technology experts envision 6G as a "sixth sense experience" that bridges the gap between biology and AI, enhancing interactions for both humans and machines. Similarly, others predict that 6G will bring about the "sophistication of cyber-physical fusion," seamlessly integrating the digital and physical worlds. As to how computers could interact with the human brain in the future, an octogenarian who experiences mobility difficulties but still values independence reported that with the use of 6G technology, it would be feasible to stay in bed a bit longer and, instead of calling for assistance, the 6G-connected exoskeleton would respond instantly by simply thinking the command.

Therefore, the need for 6G depends on how well 5G evolves and is continuously improved by manufacturers, regulators, and telecom companies. As already mentioned, experts anticipate that 6G will offer significant advancements over 5G, including higher data transmission rates, reduced latency, and enhanced connectivity. These improvements are expected to facilitate innovations such as integrated air, space, and ground communication, seamless mobile broadband access in various environments, and the development of smart factories and connected vehicles [43]. China's commitment to 6G development is evident through its strategic planning and international cooperation. The country has outlined initial blueprints for 6G and is open to collaborating with other nations to establish global standards and promote technological advancement. This said, focusing on assumptions, purpose, and real-world relevance is necessary to guide meaningful innovation and avoid "l'art pour l'art" research lacking impact [44]. Growth opportunities in the communication industry are expanding, with stakeholders from satellite communications, AI, and computation joining traditional vertical industries. However, interest in 6G varies, with some legacy players showing limited enthusiasm, while stock market trends often provide insight into the industry's optimism about 6G. In other words, 6G should address broader societal problems, such as those outlined in the UN's 17 SDGs. However, effectively linking 6G to sustainability remains challenging, as many current discussions lack a convincing connection. The focus should shift to defining a clear purpose for 6G in solving real-world issues.

To expand on Section 3.2.1 of this document and draw upon the detailed analysis presented in D1.1, the following Table provides a comprehensive examination of the identified gaps. It outlines the current and desired future state and proposed solutions to address these gaps effectively.

TABLE 2: GAP ANALYSIS OF 5G AND IMPLICATIONS FOR 6G_V0.2

Objective	Current State	Future State	Gap Description	Solution
Enhance public acceptance	Limited trust in 5G due to health, privacy, and surveillance concerns; lack of inclusive governance.	Proactive public engagement; trust-building measures; transparency in data usage and technology.	Insufficient transparency and lack of stakeholder engagement.	Build trust through transparent communication and inclusive public consultations.

Achieve sustainability goals	Energy inefficiency; no standardised sustainability indicators; ineffective e-waste management.	Energy-efficient infrastructure; robust sustainability metrics integrated into 6G design.	Absence of measurable sustainability indicators; increasing energy footprint of infrastructure.	Develop KSIs; prioritise energy-efficient technology design.
Ensure social and ethical focus	Limited inclusivity; insufficient focus on AI ethics and data privacy issues.	Ethical AI frameworks; involvement of diverse stakeholders in decision-making processes.	Lack of inclusivity in technology design and ethical considerations in AI systems.	Integrate ethical frameworks and participatory development models into 6G planning.
Develop technological resilience	Insufficient network resilience and reliability during disasters; semantic communication challenges.	Highly resilient networks; robust semantic communication systems with AI integration.	Gaps in disaster response capabilities and semantic communication trustworthiness.	Design disaster-proof networks and enhance semantic communication reliability.
Standardised global frameworks	Fragmented approaches to sustainability and interoperability standards across regions.	Unified sustainability frameworks; interoperable and certified technologies globally.	Lack of cohesive global frameworks for sustainability and interoperability.	Create globally recognised standards and certifications for sustainability and interoperability.
Strengthen governance	Reactive governance; weak policies addressing health, privacy, and environmental concerns.	Anticipatory and inclusive governance models; proactive policy-making for emerging technologies.	Governance models fail to pre-emptively address societal and environmental concerns.	Foster inclusive governance with anticipatory policies addressing public and environmental needs.

The Table highlights key gaps identified in the deployment of 5G, many of which directly influenced public perception and acceptance. Specifically, the public acceptance row of the Table addresses the trust deficits, privacy concerns, and insufficient stakeholder engagement that plagued the rollout of 5G technology. These issues, if not proactively managed, could pose significant challenges for 6G adoption. The Table underscores the importance of implementing proactive trust-building measures, transparent communication strategies, and inclusive governance models to foster public confidence in 6G technology. By addressing these gaps early, the proposed remedies aim to prevent the spread of misinformation and disinformation, improve societal engagement, and enhance the overall perception of 6G as a trustworthy and inclusive technological advancement. Public mistrust, governance challenges, and misalignments between industry goals and societal values have highlighted the need for inclusive decision-making and transparent communication. In more detail, among the primary concerns that shape public perception of 6G technology are health risks, data privacy, cybersecurity threats, environmental sustainability, and equitable access to technological advancements. A significant portion of the public's apprehension relates to health concerns, particularly around EMF exposure due to the proliferation of 6G infrastructure, such as towers and antennas. Despite scientific evidence largely dismissing health risks, the report [45] emphasises the need for transparent communication of findings and strict adherence to safety standards. By ensuring that the public is well-informed about the safety of 6G technology, stakeholders can help reduce fears and build confidence in its deployment. Privacy and security are also prominent issues affecting public perception. As 6G introduces more advanced data collection and processing capabilities, concerns over data privacy and potential misuse of personal information have intensified. The report stresses the importance of implementing robust data protection measures alongside clear and enforceable privacy policies. Furthermore, with increased connectivity comes a heightened risk of cybersecurity threats. Ensuring that strong security protocols are in place and developing rapid response mechanisms to address potential breaches are vital to maintaining public trust. Moreover, it points out the energy consumption increase and electronic waste production because devices tend to get old very quickly. Without the appropriate management of its environmental footprint, the social gains of 6G will be lost. Thus, it needs to have efficient energy technology developed and recycled along with sustainable hardware designs. On the other hand, there is a risk that 6G may deepen existing inequalities if access is limited to affluent or urban populations. This underscores the importance of equitable access to ensure that all societal groups, regardless of geographic or socioeconomic status, can benefit from technological advancements. Misinformation and disinformation about 6G technology are highlighted as another major challenge. The spread of false information can lead to unwarranted fears and resistance among the public. The report calls for proactive public education campaigns to accurately inform people about the technology’s benefits and risks. Transparent communication strategies are crucial in combating misinformation and building a well-informed society. Lastly, the aesthetic and community impact of deploying 6G infrastructure is noted as a factor influencing public perception. Installation of towers and other equipment naturally leads to resistance among local communities on the issue of visual pollution and intrusion into public space. Involvement in the planning and deployment phase may reduce resistance, while attention to aesthetic concerns should help build goodwill for 6G projects; for policymakers, calls are being made to develop inclusive policies that invest in infrastructure and bridge the gap between disparate communities. Stakeholders are called upon to establish public trust and integrate the principles of sustainability into 6G from the very beginning, with due consideration of global environmental goals, so that the successful adoption of 6G technology will be positive for the development of society. The project partners in 6G4Society introduce the SAT Framework, which assesses acceptance through dimensions such as social disruptiveness, user experience, value alignment, and trust, in order to address these issues. This framework fosters a deep understanding of the social implications of technology, underscoring the fact that acceptance is a multi-dimensional and dynamic process.

3.5 FUNDING SOURCES

Based on the 6G4Society project’s goals and a broader focus on societal impact, sustainability, and technology acceptance, several potential funding sources can be identified to support future initiatives, ensure continued development, and sustain the project's outcomes. These sources align with the project’s emphasis on knowledge-sharing, public engagement, policy development, and ethical technology integration. As reported in this document, significant investments have been made in Europe to advance 5G and 6G technologies and drive economic growth.

With this in mind, the "EU-US Beyond 5G/6G Roadmap" report [46], published in December 2023, outlines strategic recommendations for advancing 6G networks and services through collaborative efforts between the EU and the US. The report identifies six key areas for cooperation, such as promoting 6g sustainable and open solutions (e.g., by reducing the ecological footprint of 6g technologies and leveraging them to achieve broader sustainability goals), collaborative research focusing on the application of microelectronics and 6G, while also advancing cloud solutions, distributed computing, AI and 6G, as well as trustworthiness and cybersecurity. Regarding funding, leveraging EU and US funding instruments to support these collaborative efforts is proposed. Thus, opportunities should be analysed to create a concrete strategic collaboration agenda through joint R&I actions, coordinated PoC targeted toward selected vertical industries, and collaborative investments from the EU and the US to support these activities by 2025. This approach highlights the exploration of value-creation opportunities across various vertical industries, identification of common use cases to maximise economies of scale, and support for aligned standardisation priorities. It also points out the need for workforce development strategies that will increase the number of students graduating in STEM fields, thereby creating a talent pipeline essential for developing advanced 6G technologies.

However, the funding of 6G technology spans a wide range of sources: EU initiatives, national and regional funding bodies, international collaborations, private sector investments, and philanthropic foundations. These funding mechanisms are critical for furthering research, innovation, and standardisation in 6G technologies to meet societal, environmental, and economic objectives. Below is a detailed overview of key funding institutions and bodies, referencing relevant programs and initiatives. More specifically:

1. Horizon Europe[10]: As the EU's flagship research and innovation program, Horizon Europe funds projects related to sustainability, technology, and societal transformation. Given the 6G4Society project's focus on embedding societal values into 6G technologies, it aligns well with Horizon Europe's mission. Specific calls within the Digital, Industry and Space or Climate, Energy and Mobility pillars could be relevant funding opportunities.
2. Digital Europe Program[11]: This program supports Europe's digital transformation and funds projects aimed at enhancing the EU's digital infrastructure. It focuses on AI, cybersecurity, and advanced digital skills.
3. Connecting Europe Facility[12]: The Connecting Europe Facility program funds projects aimed at improving Europe's digital connectivity. Since 6G technologies will play a crucial role in digital infrastructure, this program could be a suitable funding source, particularly in areas of telecom infrastructure and cross-border collaboration.
4. SNS JU[13]: It was established to accelerate research and deployment of smart networks, including 6G. In 2025, SNS JU announced an investment of €128 million in 6G research, focusing on developing key technologies and contributing to global standards.

10 https://research-and-innovation.ec.europa.eu/funding/funding-opportunities/funding-programmes-and-open-calls/horizon-europe_en

11 The Digital Europe Programme | Shaping Europe's digital future

12 https://cinea.ec.europa.eu/programmes/connecting-europe-facility_en

13 https://smart-networks.europa.eu/

5. European Structural and Investment Funds (ESIF)[14]: ESIF, particularly the European Regional Development Fund (ERDF)[15], often supports projects that enhance regional competitiveness, foster digital inclusion, and promote innovation. 6G-related technologies contributing to socio-economic development and regional connectivity could be eligible for funding under this initiative.
6. Next Generation Internet (NGI)[16]: This initiative supports internet-based innovation aimed at improving connectivity, digital inclusion, and societal benefits. Funding from NGI could be used to develop new use cases and applications driven by 6G technologies.
7. National Funding Programs: Many EU member states have their research funding programs focused on digital innovation and sustainability.
8. Regional Funds: For example, local governments or regional development agencies can support 6G pilot projects focusing on specific regional needs, such as rural connectivity or smart city initiatives.
9. International Telecommunication Union (ITU)[17]: A UN agency focused on standardisation and regulation of telecommunications. It often partners with research and development initiatives shaping future communication infrastructures. Collaborative research funding and grants may be available for projects like 6G4Society that contribute to international policy frameworks and standardisation.
10. Bharat 6G Alliance in India[18]: It involves Indian industry, academia, and national research institutions focusing on the design, development, and deployment of 6G systems. Collaborative projects with this alliance could open doors to joint funding opportunities.
11. Telecom and Technology Companies: Major telecom operators and technology firms are key investors in 6G research and development. Companies such as Ericsson, Nokia, Huawei, Qualcomm, and Samsung are heavily involved in 5G/6G initiatives and could offer joint funding or partnerships.
12. Corporate Social Responsibility (CSR) Programs: Many corporations have CSR initiatives focused on digital inclusion, sustainability, and social impact. Aligning the 6G4Society project's objectives with these CSR goals could lead to potential partnerships and funding.
13. Public-Private Partnerships (PPP): Public-private partnerships often play a significant role in infrastructure development and technological innovation. The European Investment Bank (EIB) and similar entities frequently support PPPs in sustainable development and digital infrastructure.
14. European Green Deal Initiatives: Given 6G4Society's focus on sustainability, the project could attract funding from green-focused organisations and foundations supporting sustainable technology development. The project's alignment with climate goals makes it a candidate for funding from European Green Deal initiatives.
15. Tech-Focused Foundations: Foundations such as the Bill & Melinda Gates Foundation or Google.org provide funding for projects emphasising technology's role in societal improvement. Since the project promotes ethical technology development, partnerships with tech-related philanthropic organisations could be possible.

[14] https://ec.europa.eu/commission/presscorner/detail/en/ip_23_389

[15] Inforegio - European Regional Development Fund

[16] https://ngi.eu/

[17] https://www.itu.int/en/Pages/default.aspx

[18] https://bharat6galliance.com/bharat6G/

16. Open Society Foundations: The Open Society Foundations could be a potential source of support for initiatives focused on policy influence, public engagement, and inclusivity in technology development.

Securing adequate funding is a critical component for the successful development and deployment of 6G technologies [47]. The diverse range of funding sources, spanning public sector initiatives, private sector investments, international collaborations, and philanthropic contributions, ensures that research, innovation, and standardisation efforts can progress effectively. By fostering partnerships across these different funding bodies, the 6G ecosystem can advance not only technologically but also in alignment with societal, environmental, and economic goals. This comprehensive funding landscape underscores the importance of coordinated efforts in driving the next generation of wireless communication technologies. Therefore, the 6G4Society project can leverage a diverse range of funding sources to sustain its long-term impact and ensure that 6G technologies are developed in line with global sustainability and inclusivity goals.

Co-funded by the European Union

4 ANALYSIS OF EXPLOITATION POTENTIAL FOR 6G4SOCIETY KEY RESULTS

As already analysed, the 6G4Society project is designed to create a foundation for the sustainable exploitation of 6G technology by addressing the critical societal, ethical, and technological aspects of its acceptance and deployment. While the project itself, as a Coordination and Support Action (CSA), does not produce directly exploitable results, it plays a crucial role in shaping the exploitation environment through its combined engagement activities and tangible outcomes, such as the TAM and KSIs. These efforts will facilitate a smoother path toward 6G technology take-up and commercial adoption by ensuring that societal concerns and sustainability values are integrated into the core of technological development.

To ensure the successful sustainable exploitation and adoption of 6G technologies, the project partners will actively collect and analyse the views of stakeholders regarding the societal impacts of next-generation technologies to understand the concerns and expectations of industry experts and the general public and help create a favourable environment for their development and adoption. Creating KSIs and KVIs and refining SAT will provide measurable metrics to ensure that 6G technology aligns with societal and environmental goals and contributes to the broader understanding of how society interacts with emerging technologies, ensuring that 6G solutions are designed with public trust and user acceptance in mind. Through its active involvement in the standardisation process, 6G4Society will ensure that European values such as privacy, sustainability, and inclusivity are embedded into global 6G standards. This will enable both industry and regulatory bodies to adopt 6G technologies aligned with societal needs.

Therefore, the project’s indirect exploitation impact will manifest through two primary pathways. First, by raising awareness and understanding of societal issues related to 6G technology through engagement activities, the project informs both industry actors and citizens, thereby reducing friction in the technology take-up process and easing paths to commercialisation and wider adoption. It would empower the innovators as well as the commercial actors by providing an understanding of the technology acceptance and sustainability requirement that would allow the development of strong market differentiators aligned with ethical and societal values and which are a competitive advantage but by adhering to evolving European norms. To further support the exploitation strategy, the project actively identifies gaps and opportunities related to societal impacts, social acceptance, and sustainability indicators by analysing public policies, strategies, and programs. Gaps in data governance and technological deployment are recognised and benchmarked against regional and international standards, allowing for exploring solutions through international cooperation and policy feedback. After identifying these gaps and opportunities, working sessions with key stakeholders to validate and assess the feasibility of the proposed solutions are key to addressing societal barriers and exploring opportunities for innovation. This feedback is essential for refining the project’s outputs and ensuring that the SAT and KSIs framework are set in a relevant and effective way. Finally, the project provides feedback on policy and operational measures through the insights gathered from stakeholder engagement and the analysis of primary and secondary information. The project influences national and international policy by identifying opportunities for improving data governance, regulatory frameworks, and technology standards and promotes the ethical and sustainable development of 6G technologies.

Additionally, each project partner in the 6G4Society consortium has outlined specific exploitation plans to leverage the project's outcomes in their respective fields. More specifically:

- **MAR** (Martel Innovate) aims to strengthen its expertise in telecommunications and 5G/6G technologies by further integrating its knowledge in cloud-native architectures, edge computing, and service orchestration for telecommunication infrastructure. Through the insights gained from end-user engagement, MAR plans to expand its innovation management and consulting services in MAR (R&D&I), focusing on 5G and 6G.
- **CEL** (CyberEthics Lab), a research-oriented small and medium-sized enterprise (SME), focuses on promoting responsible research and innovation in technological development. CEL will refine and utilise its SAT methodology to assess the societal impacts of 6G technologies, building on the experience gained from the 5G-PPP. The insights gained will enrich CEL's portfolio of assessment models for 6G Smart Networks and Services Industry Association (6G-IA) initiatives. CEL also plans to produce academic publications, offer policy recommendations for policymakers, and provide operational advice for 6G industry players. Additionally, CEL will continue contributing to ethics-related standards working groups, such as the IEEE P70xx and ISO/IEC JTC1, with findings from the project.
- **NOVA**, a major telecommunications and ICT company in Greece, will capitalise on the project's results to deploy 5G and beyond 5G services across Greece, contributing to the expansion of the telecommunications economy in the country. NOVA's involvement will help enhance its service offerings, including broadband internet, TV-content services, cloud, and data services for both public and private sectors.
- **PSCE** (Public Safety Communication Europe) will use the project to facilitate collaboration between users, industry, and researchers in public safety communications. By fostering discussions, exchanging best practices, and developing roadmaps for future communication systems, PSCE aims to improve public safety communication technologies in the 6G era.
- **eBOS** will leverage the knowledge gained from the project to collaborate on joint activities with other SNS JU Projects. eBOS plans to promote a development approach emphasising ethics and legal principles, ensuring the sustainable and trustworthy evolution of 5G and beyond technologies.
- **D4P** (Digital for Planet), a non-profit organisation focused on green and digital transitions, will use its involvement in the 6G4Society project to highlight and investigate the sustainability aspects of 6G. By engaging in communication and community-building activities, D4P aims to gather stakeholders around opportunities related to both green and digital transitions, aligning with its mission. The experience gained will enable D4P to offer new services in the R&D&I space while increasing its visibility and credibility in both the scientific and industrial communities, opening new business avenues.

The individual exploitation plans of the 6G4Society partners are closely aligned with the project's overarching objectives, ensuring that the outcomes contribute to both immediate project goals and future technological developments. Partners such as CEL, eBOS, and D4P emphasise the importance of embedding ethical, legal, and sustainability principles in the 6G development process, directly supporting the project's aim of promoting responsible research and innovation. By integrating societal values into the 6G design, these plans help ensure the social acceptance of the technology, thereby addressing one of the project's key objectives. Moreover, the focus of MAR, PSCE, and D4P on public engagement and end-user involvement is crucial in increasing public awareness and trust in 6G technology. This approach is vital for overcoming societal barriers and creating a favourable environment for the wider adoption of 6G. Their engagement strategies, combined with NOVA's plans to leverage the project's results to deploy 5G and beyond services, demonstrate a commitment to promoting technological advancement and expanding the telecommunications landscape in practical and impactful ways. Collectively, these exploitation plans ensure that the project's outcomes are not only utilised effectively within the scope of the current project but also provide a foundation for future initiatives. By driving industry collaboration, regulatory engagement, and public participation, the project partners contribute to creating a more inclusive, ethical, and sustainable 6G ecosystem, which is crucial for further improving the project's scope and shaping future 6G developments.

4.1 6G4SOCIETY KEY EXPLOITABLE RESULTS (KERS)

To elaborate on the above paragraphs, the project partners in 6G4Society aim to take several actions to foster a better understanding of the various effects of 6G and its technologies. The project consortium has developed and submitted key reports that enhance this information by mapping their methodology and promoting knowledge-sharing through research and collaboration with other key players in the industry. More specifically, besides D1.1, the analysis of D4.1 “Dissemination and Communication Strategy and Plan” (M04), D5.4 “Ethics and legal guidelines” (M06), and D2.1 “Public Engagement Strategy and Plan” (M06) provide:

- Generated Knowledge: Project materials such as white papers, deliverables, publications, etc., form the foundation for disseminating the findings and best practices of the 6G4Society project. They represent valuable intellectual assets that can be exploited for industry training, academic collaboration, and public education.
- Feedback to Policy Measures: Specifically, the necessity to continuously monitor regulatory frameworks that pertain to 6G-related concerns, including power consumption, EMF, security, privacy, and safety. This monitoring enables the identification of gaps and opportunities in current policies and the provision of recommendations to policymakers. A set of policy options to foster societal benefits and mitigate risks will be developed through collected insights. These recommendations will be consolidated in a final policy brief (D1.2 “Towards a socially accepted and sustainable 6G – Policy Brief”, M24) at the end of the project, outlining improvements for future legislation. This work also reflects the importance of integrating societal values and sustainability into 6G technology development. Policymakers are encouraged to align 6G technologies with social and environmental priorities, particularly by using KSIs and KVIs. This feedback ensures that technological advancements not only meet performance objectives but also serve broader societal needs, such as inclusivity, privacy, and sustainability. Policy measures need to be continuously refined to ensure that these technologies are developed in line with ethical guidelines and European values, reflecting a responsible approach to innovation.
- Feedback to Operation Measures: Specifically, the need to fine-tune operational frameworks in the context of 6G, particularly by ensuring that stakeholder engagement is integral to the design and deployment of new technologies. As the project focuses on supporting 6G industry operators by identifying concerns and offering operational recommendations, this feedback focuses on balancing technical capabilities with societal impacts, ensuring transparent communication between developers and end-users. It will be based on the analysis of social acceptance, inclusiveness, security, and sustainability, and will assist in the adoption of best practices by industry operators, ensuring that they align with both current regulations and societal expectations. This approach ensures that 6G operations are sustainable, respect societal concerns, and are adaptable to the diverse needs of communities. Therefore, the final operational brief (D1.3 “Towards a socially accepted and sustainable 6G – Operation Brief”, M24) will offer suggestions for enhancements in the processes and practices of 6G deployment, ensuring alignment with societal values.
- Consultancy Services on Technology Acceptance: Specifically, the need for consulting services to focus on understanding public perception and controversies surrounding new (6G) technologies. These services are necessary to bridge gaps between technological innovation and social acceptance, ensuring that 6G technologies are

designed with public trust in mind. Consulting on technology acceptance involves analysing public concerns, addressing misconceptions, and ensuring that societal values are embedded early in technology development to facilitate smoother technology adoption using a structured and appropriate framework promoted through 6G4Society. The framework will be designed to assess and enhance the societal acceptance of 6G technology and will be key for operators and policymakers in evaluating social risks and improving public perception during the technology's rollout.

- Consultancy Services on Sustainability Indicators: Specifically, the creation of KSIs is essential for measuring the societal and environmental impact of 6G technologies. Consulting services in this area would focus on assessing sustainability in line with global standards like the UN SDGs, ensuring that 6G technologies contribute to reducing carbon emissions, enhancing energy efficiency, addressing climate change, and promoting digital inclusion. These services will guide organisations in developing strategies that align with sustainability and social responsibility goals, thereby enabling them to meet the expectations of public authorities and policymakers. KSIs will also guide companies to align their technological developments with sustainability principles, promoting the responsible growth of 6G technologies.
- KVI-KSI Ontology: This ontology provides a structured understanding of KVIs and KSIs. It helps align 6G development with societal values and sustainability goals, serving as a tool for policymakers and developers to balance performance with ethical considerations.
- KSI Framework: A dedicated framework for defining, monitoring, and assessing KSIs. This framework ensures that the environmental and societal impact of 6G technologies is measurable, guiding operators and developers in sustainable technology deployment.
- Consultancy Services on Participatory Design: Specifically, a participatory design approach, where stakeholders, including end-users, citizens, and industry experts, are involved in the 6G innovation process from the outset. Consultancy services in this area would help facilitate multi-stakeholder dialogues, ensuring that diverse perspectives, concerns and expectations of various societal groups are incorporated into the technology design and deployment process. By fostering dialogue between technologists and the public, participatory design can help operators develop technologies better aligned with public interests, thus facilitating greater acceptance and smoother market adoption of 6G innovations. This approach aims to build trust and social acceptance by ensuring that technology reflects the values and needs of all involved parties.
- Methodology to Identify Driving Values: A systematic approach for identifying societal and ethical values that should guide 6G development. This methodology supports participatory design and ensures that the technology meets the diverse needs and expectations of society.
- Competence Centre (Spin-off NGO): The competence centre will be a long-term outcome of the project, potentially established as a spin-off NGO after the project's conclusion. It will serve as a hub for expertise, offering ongoing consultancy services, training, and guidance on social acceptance, sustainability, and participatory design.
- Pool of 'Experts' – HUB: A hub of experts across various fields who can provide ongoing support, guidance, and consultancy on the development and deployment of 6G technologies. This hub will act as a resource for industry stakeholders seeking specialised knowledge in social acceptance, sustainability, and policy alignment.

These efforts collectively ensure that 6G technologies are developed and deployed in a way that is ethical, sustainable, and socially accepted while also influencing the regulatory landscape to support these goals. Communication guidelines will be focused on effectively addressing scientific controversies surrounding 6G, such as health concerns and privacy issues, and will be crucial for industry stakeholders and regulators in ensuring transparent communication and combating misinformation. Additionally, concrete deliverables generated in 6G4Society emphasise that the project will result in tangible, exploitable assets that contribute to both academic research and industry practice. The consultancy services on participatory design and sustainability indicators, along with the competence centre, can be positioned as long-term outcomes that will ensure continuous support and knowledge-sharing even after the project's formal end. Lastly, the SAT framework, KSI framework, and KVI-KSI ontology will be framed as tools that provide structured approaches to evaluate and improve societal acceptance, sustainability, and value-driven design in 6G technologies.

Those mentioned above are highly relevant to the 5G domains expected to be profitable by 2025. Specifically, they refer to automotive, healthcare, utilities, smart cities, agriculture, transport, and logistics. This said, the 6G4Society consortium will focus the marker research on identifying emerging verticals where 5G can drive value, evaluating readiness for 5G adoption across different regions, understanding regulatory challenges and developing strategies for compliance, as well as analysing consumer and business demand for 5G-enabled services, and assessing investment requirements for infrastructure deployment and operational scalability. Based on those, and through the 6G4Society work and activities, the project partners will address communication guidelines on scientific controversies, meaning a structured set of best practices, strategies, and approaches designed to manage and convey complex or potentially contentious scientific information to diverse stakeholders, including the general public, policymakers, and the media. These guidelines are particularly relevant to 5G and 6G and raise societal concerns about health, privacy, environmental impact, or ethical issues. As already analysed, those key aspects refer to transparency and clarity, evidence-based communication and risk communication, stakeholder engagement (including framing of messages that positively influence the public perception), managing controversies (such as public debates over health risks associated with EMF in 5G/6G), ensuring multi-channel dissemination, and continuous monitoring and providing feedback.

4.2 ACHIEVED ACTIVITIES UP TO M12

This section highlights the exploitation and sustainability progress and milestones achieved by the 6G4Society project during the first 12 months (M12). As the project focuses on fostering societal acceptance, sustainability, and stakeholder engagement in developing 6G technologies, the initial phase has laid the groundwork for achieving these objectives. In more detail, each project partner has contributed to the project by undertaking activities aligned with the project's core goals, including developing methodologies, frameworks, and tools to address key challenges in 6G adoption. Such activities are towards the integration of the concerns of societal and environmental perspectives with the designing, deployment, and policy formulation aspects of 6G technology as well. With this end in view, this has started exploiting the marketplace along the way. These results, up until now, comprise designing key frameworks in the context of SAT, KVIs, and KSIs. Furthermore, significant strides have been made in engaging stakeholders, mapping regional initiatives, and facilitating public dialogue to align the project's outputs with real-world needs and expectations. This section provides a comprehensive overview of these activities achieved by each project partner and their relevance to the project's exploitation and sustainability strategies (see also APPENDIX A – EXPLOITATION AND SUSTAINABILITY PLAN). More specifically:

1. **Project partner: MAR**

- Achieved Activity: Developed a methodology for mapping Member State initiatives and engaging with stakeholders to better understand and align with sustainability efforts across the European Union.
- Relevance to Exploitation: This activity supports knowledge transfer by integrating insights derived from the Corporate Sustainability Reporting Directive (CSRD). By

leveraging the directive's focus on transparency and accountability, MAR enables the project's results to align with corporate reporting requirements, increasing their appeal and adoption potential within the private sector.

- Relevance to Sustainability: The methodology contributes to streamlining the European industry's sustainability practices, leveraging the broad scope of the CSRD to ensure compliance with environmental and societal sustainability goals. This integration promotes responsible innovation and supports long-term sustainability by fostering a culture of accountability and continuous improvement.

2. **Project partner: CEL**

- Achieved Activity: Developed a framework to explore and analyse social acceptance aspects of 6G in socio-technical contexts.
- Relevance to Exploitation: Serves as a tool for SNS projects to address acceptance issues early, identifying potential concerns. The framework also benefits broader projects beyond the SNS community.
- Relevance to Sustainability: Highlights societal values important to sustainability and demonstrates their relevance within the business modelling process.

3. **Project partner: NOVA**

- Achieved Activity: Developed a 6G ontology for KVIs and KSIs.
- Relevance to Exploitation: Ensures interoperability and alignment across 6G research initiatives and facilitates pre-standardisation processes to bridge fragmented and regional perspectives for sustainable innovation. The ontology will be NOVA's point of participation in pre-standardisation activities to push for sustainability inclusion into technical standardisation goals of major standardisation organisations.
- Relevance to Sustainability: Promotes multi-stakeholder collaboration and the inclusion of societal, environmental, and economic values in the 6G pre-standardisation phase for a sustainable 6G development.

4. **Project partner: PSCE**

- Achieved Activity: Developed a framework for KSIs and facilitated dialogues on sustainability metrics and collaborative methodologies.
- Relevance to Exploitation: Improves the capacity of R&D teams and early adopters to integrate sustainability principles into 6G projects and demonstrate the beneficial impact on society that comes from using a new tool. For example, this would improve the ability of PPDR actors to encourage ICT developers to produce the solutions they need despite not having a strong market drive. It would also make it possible to better provide specifications of the technological solution according to sustainability issues, shifting business models to not treat these longer-term outcomes as those to be traded off for short-term performance or profit. The results can also inform policy recommendations and foster public-private partnerships where technology developers/PPDR organisations/policymakers collaborate to co-develop solutions that have both societal impact and commercial viability.
- Relevance to Sustainability: Supports projects in addressing, in particular, the societal aspects of sustainability, ensuring the issues that drive societal well-being and prosperity also drive innovation.

5. **Project partner: eBOS**

- Achieved Activity: eBOS has actively worked with partners to refine the KERs initially identified in the project proposal to align with partners' portfolios and market potential. Through iterative assessments, the team evaluated these results' commercialisation interest and technical feasibility, ensuring their relevance to both societal needs and market demands. eBOS led efforts to establish a continuous monitoring framework for the market, research, and societal developments related to 6G technologies. By conducting a techno-business-societal assessment, eBOS provided insights into the positioning of the project's portfolio within the competitive landscape. This activity also identified opportunities for 6G4Society's KERs, including their alignment with emerging trends, stakeholder priorities, and potential applications in key verticals.

- Relevance to Exploitation: eBOS's work has directly contributed to the project's exploitation potential by ensuring that the KERs align with market needs, stakeholder expectations, and technological trends. The refinement of these results has verified their commercialisation potential, while the continuous monitoring framework has positioned the project as a forward-looking contributor to the 6G ecosystem.
- Relevance to Sustainability: Through the development of the exploitation and sustainability plan, eBOS has laid the groundwork for ensuring the long-term impact of the project. The focus on funding opportunities, standardisation, and certification ensures that project outputs remain relevant and applicable in both commercial and societal contexts.

6. **Project partner: D4P**

- Achieved Activity 1: Engaged the public through surveys, creating materials to inform citizens about 6G technologies.
- Relevance to Exploitation: Gathered insights from citizens, enabling 6G technologies to align with societal concerns and expectations. Engaging with the public gathers valuable insights into societal concerns, fears, and expectations surrounding 6G. This understanding informs the exploitation process, ensuring that the deployment and commercialisation of 6G are socially acceptable and aligned with public interests. Effective public engagement helps mitigate risks associated with societal pushback or ethical oversights, thus enhancing the success and sustainability of 6G technologies in real-world applications.
- Relevance to Sustainability: Tackles challenges like energy consumption and equity through informed development strategies and societal and environmental sustainability goals.
- Achieved Activity 2: Established and maintained digital platforms (website, newsletter, social media), amplifying the project's dissemination by promoting the project's results, findings, and whitepapers.
- Relevance to Exploitation: Expanded the project's visibility and reach to SMEs, start-ups, and stakeholders.
- Relevance to Sustainability: Facilitated collaboration on sustainable 6G development and engaged stakeholders in societal and environmental discussions to raise awareness.

The activities achieved by the project partners up to M12 have contributed significantly to the development of frameworks, methodologies, and public engagement strategies. This ensures that exploitation efforts align with stakeholder priorities while embedding sustainability principles into 6G innovation processes. This collaborative work underscores the project's focus on inclusivity, environmental awareness, and societal value creation; thus, additional and relevant results (e.g., Citizen Survey, etc.) will be reported in the following months and at the end of the project (e.g., D4.4 "Exploitation Report v2" in M24). Additional information regarding the consortium's Exploitation and Sustainability Strategy Plan and future activities (e.g., application of the framework in the context of 6G SNS projects, further development and promotion of the Information Package, community and public engagement activities, etc.) can be found in Chapter 7 of this document.

5 6G4SOCIETY KEY-VALUE AND SUSTAINABILITY INDICATORS

As already stated, and extensively reported, D1.1 is a key foundational document within the 6G4Society project, focusing on the interplay between emerging 6G technologies and societal factors. Unlike previous generations, 6G is envisioned not merely as a technical upgrade but as a technology with transformative societal implications. The document highlights the importance of embedding societal values, sustainability, and ethical considerations into the design and deployment phases of 6G to ensure widespread acceptance and alignment with societal needs.

The primary objective of D1.1 is to explore the factors influencing societal impacts and sustainability in 6G development. The report begins by identifying the lessons learned from 5G deployment, which faced significant societal pushback over privacy, environmental impact, and health concerns. It stresses that the success of 6G will depend on its ability to balance technical performance with societal priorities. One of the ways to do this is through KVIs and KSIs. The deliverable presents a pathway towards a KSI, which is designed to ensure that 6G technologies are socially accepted, ethically designed, and environmentally sustainable. Another significant component of the report is the exploration of societal acceptance dynamics. This is done by proposing the SAT framework, which includes trust, social values, and inclusivity as critical factors in driving public support for 6G technologies. In this context, KVIs and KSIs are essential tools for ensuring that 6G technologies contribute positively to societal well-being while minimising potential risks.

In more detail, the concept of KVIs introduced in D1.1 represents a shift from traditional KPIs, which primarily focus on measuring technical attributes such as speed, latency, and reliability. In contrast, KVIs are designed to capture societal dimensions, ensuring the technology development process reflects core societal values. Therefore, the report identifies several critical KVIs, including trust, privacy, security, inclusivity, and transparency. Trust is highlighted as a fundamental value, given the widespread concerns during the 5G rollout regarding potential health risks and data privacy. Without trust, public resistance to 6G could undermine its deployment, regardless of its technical superiority. To foster trust, the document stresses the need for transparent communication about the technology's capabilities, risks, and benefits. Privacy and security are equally important KVIs, particularly with the trend of reliance on data-driven technologies. Deliverable D1.1 asserts that user data protection and secure communication must be a guarantee for public trust to be established. The report also identifies inclusivity as one of the core values, emphasising that 6G should bridge the digital divide instead of widening it. Ensuring equitable access to 6G technologies across different socio-economic groups and geographic regions is crucial for fostering widespread adoption and societal benefit.

The introduction of KSIs in D1.1 responds to growing concerns about the environmental impact of advanced communication technologies. While 5G offered improvements in connectivity and performance, its deployment also led to increased energy consumption and electronic waste. Recognising these challenges, D1.1 advocates a sustainability-centric approach to 6G development. Key sustainability metrics proposed in the report include energy efficiency, carbon footprint reduction, resource optimisation, and digital inclusion. Energy efficiency is particularly emphasised, as the increased demand for connectivity and data processing in 6G networks could lead to a significant rise in energy consumption if not properly managed. The document recommends incorporating energy-saving technologies and renewable energy sources to mitigate this impact. In addition to environmental factors, D1.1 stresses the importance of social sustainability. Digital inclusion is framed as a critical KSI, ensuring that 6G technologies are accessible to underserved communities. By promoting equitable access, 6G can drive societal progress, reducing inequalities and fostering greater social cohesion.

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That aside, the SAT framework, proposed in D1.1, is a leading methodology designed to cause societal acceptance of 6G technologies. Technical excellence in this regard would be insufficient to create a more widely adopted environment for emerging technologies. Rather, it is a public perception of the trust, values, and norms of the society that ultimately dictate whether these innovations, including 6G, will be welcomed or resisted. This framework draws on lessons from the 5G deployment, which, although at a more advanced technological level, nonetheless had to confront unusually widespread public resistance on grounds of privacy, security, health risks, and environmental impact. One of the cornerstones of the SAT framework is trustworthiness and transparency. It is stated that trust will be one of the main drivers for public acceptance, and further, communication about transparency will be necessary to create and maintain trust. One of the key criticisms of 5G was the perceived opacity in its rollout, where many communities felt inadequately informed about its benefits and risks. To avoid similar issues with 6G, the SAT framework advocates for proactive engagement with the public, ensuring that information about the technology's potential impacts—whether positive or negative—is communicated clearly and accessibly. Transparency is not only a means of dispelling misinformation but also a way to create a sense of co-ownership and involvement among stakeholders. The second critical dimension of the SAT framework is inclusivity and engagement. D1.1 emphasises that societal acceptance cannot be achieved without involving a wide array of stakeholders in the technology development process. These stakeholders include policymakers, industry leaders, researchers, civil society organisations, and, most importantly, the general public. This means that inclusivity goes beyond mere token consultation into genuine participation, making communities have voices in decisions that affect their lives. By working with a participatory approach, the SAT framework tries to bridge the gap between technologists and society to make sure that 6G technologies would adequately satisfy the various needs and values attributed to all those societal groups. Such engagement is very important in pre-empting conflicts as well as creating goodwill for innovations.

Another key component of the SAT framework is its focus on social values and ethical considerations. To gain acceptance, the report stresses that technology must align with widely held societal values, such as privacy, equity, and sustainability. If a technology is perceived as conflicting with these values, it will likely face resistance, regardless of its technical benefits. Ethical considerations are particularly relevant in the context of 6G, which is expected to rely heavily on data-driven technologies and AI. The SAT framework calls for the integration of ethical guidelines into the development process to ensure that issues such as data sovereignty, fairness, and bias are addressed from the outset. By embedding ethical principles into 6G's design, developers can foster greater trust and acceptance among users. The balance between the perceived benefits and risks is something stressed in the SAT framework even further. More generally, D1.1 held that societal acceptance was a response to cost-benefit analysis executed by individuals or societies. A particular technology should, therefore, be embraced if one believes its respective advantages, connectivity or economic growth are greater important than their disadvantages. Whereas, if the risks, be those invasions of privacy or environmental decline, appear to be too great, resistance may follow. It says that in order to secure better public perception, the stakeholders must underscore a show and tell of real benefits to society, such as improved health, education, and environmental protection that could improve quality of life.

Lastly, the framework emphasises the critical role of governance and regulation in shaping societal acceptance. D1.1 points out that weak or reactive governance was one of the factors contributing to the controversies surrounding 5G. In contrast, the SAT framework advocates for proactive, anticipatory governance models that address societal concerns before they escalate into conflicts. This involves developing robust regulatory frameworks safeguarding societal interests while enabling technological innovation. The report recommends continuous dialogue between regulators, industry stakeholders, and the public to ensure that governance mechanisms remain responsive to evolving societal expectations and technological advancements. The SAT framework in D1.1 presents an integrated approach to societal challenges of 6G development: trust, inclusiveness, ethics, balance between benefit and risk, and governance will give a route to achieve high levels of societal acceptance and will make the technologies technically advanced but socially apt. The framework highlights that societal acceptance is not a point in time but rather a process that includes continuous engagement, transparency, and adaptability to shifting dynamics within society. This framework, if implemented successfully, can reduce public resistance, build trust, and create a path for seamless adoption of 6G technologies. Further and more detailed information is provided in D1.1.

The above-mentioned must be aligned with the UN's SDGs. The 6G-IA Position Paper [48] underscores that sustainability encompasses environmental, societal, and economic dimensions, which are crucial for the holistic advancement of 6G networks. The paper calls for energy-efficient network components and systems that can reduce the ecological footprint of 6G infrastructure in the context of environmental sustainability. This directly contributes to SDG 13: Climate Action, since the greenhouse gas emissions due to digital technologies are intended to be reduced. The emphasis on sustainable microelectronics and materials further supports SDG 12: Responsible Consumption and Production in enhancing resource efficiency and reducing waste. On societal sustainability, the position paper emphasises that 6G networks should be inclusive and accessible. In this regard, the development of 6G aligns with SDG 10: Reduced Inequality and SDG 9: Industry, Innovation, and Infrastructure through access to advanced communication services by different populations, especially those in unserved regions. In addition, security and privacy features within the framework of technology allow for the facilitation of SDG 16: Peace, Justice, and Strong Institutions by building trust and protecting users' rights in the digital space. Under economic sustainability, it is proposed to develop open smart network solutions and to provide interoperability between cloud infrastructures. These will incentivise innovation, competitiveness, and technological sovereignty, which in turn will help contribute to achieving SDG 8: Decent Work and Economic Growth. By fostering a robust and secure digital economy, the approach of 6G-IA will also contribute to SDG 17: Partnerships for the Goals by fostering collaboration among many different stakeholders in order to achieve common objectives in sustainable development. Therefore, the 6G-IA Position Paper has developed a broad strategy for embedding the United Nations SDGs into research, development, and deployment activities of 6G technologies so that future networks are supportive of sustainable development in a global context.

In fact, the Hexa-X-II D1.1 entitled "Environmental, Social and Economic Drivers and Goals for 6G," [49] closely connects to the theme of our past discussion on integrating sustainability into 6G development. This report makes it quite explicit that from the inception of the 6G system design, one has to take environmental, social, and economic sustainability into consideration so that emerging technologies should be energy-efficient, inclusive, secure, and capable of enabling new business opportunities. That is, the report insists that the development of 6G technologies should have a minimal footprint on the environment; thus, energy efficiency and preservation of natural resources will have to be a concern. This view falls in line with our earlier discussions on the need for sustainable practices in the deployment of next-generation networks. Hexa-X-II also stresses social sustainability through the promotion of inclusivity and trustworthiness in 6G technologies. That will also mean that the 6G benefits are for everyone, and for every community, which resonates with the earlier messages about inclusivity and confidence in technology adoption by the general public. The report addresses economic sustainability, too, underlining long-term economic growth within environmental and social limits. This includes the ability to enable new business opportunities, while the development of the economy does not compromise the possibility to satisfy the needs of future generations, echoing our earlier discussion on balancing economic growth with sustainability. It also introduces "Sustainability Guidelines for 6G Design," to serve as a baseline for developing a sustainable, inclusive, and trustworthy 6G platform. Guidelines set up in such a way as to affect the whole 6G ecosystem, ensuring that any action of 6G development will consider sustainability.

Additionally, the "European Vision for the 6G Network Ecosystem" White Paper [30] has made it crystal clear that societal and sustainability considerations are an integral part of the development process of the 6G technologies. Section 1.1.3, "Societal & Sustainability Aspects," underlines that 6G should be environmentally concerned, socially inclusive, and economically viable. It underlines that 6G will play a very important role in the European Green Deal goals of climate neutrality by 2050 and contributes, more generally, to the UN SDGs. It calls for the design of the 6G systems in such a way that it is energy-efficient, scalable, and affordable; hence, technological advances create benefits for all parts of society, not increasing the existing gaps. Section 6.4, "Sustainability Roadmap", provides a strategic direction on how sustainability can be integrated into the 6G development process. It calls for integrating sustainability metrics, such as Key Value Indicators and KVIs, into research and development in order for 6G technologies to meet technical performance targets with positive societal and environmental impact. The roadmap calls for collaboration on the part of policymakers, industry leaders, and academia in order to create frameworks that promote energy efficiency, reduce carbon footprints, and engender sustainable best practices throughout the 6G ecosystem. The roadmap would thus make 6G an enabler of transformative connectivity toward a much more sustainable future and one with equity.

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6 STANDARDISATION AND CERTIFICATION ROADMAP

As the development of 6G technology is still in its formative stages, standardisation plays a pivotal role in shaping its evolution. While 6G standards do not officially exist, the groundwork for their development is actively underway through research, pre-standardisation activities, and contributions to formal standardisation efforts. These steps are essential to establish a unified framework that ensures interoperability, efficiency, and sustainability across regional and global 6G deployments. Pre-standardisation activities lay the foundation for formal standards creation efforts by responsible organisations. The pre-standardisation phase for 6G within the SNS framework is expected to start before 2026 with the initiation of the Call 3 projects. This phase will focus on foundational work like taxonomy development, alignment of research outputs, and early coordination with standardisation bodies. By 2026, the pre-standardisation efforts will advance toward more concrete contributions, paving the way for formal standardisation activities in preparation for 6G's anticipated deployment by 2030. This timeline was adopted to allow enough time for research to address interoperability, sustainability, and societal needs comprehensively.

Aligning with the activities and timelines of leading organisations such as SNS JU, 6G-IA, ITU, and 3GPP, we are currently in the pre-standardisation phase of 6G development, that focuses on research coordination, creating unified frameworks and taxonomies, proactively contributing to global standardisation efforts and pre-standardisation workshops. The ITU's IMT-2030 process establishes global standards for 6G, enabling access to internationally recognised frequency bands and supporting a global commercial ecosystem. Between 2024 and 2026, ITU will define performance requirements and evaluation methodologies, with technology submissions, including 3GPP evaluations, occurring from 2027 to 2029. The final designation of IMT-2030 is expected by 2030, aligning with the timeline for global 6G deployment [50].

The 3GPP timeline for 6G development starts with the work on Release 19 in 2024, focusing on use cases and requirements, progressing through technical studies, and resulting in implementable specifications in Release 21 by the end of 2028. Key principles for 6G include seamless 5G-to-6G migration, global standardisation, energy efficiency, enhanced support for AI/ML, and wide-spectrum sharing. In June 2026 at the latest, 3GPP will decide the duration of the Release 21 work item and, hence, the date for the availability of the first versions of 6G specifications [51].

5G-Advanced is the intermediate phase of 5G, including Release 18 and Release 19. It introduces key innovations to bridge the gap between today's 5G capabilities and the future vision of 6G [52]. These include deeper integration of AI into the network, allowing for more precise positioning technologies and overall performance and efficiency of the network. These developments are not only technological but have deep implications for society. However, perhaps the most revolutionary of all the innovations coming with 5G-Advanced is integrating Native AI directly into the network architecture. This makes the network much smarter and adaptive, using AI to analyse data in real time and optimise operations. With such capabilities, predictive maintenance, efficient resource allocation, and dynamic adjustments according to network demands are enabled. For instance, it would mean that in the healthcare sector, connectivity will be better for telemedicine and remote surgeries, while in transportation, it will be about smart mobility systems through seamless and reliable communication between connected vehicles. Another major development is centimetre-level positioning technology, which provides location accuracy. This has huge implications for industries such as logistics, manufacturing, and autonomous transportation. For example, precision positioning can improve the safety and reliability of autonomous vehicles, enabling them to navigate complex environments with greater accuracy. It enables precision farming in agriculture for better yields with optimised use of basic resources such as water and fertilisers, contributing less harm to the environment. The new uses opened with such developments also concern augmented and virtual reality, value-added entertainment, and professional training. 5G-Advanced: Implications for Society The inclusion of AI and precision technologies within these releases gives way to very important challenges, such as narrowing the gap in digital access and the extension of services related to vital assets toward sustainability. The enhancement in network operation cuts energy costs, hence enabling one toward environment-related policies and goals; above all, communities would be given empowerment through being reliably connected at good speeds and facilitating economic gains into better lifestyles. In all, 5G-Advanced is an essential evolution of 5G, considerably enhancing its capabilities in Releases 18 and 19: from Native AI to precise positioning, these are not only technological advancements but also social ones, enabling smarter, more efficient, and fairer solutions in many aspects of life. The innovations set the stage for what could be possible with 6G. Qualcomm's presentation offers much deeper insight into all of these developments and more on their broader ramifications.

Taking the above-mentioned into account, we understand that coordination between international standardisation bodies, national initiatives, and research projects is critical in fostering a robust and cohesive set of standards. The role of SNS-JU's collaborative approach not only bridges regional and global perspectives but also addresses interdisciplinary challenges, ultimately ensuring that 6G technology aligns with societal, technical, and environmental objectives. This will allow for the introduction of the first commercial 6G systems to the market by 2030 [53]. Thus, against this transformative scenario of 6G technologies, a fully integrated framework that meets technical development with considerations toward sustainability and acceptance by society is required. The 6G4Society project will contribute to the pre-standardisation process by developing this gap in existing frameworks and by fostering a shared ontology for Key Values (KVs) and KVIs toward consistency, interoperability, and actionable frameworks that help merge societal values into technical standards.

6.1 CURRENT LANDSCAPE OF 6G STANDARDISATION

Regarding the current landscape, and despite the strong frameworks put in place for previous generations of telecommunication networks, some gaps still remain in the area of standardisation and certification.

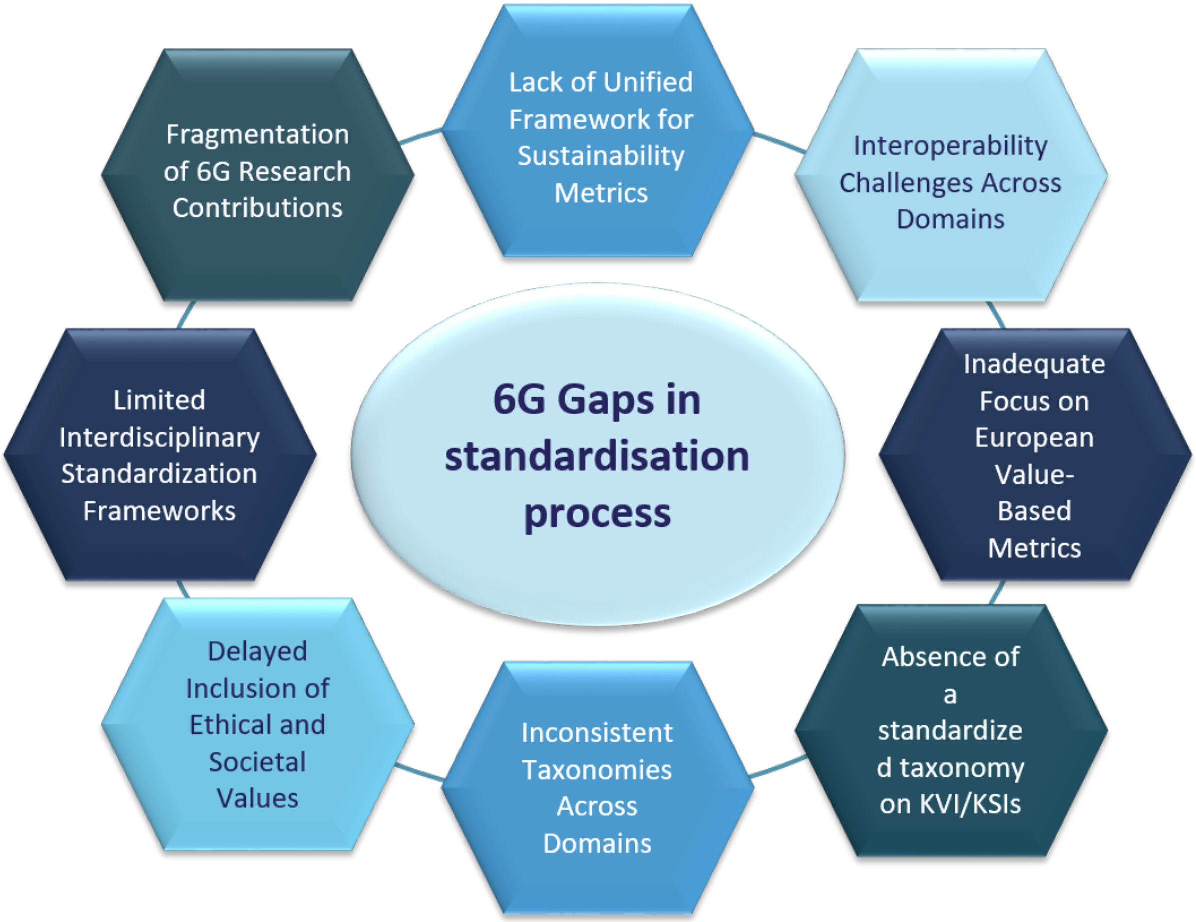

FIGURE 26: IDENTIFIED GAPS IN THE STANDARDISATION PROCESS

Various research projects and organisations prepare pre-standardisation contributions, but because these activities are badly coordinated and integrated, much of this work is either inefficiently duplicated or repeatedly done with incompatible ways of considering sustainability, interoperability, and societal values. The path to bridging these gaps is important in establishing cohesive, globally accepted standards that reflect the diverse needs of stakeholders while fostering innovation. For example, while European projects such as 6G-IA and SNS JU focus on sustainability and societal values, other global initiatives, including those in North America and Asia, place greater emphasis on technical performance metrics such as spectral efficiency and latency. This lack of coordination leads to the fact that for most of the critical concepts, different definitions are used, making their integration into global standards cumbersome. For example, ETSI SAREF ontology, focused on semantic interoperability for IoT, is mostly developed independently from the vertical-specific contributions in healthcare or transportation sectors, which reduces cross-sector harmonisation. Currently, various taxonomies exist, which address different architectural aspects of 6G and application domains, but most of them are sectoral, missing a common ontology that would enable consistent interpretation across projects and standardisation bodies. In the same direction, the pre-standardisation work of 3GPP in Release 19 is focused on the requirements of use cases that are not always aligned with parallel research coming from either academic or industrial collaborations.

Another important gap in the 6G standardisation landscape is the delayed inclusion of ethical and societal values, which stems from a longstanding focus on technical and performance-based metrics, such as spectral efficiency, latency, and network reliability, which often overshadow broader societal considerations. This imbalance has resulted in an insufficient emphasis on critical issues like privacy, inclusivity, and trustworthiness during the early stages of standardisation. For example, while initiatives like 3GPP and ITU focus on technical frameworks, they often integrate ethical and societal concerns only after technological foundations are set, limiting their impact. Furthermore, fragmented global efforts exacerbate this delay, with regions prioritising different aspects of 6G development. European projects, such as those led by the 6G-IA and SNS JU, emphasise sustainability and societal values, while other regions may focus primarily on economic or technical scalability. This misalignment delays the establishment of unified global standards. Without early incorporation of ethical considerations, the resulting standards risk being reactive rather than proactive, addressing issues only after public trust has been compromised. To overcome this, unified frameworks and interdisciplinary collaboration between technical and social science communities are essential to embedding societal values into standardisation processes from the outset. A successful example is the Organisation for Economic Co-operation and Development (OECD) AI Principles, which is a set of guidelines that aim to ensure that AI systems benefit society, respect human rights, and are aligned with democratic values. They are the first intergovernmental standards on AI and have been endorsed by 38 OECD member countries and several non-member countries [54].

Development of the standards of 6G also faces big challenges because of limited interdisciplinary standardisation frameworks that cannot fully integrate technical, social, and ethical dimensions. This stems from the absence of close cooperation between technical standardisation bodies and interdisciplinary stakeholders, such as social scientists, ethics experts, and environmental experts. For example, while initiatives such as the OECD AI Principles place a strong emphasis on ethical AI and social wellbeing, they are not systematically integrated into early standardisation processes, which has contributed to fragmentation. The absence of such frameworks also heightens inconsistencies in how KVI and, in turn, sustainability indicators are defined and implemented across sectors and regions. This seriously limits the possibility of addressing critical challenges, such as the ethical implications of AI-native 6G networks or the environmental impacts of ultra-dense deployment. Further, a more integrated approach will be required in cases where 6G standards are to be technologically robust, ethically sound, socially inclusive, and environmentally sustainable.

A notable example of a framework that integrates standardisation with societal perspectives is the Institute of Electrical and Electronics Engineers (IEEE) Global Initiative on Ethics of Autonomous and Intelligent Systems, which provides ethical guidelines for the development and deployment of autonomous systems, including AI and next-generation networks. It offers frameworks such as the Ethically Aligned Design (EAD) guidelines, which suggest actionable steps to incorporate ethics into technical standards. This framework provides comprehensive guidelines to ensure that autonomous and intelligent systems (A/IS), including AI technologies, are designed and implemented in ways that prioritise human well-being, ethical principles, and societal values. As a matter of fact, EAD has informed the development of several IEEE P7000 series standards, which address specific ethical issues, such as transparency of autonomous systems (P7001) and algorithmic bias considerations (P7003).

The development of 6G, especially in the sustainability-related aspects, has not been presented under a single framework for the measurement metrics. Consequently, the unsustainable environmental and social consequences do not allow consistency in measurement and action to be effectively achieved during the standardisation process for 6G technologies. While much attention has been focused on sustainability, for example, by initiatives like ITU-T Focus Groups on Environmental Efficiency and the European Green Deal- no widely accepted suite of sustainability metrics for 6G technologies exists. Moreover, important concept terminologies such as network resilience, security, privacy, and energy efficiency are defined differently across projects and industries. This is also very fragmented, with multiple and often incompatible ways to measure metrics like energy efficiency, carbon footprint, or resource optimisation. For instance, some projects might focus on the energy consumption of dense networks, while others may look into material recyclability or circular economy principles. These discrepancies stand in the way of the creation of coherent global standards and make interoperability more complex.

While Europe underlined unique values through initiatives such as the European Green Deal and Digital Decade Compass, these priorities are presently not considered part of the worldwide processes for standardising 6G. As touched upon above, KVIs on inclusiveness, ethical AI, and environmental impact are usually pushed to the side compared to traditional technical metrics like latency, throughput, and spectral efficiency within globally convened frameworks led by 3GPP and ITU. In so doing, this misalignment could relegate European values in the race to define global 6G standards, with a consequent reduction of the region's influence in the shaping of new technology. Otherwise, if the metrics that underline societal impact are not embedded in the 6G frameworks, it will probably go through the same process that 5G went through: the adoption of technology taking a back seat due to low public trust and alignment with society. In this respect, proactive attitudes of European stakeholders, like 6G-IA and SNS, would be required in order to position European value-based metrics within pre-standardization phases.

The interoperability challenges between domains stand in the way, most significantly, in developing integrated and operational schemes of 6G systems conveniently, as also expected to serve these diverse segments. Verticals that include healthcare, agriculture, and transport will develop the needed technological solutions mostly or entirely on premises without compatibility with the various respective sectors or in line with the general standards of 6G. Health systems may have low latency for remote surgery, while agriculture would aim at IoT-enabled monitoring; many of these systems do not have generally accepted integration frameworks. Fragmented approaches to the elaboration and deployment of standards at different levels create systems that cannot easily talk to one another, thus limiting the potential of 6G for cross-domain solutions. For instance, although frameworks like ETSI SAREF tackle interoperability at the IoT environments level, the sector-specific nature of their development often restricts their broader application in multi-domain 6G use cases. This not only creates significant delays in the deployment of 6G technologies but also more complex and costly operations for businesses implementing multi-domain solutions.

There is a distinct lack of integration between technical and societal indicators. Many 6G projects focus exclusively on technical Key Performance Indicators (KPIs) like latency, spectral efficiency, and coverage without integrating societal KVIs such as trustworthiness, inclusivity, and sustainability. For instance, a project may propose high-density deployments to enhance connectivity but overlook their environmental impact. This approach prevents a holistic view of 6G’s impact, weakening its ability to meet global societal and environmental goals.

6.2 6G4SOCIETY KEY VALUES AND KEY VALUE INDICATORS ONTOLOGY

Taxonomies can be provided both at technical and non-technical levels for the same conceptual domain by offering a systematic structuring, categorisation, and meaning of complex information. These technical taxonomies allow the consistent, hierarchical definition of concepts that will be analysed and interpreted by various stakeholders in the context of 6G. Non-technical taxonomies, such as those addressing societal or ethical aspects and considerations, will bridge the gap between technical developments and societal expectations, thus building inclusiveness and trust. Taxonomies allow for interoperability, decision-making, and even the basis for robust, globally harmonised standards by creating a common vocabulary and aligning fragmented research contributions.

Various projects tend to offer disjointed and sometimes conflicting definitions of KVIs, leading to a lack of cohesion and uniformity in their interpretation and application across the 6G landscape. A core example is that different projects define "sustainability" in varying ways. For instance, Project A may emphasise energy efficiency as the primary metric for sustainability. Project B could focus on the recyclability of materials or carbon footprint. Even given the same KVI, they may provide different definitions. Project A could define “energy efficiency” as the total energy consumed by the network infrastructure per unit of data transmitted (measured by Joules/bit). In contrast, for project B, “energy efficiency” refers to the overall reduction in carbon footprint by integrating renewable energy sources and optimising energy usage across the entire 6G ecosystem, including devices, networks, and edge computing nodes, provided as a potential metric the carbon emissions avoided (in tons). These inconsistent definitions hinder the ability to create a cohesive standard for evaluating the sustainability of 6G technologies. Without a unified vocabulary of these values, these fragmented definitions create barriers to interoperability and, subsequently, to standardisation inputs.

An important contribution of the 6G4Society project is the attempt to create a unified and comprehensive taxonomy of all identified Key Values and their respective KVIs, gathered from SNS JU 6G-related projects, expressed in ontology format. By defining clear relationships between sustainability metrics, performance indicators, and deployment scenarios, this ontology will ensure interoperability between diverse research projects. This interoperability is essential for aligning their contributions to major standardisation bodies, where consistency and cohesiveness are prerequisites for impactful outputs. These organisations depend on tangible, well-defined metrics to develop globally applicable standards. Moreover, a shared ontology enables researchers and standardisation bodies to bridge regional and global perspectives, aligning differing priorities and ensuring that key values like trust, inclusivity, and sustainability are universally recognised and implemented. It is meant to serve as a bridge, ensuring that research findings are not lost in translation and are seamlessly integrated into the technical and societal frameworks of 6G.

6.2.1 DEFINITIONS

Ontology creation follows the general concept of semantic modelling. The semantic data model is a method of structuring data in order to represent it in a specific logical way. It is a conceptual data model that includes semantic information that adds a basic meaning to the data and the relationships that lie between them. This approach to data modelling and data organization contributes to easy development of application programs and also easy maintenance of data consistency when data is updated.

In computer and information science, ontology is a technical term that refers to a tool or framework created to facilitate the representation and organisation of knowledge. One of the most well-known definitions was presented by Studer and colleagues [55]: “An ontology is a formal, explicit specification of a shared conceptualisation”. The definition explains ontology as an approach of an abstract model of some incident in the world with relevant concepts of that incident. Concepts and relationships are defined in an accurate way. The ontology should be machine-readable as well as generally accepted.

6.2.2 ONTOLOGY COMPONENTS

Gruber [56], proposed modelling ontologies using frames and first order logic. He identified five kinds of components: classes, relations, functions, formal axioms and instances.

Classes represent broad concepts or categories in the domain. For instance, in the healthcare domain, concepts can be patients (adults, children, elderly), medical facilities (hospital, clinic, laboratory), and medical procedures (surgery, diagnostic test, physical therapy). Classes in ontology are usually organised in taxonomies through which inheritance mechanisms can be applied. Classes can represent abstract concepts (intentions, beliefs, feelings, etc.) or specific concepts (people, computers, tables, etc.).

Relations define connections or associations between these concepts, such as *Treated-By*, which links a patient to a doctor. They are formally defined as any subset of a product of n sets: $R \subset C1 \times C2 \times ... \times Cn$. Ontologies usually contain binary relations. The first argument is known as the domain of the relation, and the second argument is the range. For instance, the binary relation Subclass-Of is used to build the class taxonomy. Examples of classifications are Pediatrician as a Subclass-Of a Doctor.

Functions, a special relation type, yield unique outputs for specific inputs. This is usually expressed as: $F: C1 \times C2 \times ... \times Cn\text{-}1 \Rightarrow Cn$. For example, the function *Prescribes*, which maps a doctor to a specific medication (e.g., Dr. Smith Prescribes Ibuprofen for Patient A), or *BMI*, which calculates the body mass index of a patient given their weight and height (e.g., BMI (Weight, Height) ⇒ 25.4).

Formal Axioms are statements always assumed to be accurate and are used to represent knowledge that cannot be formally defined by the other components and ensure consistency of the ontology. Formal axioms are very useful for inferring new knowledge. For example, an axiom might state that a patient cannot be treated in two different hospitals simultaneously or that if a procedure is classified as a surgery, it requires an operating room and a surgeon.

Instances represent elements or individuals within the ontology. They form the ground or atomic level of the ontology. An instance of the healthcare domain concept is a medical procedure, such as an appendectomy performed on Jane Smith by Dr. Thompson on March 15, 2023.

6.2.3 METHODOLOGICAL FRAMEWORK

A strong advantage regarding ontologies is that they are independent of lower-level data models and used for integrating heterogeneous databases, enabling interoperability among disparate systems, and specifying interfaces to independent, knowledge-based services. In the technology stack of the Semantic Web standards, ontologies are called out as a definitive layer. A multitude of standard languages and a variety of tools have been built for creating and working with ontologies.

Ontology languages are formal languages designed for building and structuring ontologies. They enable the representation of knowledge within specific domains and often include reasoning capabilities to facilitate the processing and inference of that knowledge. The choice of the appropriate ontology language is a crucial step in the ontology development process. In this respect, a variety of ontology implementation languages and general Knowledge Representation KR systems can be used. With a view to choosing the most suitable language, it is necessary to identify the required level of expressiveness and reasoning first so that the chosen language can meet the requirements. Some of the traditional ontology languages are Ontolingua and KIF, LOOM, OKBC, OCML, and FLogic. Most of these languages are powerful in certain contexts but usually suffer from limited interoperability, scalability, and integration with the web. Generally, they are domain-specific, complicated, and not originally designed to fit into a distributed, web-based environment-the required paradigm for state-of-the-art ontology applications. Consequently, markup-based languages are favoured in modern ontology development due to the demanding needs of web-based interoperability and scalability. These languages also align with widely adopted standards like RDF and SPARQL and are supported by robust tools for editing, reasoning, and validation. The state-of-the-art ontology markup languages include languages like SHOE, XOL, RDF and RDF Schema, OIL, DAML+OIL, OWL, OWL 2 and SPARQL.

The OWL 2 Web Ontology Language (OWL 2), which is selected to be used for the 6G4Society ontology purposes, is a language designed for the Semantic Web that provides a formally defined framework for representing knowledge. It is an extension and refinement of the original OWL language, developed by the W3C Web Ontology Working Group. OWL 2 maintains a similar structure to OWL 1 but introduces new features, including support for richer datatypes, data ranges, keys, property chains, and cardinality restrictions. OWL 2 ontologies consist of classes, properties, individuals, and data values and are stored as documents for the Semantic Web. They integrate seamlessly with information written in RDF and are primarily exchanged as RDF documents, making them highly compatible with other Semantic Web technologies.

In order to ease the task of building ontologies and implementing them in ontology languages, a lot of tools and building environments were created. Some interfaces help users in the ontology development process by performing some of the main activities, such as conceptualisation, implementation, consistency checking and documentation. The common environments for the creation of ontologies include Protégé, Open Semantic Framework, Anzo, Vocol, and Mobi tools. Protégé was chosen as the tool of choice for KVI ontology creation because of its strong features, ease of use, and wide adoption in the ontology engineering community. Protégé provides a user-friendly, extensible platform for designing, visualising, and managing ontologies. It will be able to support ontology development using OWL, RDF, and other Semantic Web standards; it will be versatile in creating complex, scalable ontologies. It offers integrated reasoning tools, such as HermiT and FaCT++, that enable users to check the logical consistency of an ontology, infer new knowledge, or find logical errors. Overall, it is a reliable and flexible choice for ontology creation, especially when following Semantic Web standards and handling complex data relationships arising during the traversal of the 6G value landscape.

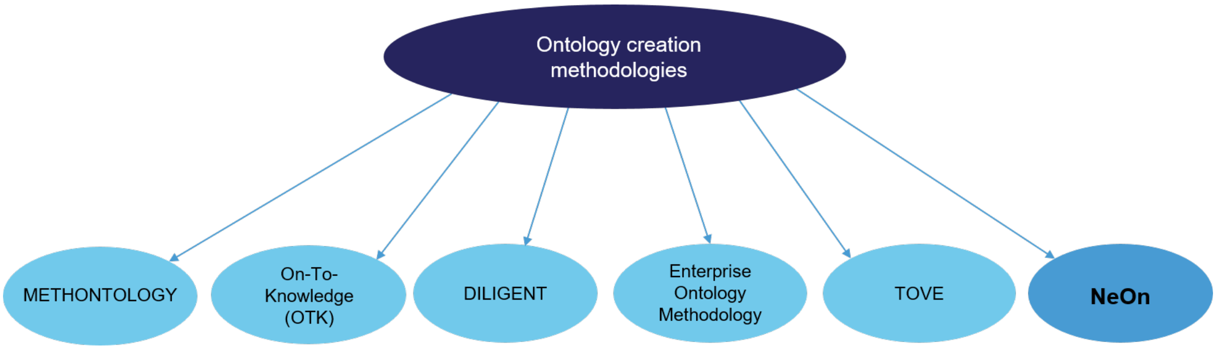

FIGURE 27: ONTOLOGY CREATION METHODOLOGIES

Ontology creation methodologies are structured approaches to designing, developing, and implementing ontologies. These methodologies drive the process of capturing domain knowledge, defining key concepts, relationships, and constraints, and organising them into a structured framework. They usually comprise the following steps: requirements analysis, conceptualisation, formalisation, implementation, and evaluation. Well-known methodologies include Methontology, On-To-Knowledge (OTK), DILIGENT, and NeOn (Figure 27), which provide structured processes and tools for knowledge acquisition, modular ontology development, and collaborative ontology engineering.

The *NeOn methodology* [57] was developed as part of the NeOn Project (2006 to 2010), a research initiative funded by the European Union's Sixth Framework Programme (FP6). It was designed to address the challenges of creating and managing networked ontologies in dynamic, distributed, and collaborative environments. It is particularly suited for collaborative and modular ontology development, emphasising flexibility, reusability, scalability, and integration, which makes it ideal for complex, evolving domains like 6G networks.

This methodology provides the ability to manage multiple interconnected ontologies within a specific context, supporting their collaborative creation, dynamic evolution, and constant adaptation. It is a scenario-based approach, and as such, NeOn addresses various aspects of the ontology development process, including the reuse and iterative refinement of networked ontologies. In distributed environments, knowledge contributions are made by diverse participants, such as domain experts and ontology practitioners, at different stages of development. This methodology has been applied to construct ontology networks across various domains and by individuals with a wide range of expertise.

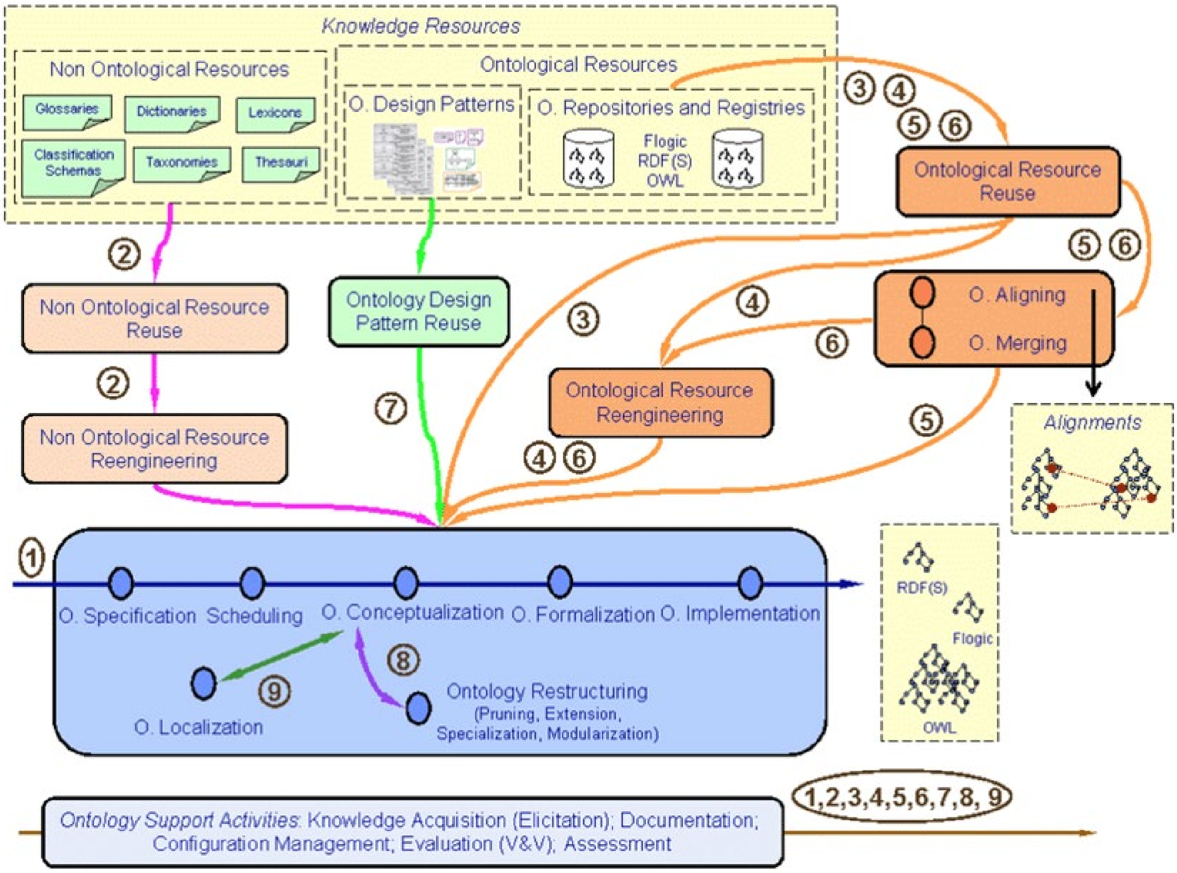

FIGURE 28: SET OF NINE SCENARIOS FOR BUILDING ONTOLOGY NETWORKS WITH THE NEON METHODOLOGY

The NeOn Methodology proposes a variety of different pathways to develop ontologies. These pathways are classified by nine proposed scenarios that cover the most common needs during the ontology design phase. The aforementioned nine scenarios (Figure 28) for ontology and ontology network building are the following:

<u>Scenario 1</u>: *From Specification to Implementation* covers the basic case of ontology development from scratch without any reuse of previous knowledge.

<u>Scenario 2</u>: *Reusing and re-engineering non-ontological resources* unfolds those cases where non-ontological resources were analysed and used in order to build the new ontology.

<u>Scenario 3</u>: *Reusing ontological resources* is about reusing ready ontological resources.

<u>Scenario 4</u>: *Reusing and re-engineering ontological resources* refers not only in ontological resources reuse, but in the re-engineering of these resources.

<u>Scenario 5</u>: *Reusing and merging ontological resources* covers the case in which the developers choose more than one ontological resources to use.

<u>Scenario 6</u>: *Reusing, merging, and re-engineering ontological resources* covers the case that developers not only choose and merge ontological resources but also re-engineer them.

Scenario 7: *Reusing ontology design patterns* is related to cases where developers access repositories in order to reuse design patterns.

Scenario 8: *Restructuring ontological resources* refers to cases where developers restructure the ontological resources to be integrated into the developed ontology network.

Scenario 9: *Localising ontological resources*. Here the ontology developers adapt an ontology to other languages and create a multilingual ontology.

Except for the above scenarios, the NeOn Glossary of processes and activities is also provided by NeOn methodology. It is a structured guide developed as part of the methodology that serves as a reference for practitioners, ensuring consistency and clarity to standardise the terminology and describe the processes and activities involved in ontology engineering. This glossary identifies and defines the processes and activities involved in ontology's construction. It tries to address the lack of a standard in Ontology Engineering.

As depicted in the previous Figure and from the aforementioned brief analysis of nine scenarios for building ontologies, Scenario 2 is the one which is completely related to 6G4Society KV/KVI Ontology's purposes and specifications. It was chosen because it provides a systematic approach to leveraging existing non-ontological resources, such as structured knowledge from multiple SNS JU projects, questionnaire outcomes, glossaries, and other domain knowledge artefacts, to create ontologies. This scenario aligns well with the 6G value ecosystem, where existing resources contain valuable domain knowledge but are not yet formalised as ontologies.

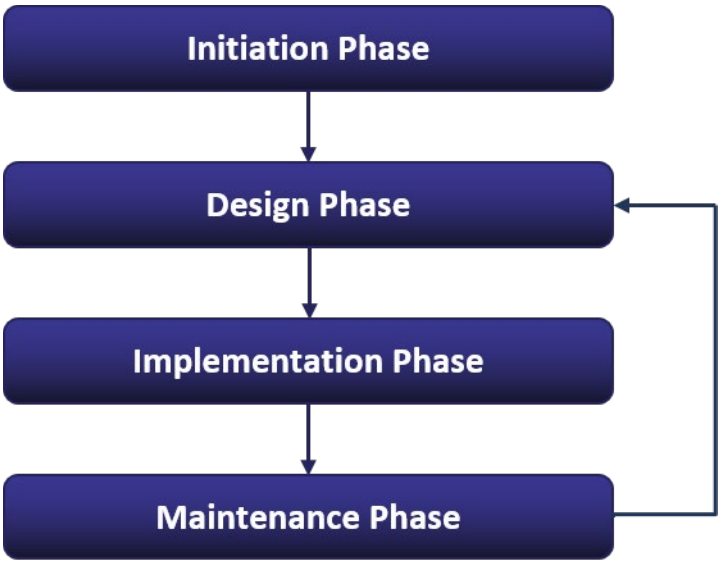

FIGURE 29: WATERFALL ONTOLOGY NETWORK LIFE CYCLE MODEL

Unlike traditional methodologies, NeOn is lifecycle-oriented, addressing activities such as ontology reuse, reengineering, merging, alignment, and modularisation. The ontology network life cycle model defines, in an abstract way, how to develop an ontology network project, in other words, how to organise the processes and activities of the NeOn Glossary into phases or stages. For the purposes of KV/KVI Ontology, the waterfall ontology network life cycle model has been selected. It is the simplest model which relies upon the assumption that the requirements are completely known, without ambiguities and unchangeable at the beginning of the ontology network development. Scenario 2 shows that we are not directly reusing existing ontological resources but extracting knowledge from non-ontological sources and transforming that knowledge into a new ontology. The waterfall model assumes that the project requirements understood as a 6G KVI organisation, do not need additional reuse or merging phases. It starts by specifying the ontology requirements and defining the purpose, scope, and goals of the project. This is followed by ontology design, whereby new ontologies are created or existing ones extended using modular principles formalised in ontology languages such as OWL or RDF. Implementation: This stage involves transforming the conceptual design of the ontology into a formal machine-readable representation using ontological languages, such as OWL or RDF. Evaluation: This forms an intermediary critical step wherein the quality of the ontology is validated for its consistency and adherence to specified requirements. Last but not least, NeOn offers the facilities needed to perform iterative maintenance and evolution, allowing for refining ontologies with evolving knowledge and context. More concretely, in the context of Scenario 2, ontology developers have to execute, during the design phase:

1. Search for Non-Ontological Resources: Identify and collect non-ontological resources (NORs) relevant to the ontology's domain.

2. Assess and Reuse Candidate Non-Ontological Resources: the process of choosing the most suitable non-ontological resources for the development of ontologies, based on the ontology requirements specification document (ORSD):

Task 1. Extract Lexical Entries: Use terminology extraction tools to gather terms and concepts from each resource.

Task 2. Calculate Precision: Measure the overlap between extracted terms and the terms defined in the ORSD.

Task 3. Calculate Coverage: Assess how well the resource's content covers the expected domain as defined by the ORSD.

Task 4. Evaluate Consensus: Consult domain experts to verify whether the terminology aligns with community standards and conventions.

Task 5. Build an Assessment Table: Compile precision, coverage, and consensus results into a table to rank resource suitability.

3. Select the **Most Suitable Non-Ontological Resources** for reengineering based on the assessment table. Finalise a subset of NORs that will be transformed into ontology components.

4. Reverse Engineer the Selected Non-Ontological Resources:

Task 1. Examine the structure, data model, and semantics of each resource.

Task 2. Represent the components of the resource at different abstraction levels (design, conceptual, and requirements)

Task 3. Identify existing patterns for reengineering (e.g., PR-NOR patterns for transforming thesauri or classification schemes)

Task 4. If no pattern exists, create an ad-hoc transformation procedure.

5. Transform the NOR into Ontology Components

6.2.4 REQUIREMENTS SPECIFICATION

Identifying requirements is a crucial step in ontology development. The requirements specified in the ORSD play a pivotal role in guiding the process because they determine the specific knowledge that needs to be represented within the ontology, as well as facilitate the reuse of existing knowledge resources by narrowing the search to focus on the relevant knowledge areas. These requirements will also be used to enable the verification of the ontology to ensure it meets the defined requirements. This structured approach ensures that the ontology is both accurate and aligned with its intended purpose.

The process of creating an ORSD, as depicted in Figure 30, begins with identifying the purpose, scope, and implementation language of the ontology by evaluating the needs of users and domain experts. The developers then need to define the intended end-users of the ontology, which will subsequently inform the ontology's intended uses. In the next task, ontology requirements are established and categorised into two types: functional requirements, which specify the knowledge content to be represented, and non-functional requirements, which refer to general aspects not directly related to the ontology content. This will lead to grouping these requirements for clarity and organisation, followed by the requirements validation to ensure both functional and non-functional needs are adequately addressed. If the requirements are found valid, they are prioritised based on importance and relevance. In the final step, the key terminology and frequency are extracted to align with the ontology's focus. The outcome of this systematic process is a comprehensive ORSD, which guides ontology development effectively. This activity must be carried out at the beginning of the ontology project and in parallel with the knowledge acquisition activity.

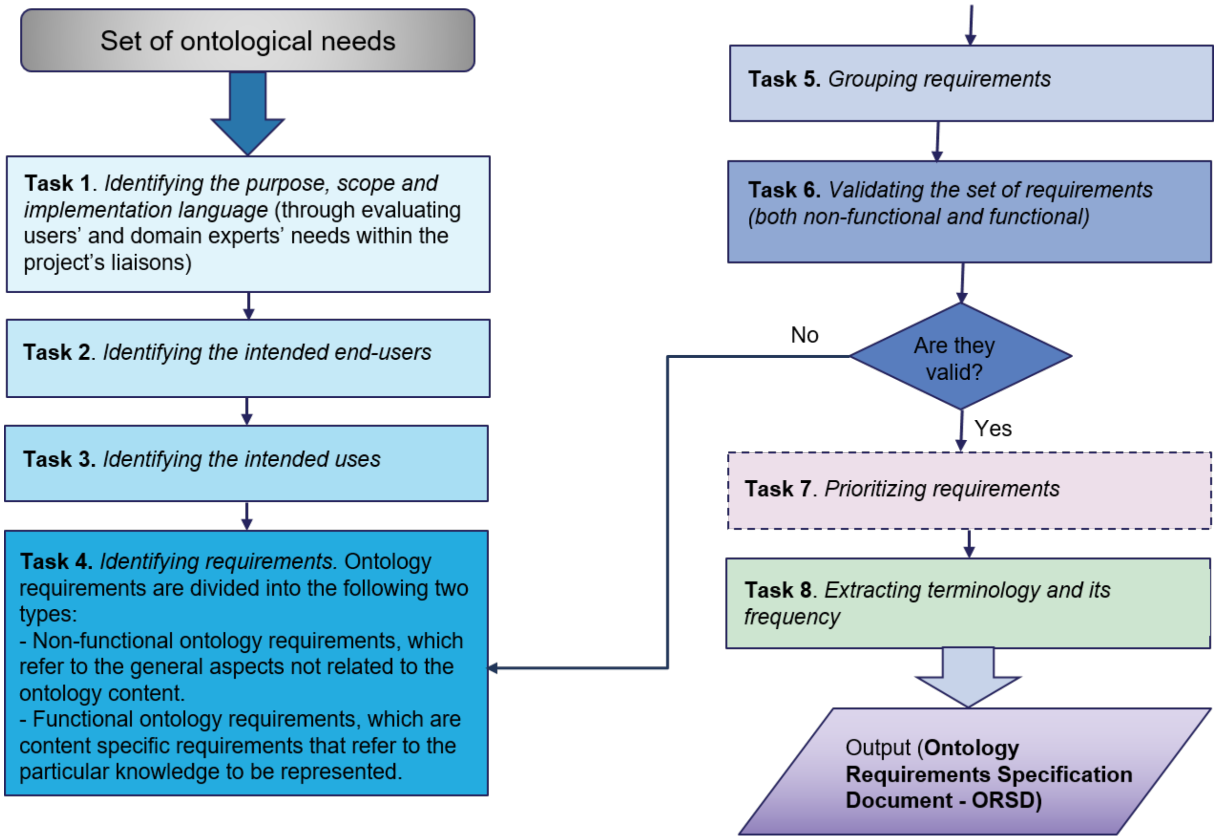

FIGURE 30: ONTOLOGY REQUIREMENTS SPECIFICATION PROCESS

The requirements of the KV/KVI Ontology are modelled in APPENDIX B – ONTOLOGY REQUIREMENTS SPECIFICATION DOCUMENT, ORSD, as proposed by NeOn methodology. The ontology will cover the societal and sustainability aspects of 6G technology, especially within the European value-based approaches to the 6G development framework. This includes KVs, KVIs, which measure the broader societal impact, and KSIs, which focus on the environmental, economic, and social sustainability of 6G technology. The KSIs that the 6G4Society project attempts to define are interdependent to KVIs, with the understanding that they will form a subset of the latter, more focused on sustainability, addressing environmental, resource, and long-term operational impacts. Their metrics can be quantitative and related to scientific evaluation. Example metrics could be metrics like energy consumption per data unit, material recyclability, carbon emissions, and renewable energy usage. The KSIs should, therefore, be directly tied to specific goals such as climate change mitigation or sustainable resource use.

As can be seen, the intended users were sectioned into primary and secondary to better organise the extensive target field. The involvement of these groups was considered necessary for a holistic, multi-stakeholder approach to the ontology's design and use:

- Industry, Designers, and Technology Providers are at the forefront of developing and implementing 6G systems. Aligning their work with societal and environmental values ensures that technology is designed responsibly and for the public good.

- Decision-makers and Policymakers set the regulations and policies that govern 6G deployment. The ontology helps them track progress, enforce accountability, and establish clear societal goals.
- Market and Enterprises create economic opportunities around 6G. Including societal and environmental KVIs can drive innovation that benefits people and the planet.
- Civil Service Organizations advocate for communities and marginalised groups, ensuring that key societal values such as inclusivity and accessibility are not overlooked.
- Research Institutions provide data, models, and frameworks to test and validate the ontology's effectiveness, enabling continuous improvement.
- Standardisation organisations: Without their involvement, the ontology risks being fragmented or overlooked by the major players in 6G development. Their role ensures that ontology becomes a recognised global framework for linking societal values with technology.

Researchers and engineers working on 6G-related projects inside 6G SNS, particularly those focusing on sustainability and societal impacts of emerging telecommunications technologies, can find the taxonomy very useful. Ideally, standardisation organisations will use it to align 6G-related sustainability and societal standards across Europe and internationally. Members of standardisation working groups will rely on its hierarchy to ensure consistent assessment and terminology for 6G technologies, which aligns with European objectives. This taxonomy will primarily target EU and international policymakers who need a clear framework for developing and enforcing regulations related to 6G sustainability and societal aspects. Post-project, relevant standardisation bodies and new projects –both inside and outside SNS- could take over the responsibility of maintaining and updating the ontology, ensuring it stays relevant to future developments in 6G.

Feedback loops will also exist between stakeholders. Secondary users can act as a check-and-balance system, ensuring the ontology remains relevant and applicable in real-world scenarios. They provide feedback to primary users, enabling continuous refinement of how values are defined, measured, and communicated.

6.3 PRE-STANDARDISATION ROADMAP

The project is actively working towards facilitating a consensus process among SNS projects by raising the issue within 6G-IA's Pre-Standardisation Working Group, circulating questionnaires to achieve agreement on the common set of values and accurate indicator definitions, and contributing to relevant ETSI/CEN initiatives.

The development of the pre-standardisation activities roadmap stems from the need to align 6G technologies with societal values and sustainability goals that were highlighted in the gap analysis. As 6G progresses through its pre-standardisation phase, the importance of creating structured, machine-readable frameworks to define and evaluate KVIs and KSIs has become increasingly evident. This roadmap was devised by analysing requirements from technical and societal perspectives and outlining a structured process that prioritises the integration of sustainability and inclusivity into 6G development. Collaboration with pre-standardisation working groups is crucial in order to ensure that the aforementioned ontology aligns with existing frameworks, while feedback from key stakeholders will inform iterative refinements.

Figure 31 provides a clear pathway for defining, creating, validating, and contributing the KVI/KSI ontology to the European and global pre-standardization landscape. The pre-standardisation roadmap focuses on defining machine-readable frameworks for KVIs and KSIs hierarchy. This effort has involved analysing technical and societal requirements and collaborating with relevant working groups to ensure alignment with ongoing pre-standardisation efforts.

FIGURE 31: OVERVIEW OF THE PRE-STANDARDISATION ACTIVITIES

The first step in the process involves defining the requirements for the KVI and KSI ontology. This phase, as analysed in Section 6.2.5, is critical for establishing the purpose, scope, and structure of the ontology by identifying the specific knowledge, concepts, and relationships that need to be represented. It ensures alignment with stakeholder expectations and provides a foundation for building a coherent framework. The outcome of this step is a comprehensive ORSD, which serves as a guideline for the subsequent ontology development phases.

The second phase involves developing the preliminary version of the ontology. This phase formalises the concepts, relationships, and logical rules identified in the ORSD into a structured, machine-readable ontology. The preliminary version is essential for iterative refinement and serves as a prototype for further validation and extension. At the same time, it includes leveraging existing connections with pre-standardisation working groups, especially the Pre-Std WG inside 6G-IA, to ensure alignment with ongoing collaborative efforts and gather feedback from external stakeholders.

The third phase focuses on active participation and contribution to working groups, including but not limited to SNS or 6G-IA scope. Herein, technical specification groups inside ETSI with respect to SAREF - Smart Applications REFerence ontology were considered. This will ensure that the developed ontology will be part of the already existing ETSI frameworks and standards for better interoperability and wider acceptance. These types of contributions, in this stage, are paramount to integrating ontology into the wide-standardising environment and also ensure that the reviews obtained by the industry players and technical interested parties are adequately taken into consideration. SAREF ontologies are a set of standardised, interoperable semantic models put forward by the ETSI-European Telecommunications Standards Institute to permit communication and the exchange of information across smart applications and IoT ecosystems.

The ETSI Smart Machine-to-Machine (SmartM2M) Technical Committee is responsible for creating and updating the core ontology as well as its domain-specific extensions. SAREF was originally created in 2015 as a result of a collaboration between the European Commission and ETSI. It was originally developed to meet the interoperability issues in the energy domain and aimed at offering a common semantic framework to IoT devices and smart applications. Success in the energy sector contributed to the extension of SAREF in other domains: now there exists a family of SAREF extensions focused on different industries: building, city, water, and health. These ontologies provide a common semantic framework that defines key concepts, relationships, and data structures, enabling devices and systems from different manufacturers and sectors to interact seamlessly. SAREF is designed to promote interoperability by bridging diverse IoT architectures and aligning with global standards, such as oneM2M and the Semantic Web stack (e.g., OWL, RDF). The SAREF ontology is a strong fit for the 6G KVI ontology due to its proven ability to enable semantic interoperability, modularity, and cross-domain scalability while maintaining compatibility with its core structure, provided that the proposed extension does not conflict with existing domain-specific ontologies. The existing domain-specific extensions, such as SAREF for Energy, SAREF for Health, and SAREF for Smart Cities, show their capacity to integrate new verticals. A KVI ontology could be integrated as a new extension, following the same principles of modularity and semantic consistency. As KVIs are critical to defining societal and sustainability goals in 6G, alignment with standardisation goals is feasible, particularly as KVIs fit into the broader scope of metrics and indicators for emerging technologies, demonstrating practical value for this extension.

The final phase involves incorporating feedback from stakeholders and making a formal contribution under the CEN Workshop Agreement (CWA). This phase ensures that the ontology meets the agreed-upon requirements and is refined based on real-world input. The CWA provides a formal mechanism for validating the ontology within a broader standardisation context, solidifying its role as a key resource for aligning 6G technologies with societal and sustainability goals. This step marks the completion of the ontology development process and its readiness for deployment in standardisation efforts.

The 6G4Society project is responsible for defining the ontology and structured framework for KVIs/KSIs. However, formal standardisation is driven by organisations like ETSI and CENELEC. The project contributes by ensuring that these indicators are recognized and integrated into pre-standardisation working groups and communicated through the formal CWA procedure.

6.4 STAKEHOLDER ENGAGEMENT THROUGH QUESTIONNAIRES

The 6G4Society project puts a strong emphasis on a multi-stakeholder approach, ensuring the inclusiveness of different perspectives of research initiatives, industry leaders, and civil society. An agreed framework of KVs and KVIs, universally, will be fundamental to the development of an ontology that guarantees consistency, interoperability, and common understanding among the stakeholders. This process of harmonisation is cumbersome but very important in that it prevents a fragmented approach towards societal and sustainability metrics and will allow KVIs to be integrated into 6G standardisation work.

Recognising the distinct roles and contributions of different stakeholder groups, the project has developed two targeted questionnaires (APPENDIX C – SNS KVI PROJECT QUESTIONNAIRE, APPENDIX D – 6G DESIGNERS KVI QUESTIONNAIRE). The first questionnaire is designed for SNS projects and researchers, focusing on further understanding the KVI landscape and how values are interpreted and defined in the context of each project. KVIs are also integrated into the design, development, and operationalisation of 6G systems. The second questionnaire contains an extra section for 6G designers in order to gather and analyse their understanding of the KVI framework to incorporate into the developed ontology.

This approach ensures that the questionnaires address the unique perspectives, responsibilities, and challenges faced by each group, fostering a comprehensive understanding of how KVIs can drive societal and technological advancements in the 6G era. Inputs from the questionnaire answers will directly influence the ontology design stage by clarifying the relationships that exist between values, KVIs, verticals, project KPIs, and objectives that each stakeholder is focusing on.

6.5 CHALLENGES AND NEXT STEPS

The development of the KV/KVI ontology intended for the 6G standardisation and certification roadmap is fraught with several challenges that stem from both technical and organisational aspects. The process of developing ontologies is inherently complex, requiring the integration of diverse domain knowledge derived from multiple SNS projects with different priorities and focus areas, alignment of terminologies, and formalisation into a machine-readable structure. Challenges arise in defining comprehensive and universally accepted KVIs and, subsequently, KSIs that can cater to the varied requirements of multiple target stakeholders while maintaining logical consistency and scalability. Agreement on a universal set of indicators across sectors is essential but also very challenging. Additionally, standardisation bodies included in the roadmap, such as ETSI and CEN, often operate on differing timelines for developing 6G standards. These conflicting schedules create misalignment between ontology development efforts and the requirements set by these organisations.

To address these challenges, a set of next steps has been identified to facilitate progress in this task. A structured consensus process needs to be established among SNS projects and, where feasible, external stakeholders to define a common set of key values along with their precise definitions. To this end, the stakeholder questionnaires will be employed, the outcomes of which will be evaluated to identify requirements and priorities, along with value description in the context of each project and use case. Building upon this foundation, the process will move towards an agreement on a unified set of KVIs that will represent classes in the ontology. This collaboration will ensure alignment across sectors and inform the preparation of the preliminary structure of the Protégé ontology for 6G KV/KVIs. This ontology structure will serve as a critical framework for integrating and formalising diverse contributions. This preliminary version will be paired with an assessment of contributions to major 6G standardisation actors to ensure that the ontology development aligns with the expectations and timelines of bodies such as ETSI and CEN. By bridging the gap between stakeholder feedback and standardisation requirements, this approach will create a more robust and relevant ontology. Early prototypes will focus on high-priority use cases and sectors, enabling quick validation and refinement. Regular feedback loops involving stakeholders from the 6G-IA ecosystem will ensure the ontology evolves to address its requirements effectively.

Engagement with standardisation bodies will be prioritised to better understand and align with their timelines, to be ready for timely contributions. It is estimated that the minimum required time for a CWA publication is around 6 months, a period that includes the initial proposal and preparation stage and the consultation and announcement stage. These stages can co-exist with ontology refinements as new information is incorporated, making the available time count before the actual standardised ontology submission.

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7 EXPLOITATION AND SUSTAINABILITY STRATEGY PLAN

The 6G4Society project, now midway through its lifecycle, has reached a critical stage where the focus is shifting from the development of research outputs to ensuring their long-term exploitation and sustainability. The project consortium has successfully completed the first year, which involved progress in research, methodology development, and stakeholder engagement. As we move towards the final year, ending in December 2025 (M24), the emphasis is on refining key results, aligning them with market needs, and ensuring the project's societal and economic impact is maximised. This strategy plan outlines the methodology, future steps, and a detailed timeline to achieve these objectives.

Henceforth, the strategy for exploitation and sustainability is built on a comprehensive approach that includes the following **key components and future steps**:

1. Identification and Refinement of KERs: Over the past year, the project partners have identified several KERs, including the SAT framework, KSI/KVI methodologies, participatory design approach, policy recommendations, etc. (see Chapter 4). The ongoing refinement of these KERs ensures they remain adaptable to changing societal and market dynamics. The second year will focus on finalising these outputs, enhancing their applicability, and aligning them with real-world needs.
2. Stakeholder Engagement and Market Validation: The success of 6G technologies hinges on societal acceptance and industry adoption. Therefore, the project consortium will intensify engagement with key stakeholders, including policymakers, industry leaders, civil society, and research organisations, to validate the KERs and gather feedback. This engagement will also support disseminating best practices, ensuring broad market uptake.
3. Development of a Competence Centre: One of the primary exploitation paths involves creating a 6G4Society Competence Centre. This centre will be a hub for ongoing research, training, and consultancy services post-project. It is envisioned as a spin-off or NGO that will continue promoting the project's key outputs, fostering innovation, and facilitating collaboration across different sectors. Steps will be taken to establish it, including drafting a business model, securing initial funding, and identifying key partners. The centre is expected to be operational towards the project's end, estimated for December 2025.
4. Standardisation and Certification: To ensure interoperability and compliance, the project partners will actively contribute to international standardisation bodies. By aligning the SAT framework and KSI/KVI methodologies with emerging global standards, the project will enhance the potential for widespread adoption of its results.
5. Funding and Partnership Development: Beyond the project’s lifetime, sustainability will rely on securing additional funding and forming strategic partnerships. The project consortium will explore opportunities under EU programmes such as Horizon Europe, Digital Europe, and SNS JU initiatives. Partnerships with private sector players and research institutions will also be fostered to ensure continuous development and impact.
6. Finalising Deliverables: Deliverables such as the Final Exploitation Report (D4.4), Operational Guidelines (D1.3), Policy Brief (D1.2), Public Positions on 6G Technology (D2.3), 6G-IA Papers on social acceptance and KSIs (D3.2, D3.3), etc. will be completed in 2025. These documents will consolidate the project’s findings and provide actionable recommendations for policymakers and industry stakeholders.
7. Piloting and Demonstration Activities: Piloting the SAT framework and KSI methodologies in selected vertical sectors (e.g., healthcare, smart cities, transportation) will be critical to showcase the project’s results' applicability and benefits.

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8. Scaling Dissemination and Communication: The consortium will intensify dissemination efforts through workshops, conferences, and publications to maximise visibility. Special focus will be given to engaging with media and the general public to foster a better understanding of 6G's societal impact.

The methodology for the 6G4Society Exploitation and Sustainability Strategy Plan was collaboratively developed by the project partners through a structured process. Partners contributed to the methodology by actively participating in joined discussions and activities and, therefore, providing key insights and data in a shared document titled "6G4Society Key Exploitable Results Table" (APPENDIX E – KEY EXPLOITABLE RESULTS TABLE). This document serves as a dynamic tool to capture, track, and refine the project's exploitable results (as well as partners' Intellectual Property Rights) ensuring that all identified KERs were aligned with both market needs and societal goals. As the project progresses toward its conclusion in December 2025, the shared file will be continuously updated. A final version will be prepared once all planned activities are completed and the necessary information is collected. This final version will consolidate the project's outputs, providing a comprehensive overview of the developed KERs, their exploitation paths, and sustainability strategies. This said, the 6G4Society consortium also filled in another Excel spreadsheet titled "Exploitation and Sustainability Plan" (APPENDIX A – EXPLOITATION AND SUSTAINABILITY PLAN) to report the exploitation and sustainability activities implemented by M12 from each respective organisation in this partnership and a preliminary draft of those activities that are planned until the end of the project (M24). For example, an achieved activity reported by the project partner CEL is "developing a framework to explore and analyse the social acceptance aspect in the specific 6G socio-technical context". Additional information can be found in APPENDIX A.

To continue with the analysis, it is important to stress that the demand for more sustainable networks is driven by a broad range of stakeholders, primarily due to the increasing concerns about energy consumption, carbon emissions, and the environmental footprint of digital infrastructure. Those **key stakeholders**, as concluded throughout our project analysis (and specifically from D1.1), are preliminarily mapped and referred to:

1. **Telecommunication Operators (Telcos):** Telcos are under pressure to reduce operational costs and meet regulatory and societal expectations regarding sustainability. Operating massive networks consumes significant energy, and as data traffic grows, energy efficiency becomes a critical priority. Sustainable networks can help telcos reduce their carbon footprint, achieve regulatory compliance, and improve their brand image.
2. **Vertical Industries:** Many industries that rely on digital connectivity for their operations, such as healthcare, automotive, manufacturing, agriculture, and smart cities, require sustainable networks to meet their own environmental goals. These sectors are increasingly adopting IoT, AI, and edge computing, which demand reliable, low-latency, and energy-efficient networks.
3. **Regulators and Policymakers:** Governments and regulatory bodies are pushing for greener solutions in the ICT sector. Policies such as the European Green Deal and various national sustainability frameworks require network operators and technology providers to adopt energy-efficient technologies and reduce emissions.
4. **End-users and Society:** Consumers are becoming more environmentally conscious and expect companies to operate sustainably. Additionally, the increasing deployment of connected devices and services means that a sustainable network infrastructure is critical for ensuring a lower environmental impact at scale.

Reading other chapters/sections of this report helps us understand that the market segmentation for sustainable networks can be divided into the following categories: (i) by industry (verticals), (ii) by technology (telco), and (iii) by region. The verticals have been analysed extensively in the project and can be found in many chapters/sections of this document. As to what concerns telcos, the focus is on telecom operators who are focused on deploying next-generation, energy-efficient mobile networks (5G, 6G) to meet growing data demands while reducing energy consumption, cloud and data centre providers who are amongst the largest consumers of energy in the ICT sector, manage energy costs and meet green data centre initiatives, and lastly, IoT solution providers who focus on reliable and sustainable networks. In Europe [58], the market segmentation is driven by strong regulatory mandates (e.g., the European Green Deal) and incentives for sustainability, while in Asia-Pacific [59], there is high adoption of 5G and smart city initiatives with a growing focus on sustainability. North America [60] is led by large telcos and technology companies investing in green ICT solutions, while regions in Latin America and Africa [61], where network infrastructure is still being developed, have an opportunity to adopt sustainable networks from the start. Regulators and policymakers form a strategic market for the project's work on policy recommendations and sustainability frameworks. By influencing policies and contributing to the development of standards, the project can help shape a regulatory environment that incentivises sustainable network deployment. The project's work on exploitation, sustainability indicators, and market readiness directly addresses the needs of these stakeholders, positioning it to make a significant impact in both the telco industry and beyond.

Henceforth, the project partners support that the stakeholders who have a direct or indirect interest in the research outcomes, methodologies, and frameworks developed by the 6G4Society project are telcos, vertical industry leaders, standardisation and certification bodies, policymakers and regulators, research and academic institutions, as well as the EU project consortia (e.g., Other EU-funded projects working on 6G-related topics, such as Hexa-X, SNS JU, and 6G-IA). **Potential customers** are entities that can directly apply the project's results to improve their operations, compliance, and market positioning. They are entities that can directly benefit from the project's outputs to drive innovation, improve sustainability, enhance societal acceptance, and shape the regulatory landscape for 6G. These include:

1. **Telcos:** They are under pressure to deploy more sustainable, energy-efficient, and socially responsible networks. The project's results will provide them with actionable insights and tools to achieve these goals. Therefore, they can adopt the SAT framework to improve public trust in 6G, implement sustainability indicators to meet regulatory requirements, and use market analysis for business planning.
2. **Technology Vendors:** They are companies like Ericsson, Nokia, Huawei, and Qualcomm that develop 6G infrastructure and devices. They can integrate the project's sustainability metrics and social acceptance models into product design and deployment strategies.
3. **Vertical Industry Solution Providers:** Companies developing IoT, AI-driven applications, and smart solutions for industries such as healthcare, automotive, and manufacturing. They can leverage the project's sustainability and market insights to develop 6G-enabled solutions that meet industry-specific needs.
4. **Consultancy Firms:** They are firms offering consultancy services in technology deployment, regulatory compliance, and sustainability. They can use the project's exploitation and sustainability strategy as a framework to advise clients in the telecom and technology sectors.
5. Standardisation and Certification Providers: They can incorporate the project's pre-standardisation framework and sustainability indicators into their certification schemes to promote interoperable and sustainable 6G networks.
6. **Government Agencies and Policy Advisors:** They can apply policy recommendations and sustainability strategies to national and regional regulations for 6G deployment.
7. **Investors and Venture Capitalists:** They are investors looking to fund 6G-related innovations. They can use the market analysis and exploitation strategy to identify profitable investment opportunities in the 6G ecosystem.

As to what concerns the **project's competitors**, the 6G4Society project operates in a highly competitive environment where various consortia, research initiatives, technology companies, and academic institutions are working on advancing 6G technologies. Competitors can be categorised based on their focus on societal acceptance, sustainability, market exploitation, and technical research in 6G. Below is a Table with a detailed list of the key competitors the project will take into consideration for their future work and exploitation of results:

TABLE 3: 6G4SOCIETY COMPETITORS

Competitor Category	Description	Competitor Examples	Justification
European Projects and Initiatives	Several EU-funded projects focus on advancing 6G technologies, many of which are part of the SNS JU initiative. These projects, while complementary in some aspects, also represent competition in terms of developing frameworks, methodologies, and exploitable results.	Hexa-X and Hexa-X-II	Focus: Technical enablers for 6G, including AI-driven networks, sustainability, and societal values. Competitor Aspect: Hexa-X-II also includes a focus on sustainability and societal aspects, potentially overlapping with 6G4Society's KSI/KVI framework and SAT model. Advantage: Strong industry partnerships with major telecom companies (e.g., Nokia, Ericsson) and an emphasis on pre-standardisation activities.
		REINDEER[19]	Focus: Intelligent distributed massive MIMO systems for 6G. Competitor Aspect: Focuses on new architectures for sustainable and scalable 6G networks, offering alternative solutions to energy efficiency challenges addressed by 6G4Society. The H2020 project ended in December 2024.
International Research Consortia	Several global research consortia are competing to shape the future of 6G. These initiatives have significant influence in terms of policy,	Next G Alliance (North America)[20]	Led by the Alliance for Telecommunications Industry Solutions. Focus: Building leadership in 6G for North America, with a strong focus on innovation,

[19] https://reindeer-project.eu/

[20] https://nextgalliance.org/

	standardisation, and market adoption.		sustainability, and societal impact. Competitor Aspect: Strong backing from major North American telecom companies (e.g., AT&T, Verizon, Qualcomm) and direct involvement in policy discussions, which could influence global 6G standards.
		Beyond 5G Promotion Consortium (Japan)[21]	Led by: Government of Japan and major Japanese telecom players (e.g., NTT, KDDI). Focus: Developing 6G technologies with a focus on social and industrial applications, including smart cities, healthcare, and manufacturing. Competitor Aspect: Focuses on societal applications of 6G, competing directly with 6G4Society's work on vertical industries.
		China's 6G Initiative	Led by: Ministry of Industry and Information Technology, Huawei, ZTE, and major Chinese universities. Focus: Driving innovation in 6G and influencing global standards. Competitor Aspect: China's early start in 6G research and development positions it as a global leader in the space. Its influence on standardisation and market deployment could overshadow European initiatives.
Industry Players	Major technology companies and telecom	Nokia[22]	Focus: Leading efforts in 6G research, with significant

[21] https://b5g.jp/en/

[22] https://www.nokia.com/

	vendors are heavily investing in 6G research and are developing their sustainability strategies and societal impact frameworks.		contributions to EU projects like Hexa-X. Competitor Aspect: Nokia's focus on sustainability and societal impact closely aligns with 6G4Society's objectives.
		Ericson[23]	Focus: Developing 6G technologies with a focus on AI-driven networks and sustainable infrastructure. Competitor Aspect: A strong market presence and extensive research on societal impact could compete with 6G4Society's exploitation strategy.
		Huawei[24]	Focus: Extensive research in 6G technologies, with a strong emphasis on market-driven innovations and societal applications. Competitor Aspect: Huawei's global influence and resources pose a significant challenge in terms of market adoption and standardisation.
		Qualcomm[25]	Focus: Leading innovation in wireless communication technologies, with early investments in 6G research. Competitor Aspect: Qualcomm's research on enabling technologies for 6G verticals positions it as a strong competitor in market exploitation.

[23] https://www.ericsson.com/en
[24] https://www.huawei.com/en/
[25] https://www.qualcomm.com/

Academic Institutions	Several leading academic institutions are heavily involved in 6G research, focusing on societal acceptance, sustainability, and technical innovation.	University of Oulu (Finland)[26]	Focus: One of the pioneers in 6G research, with a strong emphasis on societal impact and sustainability through the 6G Flagship program. Competitor Aspect: Their work on KVIs, KSIs, and stakeholder engagement overlaps with 6G4Society's objectives.
		KTH Royal Institute of Technology (Sweden)[27]	Focus: Research on sustainable and energy-efficient 6G networks. Competitor Aspect: Active in EU-funded 6G projects and closely aligned with sustainability goals.
		KAIST (Korea Advanced Institute of Science and Technology)[28]	Focus: Developing AI-driven 6G technologies and exploring their societal implications. Competitor Aspect: Competes on both technological innovation and societal impact frameworks.

The competitive landscape for 6G development is diverse and includes EU-funded projects, international consortia, industry leaders, and academic institutions. While many of these initiatives focus on technical advancements, there is significant overlap in areas such as sustainability, societal acceptance, and market exploitation. 6G4Society's competitive advantage lies in its holistic approach, which combines social acceptance frameworks, sustainability indicators, and a structured exploitation strategy. To remain competitive, it is essential to continue engaging with stakeholders, aligning with emerging global standards, and refining exploitable results to meet market needs. However, remaining competitive and overcoming competitors in the rapidly evolving 6G ecosystem requires a strategic and multi-faceted approach. The 6G4Society project has a unique opportunity to differentiate itself by focusing on societal acceptance, sustainability, and market relevance. While many initiatives concentrate on purely technical advancements, 6G4Society's emphasis on social values and environmental impact provides a distinctive edge. By further refining and validating its SAT framework, KVIs, and KSIs, the project can offer innovative and practical tools that cater directly to the needs of telecom operators, vertical industries, and policymakers. To ensure a competitive advantage, targeting vertical markets with tailored solutions is essential. Key

[26] https://www.oulu.fi/en

[27] https://www.kth.se/en

[28] https://www.kaist.ac.kr/en/

sectors such as healthcare, automotive, smart cities, and industrial automation are poised to benefit from 6G technologies. By developing industry-specific guidelines and frameworks, 6G4Society can position itself as a leader in providing actionable solutions that align with both societal needs and regulatory requirements. Additionally, establishing long-term partnerships with industry leaders and telecom operators will not only accelerate the adoption of the project's methodologies but also foster collaborative innovation. Joint pilot projects with vertical players can serve as real-world demonstrations of the project's results, showcasing their relevance and applicability. Active involvement in standardisation and policy advocacy is another critical strategy for maintaining competitiveness. Competitors like Hexa-X-II and REINDEER are already contributing to global standardisation bodies such as ITU, 3GPP, and ETSI. 6G4Society must proactively engage in pre-standardisation activities, providing inputs on societal acceptance and sustainability to influence the development of global 6G standards. Furthermore, the project's policy recommendations can play a vital role in shaping national and regional regulations, ensuring that the societal dimensions of 6G are prioritised in future deployments. In addition to technical and policy-related strategies, effective communication and dissemination of project results are crucial for building a broad base of support and engagement. Unlike competitors who may focus primarily on academic publications, 6G4Society should prioritise clear and engaging communication with diverse stakeholders, including the general public. Developing public-friendly reports, infographics, and videos that explain the project's methodologies and findings in a relatable manner can help build trust and transparency, which are essential for societal acceptance. Looking beyond the project's lifetime, ensuring long-term sustainability through the establishment of a Competence Centre will be vital. This centre can provide ongoing consultancy, training, and certification services, ensuring that the project's results remain relevant and continue to evolve with emerging trends. Such initiatives will help cement 6G4Society's legacy as a leader in responsible and sustainable 6G development, ensuring its long-term competitiveness even after the project concludes. Finally, continuous research and innovation will be necessary to adapt to changing market needs and technological advancements. By expanding the scope of research to include emerging topics such as AI ethics in 6G, digital inclusion, and privacy concerns, 6G4Society can remain at the forefront of thought leadership in the 6G landscape. Through a combination of differentiation, strategic partnerships, active standardisation involvement, and long-term sustainability planning, 6G4Society can not only remain competitive but also lead the way in shaping the future of 6G technologies in a socially responsible and sustainable manner. Additionally, to convince business decision-makers to integrate 6G4Society work into their daily operations, developments, and policies, the project partners must present clear, evidence-based arguments demonstrating how adopting its frameworks and methodologies can lead to financial gains, regulatory compliance, risk mitigation, and enhanced public trust. By targeting key stakeholders in telecom, vertical industries, and regulatory bodies and by offering tailored solutions and services, the project can effectively position its work as a valuable and necessary component of the 6G landscape. Through strategic partnerships, pilot projects, and active engagement in standardisation, 6G4Society can establish itself as a leader in the responsible and sustainable development of 6G technologies.

By extensively analysing the various key aspects that form the project's exploitation and sustainability strategy, we emphasise the need to form the business plan for 6G4Society. As the global race towards 6G technology accelerates, there is growing recognition that its successful adoption depends on technical advancements and addressing critical societal and environmental concerns. While previous generations of communication technologies, such as 4G and 5G, focused primarily on connectivity, performance, and bandwidth, the next frontier—6G—must deliver value across a broader spectrum, including sustainability, inclusivity, and societal trust. Thus, with a strong emphasis on societal acceptance, key sustainability metrics, and market readiness, the project's outcomes have the potential to shape the future of 6G adoption across various industries and regions. This business plan is part of the consortium's exploitation and sustainability strategy, as it outlines the strategic approach to exploiting and sustaining the key results of 6G4Society, ensuring long-term impact through market-driven solutions, partnerships, and consulting services. It provides a detailed roadmap for converting research outputs into actionable solutions that benefit telecom operators, vertical industries, policymakers, and technology providers. By leveraging its unique expertise in societal acceptance and sustainability, 6G4Society aims to become a leading force in bridging the gap between technological innovation and societal needs, creating economic and social value in the 6G ecosystem. The analysis of the **Business Model Canva** is provided in detail below:

Business Model Canvas				
Key Partners - Telecom operators (e.g., Vodafone, Deutsche Telekom, Orange). - Technology vendors (e.g., Nokia, Ericsson, Qualcomm). - Vertical industry players (healthcare, automotive, smart cities). - Standardisation bodies (3GPP, ITU, ETSI). - EU-funded research consortia (Hexa-X-II).	**Key Activities** - Development of the SAT framework and KVI/KSI methodologies. - Consulting and advisory services for telecom operators and verticals - Engagement with policymakers and standardisation bodies. - Knowledge dissemination through publications, workshops, and conferences.	**Value Propositions** - Frameworks and methodologies for societal acceptance and sustainability. - Tailored solutions for telecom operators and vertical industries - Policy recommendations for sustainable 6G deployment. - Consulting and training services.	**Customer Relationships** - Long-term partnerships with telecom operators, verticals, and regulators. - Ongoing support through the Competence Centre. - Continuous engagement via workshops, conferences, and advisory services.	**Customer Segments** - Telecom operators and network providers. - Vertical industries (healthcare, automotive, smart cities, manufacturing). - Policymakers and regulatory bodies. - Technology vendors. - Standardisation bodies.
	Key Resources - Expert team with interdisciplinary knowledge (social sciences, technology, policy). - Developed frameworks: SAT, KVI, KSI. - Strategic partnerships with industry, academia, and regulatory bodies. - Access to pilot projects.		**Channels** - Direct partnerships and collaborations. - Workshops, conferences, and industry events. - Publications, white papers, and case studies. - Online platforms and Competence Centre services.	
Cost Structure			**Revenue Streams**	

- Administrative and personnel costs for consulting, R&D, and support. - Marketing and outreach (events, publications, stakeholder engagement). - Travel and participation in international events.	- Consulting services for telecom operators and vertical industries. - Licensing of the SAT, KVI, and KSI frameworks. - Competence Centre membership fees. - Training programs and workshops.

FIGURE 32: 6G4SOCIETY BUSINESS MODEL CANVA

As to what concerns the preliminary mapping of the **consortium's future activities** (up to M24), and taking into account those aspects mentioned above, the project partners will emphasise the following:

TABLE 4: 6G4SOCIETY FUTURE ACTIVITIES AND TIME PLAN

Activity	Timeline	Description	Partners involved
Refinement of KERs	M13 – M24	Continuous improvement of KERs (e.g., participatory design, KVI-KSI ontology, KSIs framework, feedback to policy and operational measures, Competence, Centre, etc.), as well as the SAT framework, KVIs, and KSIs. Iterative updates will ensure alignment with stakeholder needs and market trends.	All partners
Stakeholder Engagement and Market Validation	M13 – M23	Intensified collaboration with policymakers, industry leaders, and researchers (e.g., pool of "experts" HUB, etc.). This includes validating KERs through stakeholder feedback and aligning with real-world applications.	All partners
Standardisation and Certification Contributions	M13 – M22	Active participation in international standardisation bodies like ETSI and 3GPP. Contributions to defining pre-standardisation frameworks aligned with KVIs and KSIs.	NOVA
Development of a Competence Centre	M17 – M24	Establishing a sustainable hub for consulting, research, and training. Drafting a business model and identifying funding opportunities and partners.	MAR
Finalisation of Deliverables	M14 – M24	Completion of the final project deliverables (e.g., D1.2, D1.3, D4.4, etc.). These will consolidate findings	All partners

		and provide actionable recommendations.	
Piloting and Demonstration Activities	M18 – M23	Application of the SAT framework and KSI methodologies in pilot projects within selected vertical sectors like healthcare, transportation, and smart cities.	All partners
Scaling Dissemination and Communication	M13 – M24	Expanded outreach efforts through publications, conferences, workshops, and media engagement. This will promote the societal impact and market relevance of 6G4Society outputs.	D4P
Policy Recommendations and Regulatory Input	M13 – M24	Submission of policy recommendations to influence the regulatory framework for 6G development. These recommendations aim to ensure ethical and sustainable technology adoption.	CEL, D4P, NOVA, PSCE

This timeline ensures the smooth progression of activities aligned with the project's exploitation and sustainability goals, culminating in the project's successful completion in December 2025 (M24). The focus on refining outputs, engaging stakeholders, and piloting applications ensures that that the project's results have lasting societal and market impacts.

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8 IMPACT ASSESSMENT

Before finalising our analysis, it is important to mark out the expected impact of the 6G4Society project, centred on fostering a balanced approach to the development of 6G technologies by addressing societal and sustainability challenges alongside technical advancements. The project acknowledges that while 6G offers immense potential for improving connectivity, it also raises concerns related to inclusivity, privacy, and environmental impact. To address these issues, 6G4Society aims to ensure that societal values and sustainability are integrated from the earliest stages of research and development. By engaging a broad spectrum of stakeholders, including civil society, policymakers, and industry leaders, the project seeks to promote a socially responsible approach to 6G innovation.

As explained, a key aspect of the project's impact is the development of comprehensive frameworks and guidelines. These include a SAT framework for assessing and improving public trust in 6G, a KSI framework to evaluate environmental impact, and policy recommendations that provide actionable solutions for sustainable 6G deployment. These aspects will help stakeholders navigate complex societal and regulatory challenges, ensuring that future 6G technologies align with ethical, social, and environmental priorities. Another significant impact of 6G4Society is the promotion of collaboration among key stakeholders. By actively engaging with other 6G-SNS JU projects, working groups, and initiatives, the project fosters a shared understanding of the societal implications of 6G. This collaboration validates the project's findings and increases the likelihood of broad adoption of its outputs across the 6G ecosystem. In this way, 6G4Society aims to serve as a catalyst for aligning industry efforts with societal expectations. The project also has a strong focus on supporting policy and standardisation efforts. By providing evidence-based policy recommendations and operational guidelines, 6G4Society seeks to influence national and international regulatory frameworks for 6G. Its contributions to pre-standardisation activities will help ensure that future 6G standards promote sustainability and social acceptance, positioning 6G4Society as a key contributor to the global 6G landscape. Strategic alliances with international bodies, such as the ITU, ETSI, and 5G-PPP, will enhance 6G4Society's influence on global standardisation and policy development. Active participation in these platforms will ensure that the project's outputs are considered in developing global 6G standards. Such alliances will also provide a channel for advocating for sustainability metrics and societal acceptance models as integral components of future communication systems. Nonetheless, beyond its immediate outcomes, 6G4Society aims to build long-term competence in the responsible development of 6G technologies. A critical component of this vision is potentially establishing a Competence Centre or network that will continue to provide research, consulting services, and training in sustainability and societal impact after the project ends. Tailoring industry-specific guidelines for telecom operators and vertical industries will ensure the project's results are more relevant and actionable. By customising the exploitation of the frameworks based on the specific needs and regulatory environments of different industries, 6G4Society can better support stakeholders in implementing sustainable and socially responsible 6G solutions. This approach increases the adoption potential of the project's outcomes and positions it as a trusted advisor for different sectors involved in the 6G ecosystem. Concerning long-term sustainability through knowledge-sharing initiatives, establishing an open-access knowledge repository where stakeholders can access key deliverables, methodologies, and case studies will help promote widespread dissemination of the project's findings. This repository will serve as a resource for continuous learning and collaborative development, fostering a global community of experts dedicated to the responsible deployment of 6G technologies. To further enhance the project's expected impact, 6G4Society aims to strengthen its collaboration with industry partners and policymakers by facilitating real-world pilot projects. These pilots, conducted across diverse verticals such as healthcare, smart cities, and transportation, will validate the project's frameworks in practical environments. By demonstrating the applicability and value of the SAT framework, KSI models, and policy recommendations, these pilot projects will provide concrete evidence of the project's ability to deliver solutions that balance technological advancement with societal needs.

This long-term strategy ensures that the project's results will remain relevant and contribute to the ongoing evolution of 6G technologies, helping stakeholders address future challenges as they emerge. In conclusion, the 6G4Society project's expected impact extends beyond the technical realm. By focusing on sustainability, societal acceptance, and policy alignment, the project seeks to ensure that 6G technologies deliver superior connectivity and tangible societal and environmental benefits. Through its comprehensive frameworks, collaborative approach, and long-term vision, 6G4Society positions itself as a leader in driving responsible and inclusive innovation in the 6G era.

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9 CONCLUSIONS

The 6G4Society project has taken significant steps towards addressing the multi-faceted challenges of developing 6G technologies. This deliverable has provided a well-rounded framework beyond purely technical aspects by integrating societal values, sustainability considerations, and market-driven exploitation strategies. The insights gained from this project are intended to guide stakeholders such as policymakers, industry leaders, researchers, and civil society towards the responsible and sustainable development of next-generation communication systems.

One of the primary conclusions of this report is that 6G cannot be merely a continuation of 5G in terms of performance improvements. Instead, it represents a paradigm shift that embeds societal acceptance and sustainability at the core of technological innovation. The lessons learned from the rollout of 5G, including public concerns about privacy, safety, misinformation, and the environmental impact of infrastructure deployment, have highlighted the need for a new approach to designing and deploying 6G. The development of KVIs and KSIs serves as a key outcome of this project, providing structured and measurable ways to evaluate the societal and environmental impact of 6G. Therefore, we conclude that one of the essential elements of the 6G4Society project is its emphasis on market potential and the exploitation of key results. Unlike previous generations of mobile communication technologies, 6G aims to serve as a foundation for various applications across multiple sectors, including healthcare, transportation, smart cities, energy, and manufacturing. The transformative potential of 6G lies in its ability to provide faster and more reliable communication and its capacity to enable innovative use cases through advanced technologies like AI-native networks, semantic communication, and ubiquitous sensing. Therefore, the project's strategy focuses on Identifying and Refining KERs, engaging and collaborating with key national, European, and international stakeholders to gather feedback, validate methodologies, and promote the adoption of project results.

The report also underscores the importance of policy alignment in fostering the adoption of 6G technologies. As 6G is expected to play a crucial role in digital transformation across various sectors, aligning technological advancements with regulatory frameworks is essential. The policy recommendations presented in this report provide a roadmap for ensuring that 6G deployment adheres to ethical guidelines, respects societal values, and promotes sustainability. Furthermore, engagement with international standardisation bodies, such as 3GPP, ITU, and ETSI, is critical to ensuring global interoperability and compliance. Moreover, the findings of this report have significant implications for the future of 6G development. By offering a comprehensive framework for societal acceptance, sustainability, and market readiness, the 6G4Society project has set a new benchmark for how next-generation communication technologies should be developed. The methodologies proposed in this deliverable can serve as a reference for future research, guiding stakeholders in addressing emerging challenges while fostering innovation. The impact assessment highlights the potential benefits of 6G in driving economic growth, enhancing societal well-being, and contributing to environmental sustainability. By aligning 6G development with the UN SDGs, the project demonstrates how next-generation technologies can act as catalysts for positive societal change.

In conclusion, the 6G4Society project offers a holistic approach to 6G development, focusing not only on technical innovation but also on societal and environmental impact. The proposed frameworks, methodologies, and exploitation strategy provide a clear roadmap for realising the full potential of 6G responsibly and sustainably. Continuing collaboration with stakeholders, proactive policy engagement, and sustained investment in research and innovation will ensure

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that 6G technologies deliver on their promise of improving lives and driving economic progress. The deliverable underscores that while significant progress has been made, the journey towards realising 6G's potential is far from over. Future efforts should prioritise refining the proposed indicators, expanding the scope of pilot projects, and fostering international collaboration to ensure that 6G technologies remain aligned with societal needs and market expectations. Through such sustained efforts, 6G can become a transformative force for good, delivering technological excellence and societal benefit.

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APPENDIX A – EXPLOITATION AND SUSTAINABILITY PLAN

Exploitation_and_Sustainability_Plan - v0.1 .XLSX

Partner Name	Achieved Activity Description	Relevance to Exploitation	Relevance to Sustainability
MAR	Methodology on MS initiative mapping and engagement	Organizing knowledge transfer through The Corporate Sustainability Reporting Directive (CSRD)	Streamlining European industry on a broad scope of sustainability through The Corporate Sustainability Reporting Directive (CSRD)
CEL	Development of a framework to explore and analyse social acceptance aspect in the specific 6G socio-technical context	It is thought as an instrument to support SNS projects to reflect on the acceptance issue beforehand, identifying possible concerns to be addressed. Also, evidences about the experience of SNS project could benefit also projects outside this specific community	Analysing acceptance helps understanding which values are important across different segments of society. As such, it might shed light on the relevance of sustainability meant as a value for society. Whenever sustainability is identified as a core value for societal group, it means there is room for it to become a constituting value within the business modelling process
NOVA	Development of the 6G Ontology for KVs/KVIs(/KSIs)	It ensures interoperability and alignment of sustainability indicators across 6G research projects, and provides a structured framework to bridge fragmented and regional perspectives for sustainabile innovation. The ontology will be NOVA's point of participation in pre-standardization activities to push for sustainability inclusion into technical standardization goals of major standardization organizations.	It contributes to the inclusion of societal/environmental/economic values in the 6G pre-standardization phase. It also promotes multi-stakeholder collaboration for sustainable and socially accepted 6G systems
PSCE	KSI framework and related dialogical and collaborative methodologies	Improved ability of those involved in R&D, procurement, and of early adopters of technology to articulate and prove/demonstrate the beneficial impact on society that comes from the use of a new tool. For example, this would improve the ability of PPDR actors to encourage ICT developers to produce solutions they need despite not a strong market drive. It would also make it possible to better provide specifications of the technological solution according to sustainability issues, shifting business models to not treat these longer-term outcomes as those to be traded off for short term performance or profit. The results can also be used to imform policy recommendations as well as fostering public-private partnerships where technology developers/PPDR organisations/policymakers collaborate to co-develop solutions that have both societal impact and commercial viability.	This will support projects in addressing, in particular, the societal aspects of sustainability, ensuring the issues that drive societal well-being and prosperity also drive innovation.
eBOS	Refine KERs, evaluate project results' commercialisation interest and technical feasibility, ensuring their relevance to both societal needs and market demands. Continuous monitoring framework for the market, research, and societal developments related to 6G technologies.	eBOS's work has directly contributed to the project's exploitation potential by ensuring that the KERs align with market needs, stakeholder expectations, and technological trends. The refinement of these results has verified their commercialisation potential, while the continuous monitoring framework has positioned the project as a forward-looking contributor to the 6G ecosystem.	Through the development of the exploitation and sustainability plan, eBOS has laid the groundwork for ensuring the long-term impact of the project. The focus on funding opportunities, standardisation, and certification ensures that project outputs remain relevant and applicable in both commercial and societal contexts.
D4P	Public engagement, Information Package, Citizen Survey	Public engagement is crucial for the responsible exploitation of 6G technologies. By engaging with the public, we gather valuable insights into societal concerns, fears, and expectations surrounding 6G. This understanding informs the exploitation process, ensuring that the deployment and commercialization of 6G are socially acceptable and aligned with public interests. Effective public engagement helps mitigate risks associated with societal pushback or ethical oversights, thus enhancing the success and sustainability of 6G technologies in real-world applications.	By understanding public concerns and expectations, we can address challenges like energy consumption and digital equity, aligning 6G development with societal and environmental sustainability goals.
D4P	Launched and maintained the project website, newsletter and social media channels, ensuring regular updates and effective dissemination of the project's results, findings, and whitepapers.	The website, newsletter and social media presence amplified the project's reach, engaging a wide range of stakeholders, including SMEs, startups, and the broader 6G community, promoting the adoption of the project's outputs.	By promoting sustainability-focused content through its digital platforms, 6G4Society raised awareness and facilitated collaboration on sustainable 6G development, engaging key stakeholders in environmental and societal conversations.

Activities_Up_to_M12 | Future_Actions_to_M24

APPENDIX B – ONTOLOGY REQUIREMENTS SPECIFICATION DOCUMENT

	ONTOLOGY REQUIREMENTS SPECIFICATION DOCUMENT
1	**Purpose**
	The purpose of creating the 6G Key Values and Key Value Indicators Ontology is to create a comprehensive, standardised framework for defining Key Values (KV) and Key Value Indicators (KVI) within the societal, environmental and economic research domains related to 6G technologies, as well as Key Sustainability Indicators (KSIs), as a subset of KVIs that focus on sustainability issues. It can be used to standardise the understanding of sustainable 6G values and their respective indicators, by providing a common, semantically rich structure that facilitates the alignment of 6G design and standardisation process with European values. The ontology is expected to be used as a knowledge base able to establish a shared, standardized vocabulary for describing key metrics and analysing existing dependencies in the evolving 6G ecosystem in order to ensure consistency across research, industry, and standardisation bodies and provide stakeholders with a common "language" when evaluating and improving future network technologies. As an additional target, it will enhance help towards transparency and enhance interoperability for technology providers, enterprises, and civil service organisations when assessing technology's contributions to societal goals.
2	**Scope**
	The ontology will focus exclusively on the 6G telecommunications domain**,** emphasising a common set of Key Values (KVs), in other words, the fundamental principles, goals, or priorities related to societal, environmental or economic outcomes that are critical for assessing sustainability, performance, and socio-economic impact of 6G technologies. It will also classify the set of respective Key Value Indicators (KVIs) that offer quantitative and qualitative measures indicative of progress towards achievement of these values, along with an attempt to provide specific metrics to these indicators. The ontology's creation process involves reengineering unstructured or semi-structured insights produced within research contexts to structure values and indicators in a semantically interoperable format. It will include relationships between key values, indicators, metrics and relevant stakeholders, enabling traceability, accountability, and shared understanding across sectors. The level of granularity will be directly driven by the competency questions and key terms identified within research outputs and their associated domains, ensuring that the ontology is both comprehensive and aligned with the specific indicators and metrics used to evaluate 6G advancements**.**
3	**Implementation Language**
	The 6G Key Value Indicators Ontology will be implemented in the OWL 2 language using the Protégé tool.
4	**Intended End-Users**
	<u>Primary Users:</u> These are the groups that use the KVI ontology directly to drive decisions that influence the social, economic and environmental dimensions of 6G systems. These groups also contribute to the ontology's development, acting as informers of the KVI definitions, methodologies and metrics. ● <u>Policymakers and Decision-makers</u> who will use the ontology to create policies and evaluate 6G initiatives based on sustainability impacts. ● <u>Industry and enterprise actors</u>, for example telecommunication providers will use the ontology to assess how their operations, technologies, and strategies can be influenced by values, to ensure compliance with sustainability and performance metrics.

	• <u>Designers and Developers</u> will use the ontology as a framework to embed societal and environmental Key Values into 6G system designs, ensuring their solutions are ethically aligned and impactful. • <u>Technology providers</u> can use the ontology to evaluate and monitor the performance of their 6G systems against standardized Key Value Indicators and metrics. • <u>Business and market.</u> This group represents the economic ecosystem, including business leaders, investors, and market enablers that drive the adoption and commercialisation of 6G technologies. They use ontology to evaluate the economic impact of sustainability. • <u>Stakeholders</u>: e.g. users/buyers within verticals, SDOs. • <u>Standardization organizations</u> that act as validators and adopters of the ontology by endorsing it and encouraging other stakeholders to adopt it in their workflows. • <u>Researchers and academics</u> who employ the ontology to study 6G technologies, evaluate sustainability impacts, and benchmark outcomes against established KVIs. As informers, they propose new KVIs as well as metrics or frameworks, ensuring the ontology evolves with emerging knowledge. **<u>Secondary Users:</u>** These are groups that indirectly influence or benefit from the ontology. They might not directly develop or deploy 6G systems but play a vital role in advocating, analysing, or supporting the alignment of 6G with societal values. • <u>Civil Service Organizations</u> can use the ontology to advocate for accountability and transparency in 6G initiatives. They bring a societal perspective to the technology assessment. • <u>EU and national initiatives</u> that make use of the standardised value framework for assessing how 6G technologies align with their priorities.
5	**Intended Uses**
	<u>Primary Uses:</u> **Use 1:** A policymaker uses the value hierarchy to assess how a proposed 6G deployment project contributes to key social and environmental indicators related to their implementation. **Use 2:** A policymaker seeks to integrate ontology-derived metrics into national or regional policy goals, such as achieving net-zero carbon emissions in the telecommunications sector. **Use 3:** An entrepreneur wants to assess the lifecycle sustainability of specific 6G infrastructure by analysing and integrating relevant KVIs into a technology roadmap and a deployment strategy. **Use 4:** A 6G designer that uses ontology as a framework to embed societal and environmental Key Values into 6G system designs. For example they design energy-efficient antennas by referring to sustainability values and energy consumption indicators and metrics. **Use 5:** A 6G designer develops network architectures that improve accessibility for rural populations by integrating the ontology's societal KVIs. **Use 6:** A technology provider could use the ontology to evaluate the performance of their products or systems, for example track how their 6G base station designs reduce carbon emissions or improve energy efficiency. **Use 7:** A business analyst can use the ontology to evaluate the economic impact of sustainability efforts in the commercialisation and adoption of 6G technologies They use the economic KVIs as a reference to perform the cost analysis of implementing sustainable practices in 6G infrastructure. **Use 8:** A research institution utilises the ontology outcomes to conduct interdisciplinary research linking societal and environmental KVs, such as exploring how "digital inclusion" correlates with "economic growth."

	Use 9: A research project validates and refines the ontology by testing its metrics in case studies, such as assessing a 6G deployment's contribution to achieving UN Sustainable Development Goals (SDGs). **Use 10:** A standardisation organisation promotes the ontology as a common framework for societal and environmental impact assessment. **Use 11:** A standardisation organisation can use the ontology as a reference framework, as it can provide a shared vocabulary of Key Values (KVs) and Key Value Indicators (KVIs) that they can incorporate into their standards, such as mandating energy efficiency targets for 6G base stations. **Use 12:** The ontology helps a standardisation organisation align and harmonise industry, policy, and societal goals. **Secondary Uses:** **Use 1:** A civil service organisation uses ontology to evaluate the impact of technology adoption on communities and ecosystems. For example, they intend to monitor the impact of 6G deployments on marginalised communities using societal KVIs related to rural populations. **Use 2:** A civil service organisation uses societal indicators to advocate for accountability and transparency in 6G initiatives by bringing the societal perspective to technology assessment. **Use 3:** A civil service organisation uses the framework to advocate for fair pricing models by analysing KVIs related to the cost of connectivity. **Use 4:** An academic institution utilises the ontology to develop models for measuring societal and environmental progress. **Use 5:** An EU initiative representative uses the standardised value framework in the ontology to assess how 6G technologies align with regional and national priorities and track progress toward EU-wide goals. **Use 6:** An EU initiative uses ontology to evaluate proposals for 6G research funding based on alignment with societal KVIs. **Use 7:** A national initiative representative uses the ontology to advocate for inclusivity and sustainability in 6G development on a national level by benchmarking national performance in 6G sustainability using the defined environmental KVIs.
6	**Ontology Requirements**
	a. Non- Functional Requirements
	NFR1: The ontology must be scalable to accommodate the evolving and expanding 6G ecosystem, with the ability to integrate new technologies, metrics, and indicators as they are developed. **NFR2**: The ontology must have a clear and consistent structure, ensuring that all terms, classes, and relationships are well-defined and coherent, preventing ambiguity and enabling accurate interpretation and use across various stakeholders. **NFR3:** The ontology must be organized in a modular fashion, with clear delineations between different domains, allowing for separate updates without affecting the overall structure. **NFR4:** The ontology must support systematic knowledge acquisition from research projects, initiatives, and 6G designers, enabling the reuse and reengineering of non-ontological resources (e.g., reports, questionnaire results) to ensure alignment with domain-specific needs and evolving 6G priorities. **NFR5:** The ontology should integrate seamlessly with existing standards, tools, and frameworks used in the 6G domain, such as those developed by ITU, 3GPP, and ETSI, supporting formats like RDF and OWL.

	NFR6: The ontology must be intuitive and user-friendly for both technical and non-technical stakeholders, providing clear and consistent naming conventions for classes, properties, and relationships and including comprehensive documentation. **NFR7:** The ontology must offer flexibility to support multiple use cases across all three dimensions of sustainability, by supporting a wide range of users, including policymakers, industry, designers and researchers. **NFR8:** The ontology must be easy to update and maintain over time. **NFR9:** The ontology must be accessible to all stakeholders, regardless of technical expertise or resource availability. **NFR10:** The ontology must be transparent in its structure, purpose, and sources. **NFR11**: The ontology must promote ethical and inclusive practices in its use and development, ensuring representation of diverse societal perspectives, including marginalized groups, in the defined Key Values and Indicators. It must avoid bias in structure or content, such as unintended prioritization of certain metrics over others. **NFR12:** The ontology should support validation mechanisms to allow stakeholders to review, test, and refine its structure and components based on real-world use cases. **NFR13:** The ontology should support a multilingual scenario by ensuring adaptability to multiple languages, including English, Spanish, French, and others, as needed for international use. **NFR14:** The ontology should reflect global societal priorities, such as the UN Sustainable Development Goals (SDGs), and enable alignment with frameworks like the European Green Deal.
	b. Functional Requirements
	FR1: The ontology must serve as a knowledge base for the 6G value ecosystem, allowing multiple stakeholders to access, query, and analyse Key Values, Indicators, and metrics. **FR2:** The ontology must provide a common set of key values at its upper level, with sublevels defining their indicators (KVIs) and agreed-upon metrics. **FR3:** The ontology should define a Key Sustainability Indicators (KSIs) level **FR4:** The ontology must support decision-making by providing query mechanisms that are simple yet expressive for extracting relevant insights according to intended uses. **FR5:** The ontology must support automatic reasoning to infer new relationships or dependencies based on new data and priorities provided. **FR6:** Ontology must describe concepts and offer definitions that express the environmental, societal and economic domains of sustainability. **FR7:** The ontology must represent and support both quantitative (e.g., numerical metrics) and qualitative (e.g., descriptive relationships) contexts. **FR8:** The ontology should enable the representation of trade-offs between Key Values. **FR9:** The ontology must provide detailed documentation of Key Values, Indicators, and metrics, including their definitions, relationships, and sources, to ensure transparency and stakeholder validation. **FR10:** The ontology must link Key Values to corresponding Key Value Indicators and metrics, enabling traceability between high-level principles and specific measurable outcomes. **FR11:** The ontology should define relationships between stakeholders (e.g., policymakers, industry actors, designers, etc.) and the Key Values and Indicators they influence or are accountable for. **FR12:** The ontology must capture and formalize interdependencies between stakeholders, Key Values, and Indicators to enable a holistic view of 6G's societal impact. **FR13:** The ontology must enable context-specific adaptation, allowing users to refine Key Values and Indicators based on regional or national priorities (e.g., EU vs. developing nations). **FR14:** The ontology must provide visualisation tools or outputs, such as diagrams of the value taxonomy.
	Groups of Competency Questions

	General Queries
	CQ1: What are the Key Values categorised under the societal/environmental/economic domain? **CQ2:** What Key Value Indicators are defined for measuring a specific Key Value (e.g., digital inclusivity)? **CQ3:** Which Key Values are related to the environmental impact of 6G technologies? **CQ4:** What are the hierarchical relationships between Key Values and their subcategories? **CQ5:** Which stakeholders are accountable for a specific Key Value or Indicator? (e.g., Industry actors, policymakers, standardisation organisations) **CQ6:** How are industry actors influencing societal Key Values? (e.g., role and provided indicators) **CQ7:** What metrics are associated with a specific KVI (e.g., energy efficiency)? **CQ8:** What is the relationship between a specific Key Value and its corresponding metrics? **CQ9:** What trade-offs exist between two Key Values (e.g., "Accessibility" vs. "Cost-Efficiency")? **CQ10:** How do metrics for two different indicators compare? **CQ11:** Which Key Values are critical for developing nations?
7	**Pre-Glossary of Terms**

APPENDIX C – SNS KVI PROJECT QUESTIONNAIRE

Understanding the Landscape
Are KVIs integrated into your workflows, and if so, how are they applied?
Are KVIs integrated into your workflows, and if so, how are they applied?
How does your understanding of KVIs align with stakeholders' expectations?
Which partners are responsible for defining and monitoring KVIs?
How is collaboration between partners facilitated when dealing with KVIs?
Are there any specific groups underrepresented in KVI discussions? Kindly provide examples
Are you using any existing tools or frameworks for KVI management?
How is data currently collected and validated for KVI measurement?
Which verticals do these KVIs apply to?
Are there any secondary verticals that the project indirectly impacts?
What are the key objectives of the project within each covered vertical?
KVI definition
What Key Values have you identified and are working towards in the context of your project?
How did you derive these values?
What are the respective KVIs related to the above values? (more than one KVI can serve the same KV)
Kindly provide your KVI definitions/descriptions in the context of your project.
What are the use cases under which these KVIs will be evaluated?
Are the KVIs in your project explicitly linked to KPIs? If so, how?
Can you provide examples where a specific KVI metric is directly linked to a use context?
Can you provide examples where a specific KVI is mapped to an enabler?
Can you provide examples where a specific KVI metric is directly linked to a system parameter (as components, not targets)?
Are KVIs and KPIs treated as distinct frameworks, or are they integrated into a unified system?
KVI Standardisation
What are the essential criteria that you can identify for a KVI to be standardised across different projects?
Has your project come across conflicting interpretations of KVIs? In your experience, how should they be addressed?
Are there any regional or national variations in KVI priorities that you have identified and should be considered?
How can trade-offs between conflicting values be managed?
Data Management
What are the primary data sources for tracking KVIs in your projects?
How is the accuracy and reliability of these data sources ensured?
What role does automation currently play in KVI data collection and analysis?

How is KVI-related data shared among stakeholders?
What measures are in place to address data privacy and security concerns?
Standardisation Activities
Is your project involved in standardization activities relative to 6G deployment? If yes, can you kindly asnswer the following questions?
Is your project currently participating in any standardisation working groups (WGs)? If yes, please specify which ones.
How does your project contribute to these WGs?
Are there any WGs or committees that your project plans to contribute to in the future?
What are the key 6G-related areas or topics that you plan to address in these groups?
Is your project engaged with any of european or international standardisation bodies? If yes, please describe the scope of your contributions.
Has your project worked on aligning KPIs/KVIs with existing sustainability frameworks (e.g., CEN-CENELEC standards)?
Is your project involved in developing or using a standard taxonomy or ontology for 6G-related research? (could be deleted)
What challenges have you encountered in aligning your project outcomes with existing taxonomies/ontologies?
Do you collaborate with other SNS JU streams projects on standardisation-related activities? If yes, how?
Are there any specific areas where improved collaboration or knowledge sharing could enhance the standardisation process?
What are the main challenges your project faces in contributing to 6G standardisation efforts?
Are there any existing standards (e.g., 5G standards, AI-related standards) that your project is leveraging or building upon?
Does your project have a standardisation plan or roadmap? If yes, how do you plan to transition your project results into relevant standard bodies?
What are the main areas where you believe existing standards are insufficient or incomplete for 6G?
In your experience, which new use cases require the development of entirely new standards?
Based on your work, do you believe entirely new standards are needed for specific 6G application domains?
Any other questions or comments?

APPENDIX D – 6G DESIGNERS KVI QUESTIONNAIRE

Designers KVI Questions
How do you incorporate KVIs into the design and development phases of 6G systems?
Are KVIs treated as "value-by-design" principles, similar to privacy and security? If so, how is this implemented in your design workflows?
When did you decide to treat a specific KVI like a KPI, and when did you choose not to focus on technology-centric metrics?
What is the process for defining the impacts of these values on technology design and societal outcomes?
How do you prioritize between competing values, such as environmental sustainability, societal inclusivity, and economic feasibility?
Do you use examples or benchmarks for Key Values when designing solutions? If so, please provide examples.
How do you map KVI metrics to specific system parameters and KPIs in your design process?
Are there trade-offs between optimizing system parameters for KPIs and achieving long-term KVI goals? How are these addressed?
How do you ensure that technology development processes are informed by and aligned with the KVIs?
Do you involve stakeholders in defining and validating KVIs for your designs?
Are co-design methods or participatory research approaches used to incorporate stakeholder voices early on? If so, what techniques have been most effective?
What methods exist in your design process to better validate KVIs with respect to their relevance to people, environments, and economies?
How do you measure the success of KVI integration into your designs?
Are there examples of iterative feedback from real-world applications or trials that have influenced your KVI framework?
How do you foresee the role of KVIs evolving in 6G system design over the next few years?
What challenges have you encountered in integrating KVIs into the 6G design process, and how have you addressed them?
Are there emerging values or priorities that you believe should shape the next generation of 6G designs?

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APPENDIX E – KEY EXPLOITABLE RESULTS TABLE

Partner	KER	Relevant Description/Activities	Relevance to other work	Your Exploitation Interest/Plan (exploitation intention of the KER)
	Technology Acceptance Model (Consultancy services)		**D1.1** Societal aspects in 6G Technology: concerns, acceptance models and sustainability indicators (M09). **D2.3** Public Positions on 6G Technology (M24). **D3.2** 6G-IA Paper "Social Acceptance of 6G Technology" (M24).	**MAR:** Offer new innovation management and consulting services in the R&D&I context with a focus on 5/6G. **CEL:** Fine-tuning and exploiting its social acceptance (SAT) methodology to assess societal implications of 6G technology and applications, built during 5G-PPP experiences, as well as at acquiring new knowledge and know how to advance and enrich its current offering in terms of analysis and assessment models for 6G-IA initiatives. Findings, knowledge and know-how acquired will be used to foster CEL services towards public and private entities, and in the context of our training and education activities. Moreover, as member of UNI CT 533 (belonging to CEN/CLC JTC1), CEL will evaluate the contribution to ethics and assessment related standards working groups (e.g. IEEE P70xx, ISO/IEC JTC 1/SC 42 and JTC21) with the outcomes of this project.
	Key Sustainability Indicators (Consultancy services)	T1.4: Engage (both internal and external) experts in judgment activities (e.g. interviews, focus groups, roundtables, workshops) - Outcome: contribution to mapping and recommendations & policy options - policy brief + input to KVIs/KSIs + list of contacts - established liaisons.	**D1.1** Societal aspects in 6G Technology: concerns, acceptance models and sustainability indicators (M09). **D3.3** 6G-IA Paper "Key Sustainability Indicators for 6G Technology" (M24).	
	Key Sustainability Indicators (Consultancy services)	T1.4: Engage (both internal and external) experts in judgment activities (e.g. interviews, focus groups, roundtables, workshops) - Outcome: contribution to mapping and recommendations & policy options - policy brief + input to KVIs/KSIs + list of contacts - established liaisons.	**D1.1** Societal aspects in 6G Technology: concerns, acceptance models and sustainability indicators (M09). **D3.3** 6G-IA Paper "Key Sustainability Indicators for 6G Technology" (M24).	
	Feedback to policy measures	regulatory framework (AI Act, Chips Act, GDPR, NIS2....) - Outcome: Identify any potential strengths, challenges, concerns, risks, gaps: opportunities and threats within the regulatory framework, specific to 6G and its industry, processes, products, and to map them to different national policies and organisation operation guidelines - elaborate map of relevant initiatives. & Engage (both internal and external) experts in judgment activities (e.g. interviews, focus groups, roundtables, workshops) - Outcome: contribution to mapping and	**D1.2** Towards a socially accepted and sustainable 6G - Policy Brief (M24). **D2.1** Public engagement strategy and plan (M06).	
	Feedback to operation measures	T1.4: Monitor the existing and continuously evolving regulatory framework (AI Act, Chips Act, GDPR, NIS2....) - Outcome: Identify any potential strengths, challenges, concerns, risks, gaps: opportunities and threats within the regulatory framework, specific to 6G and its industry,	**D1.3** Towards a socially accepted and sustainable 6G - Operations Brief (M24)	
		Engage with existing working groups and with ongoing SNS projects acting as a cross-cutting and cross-sector connector. Provide multidisciplinary advice and promote the experimentation, validation and take-up of its outcomes. & The final objective will be to support the adoption and integration of key founding values within standardisation		

Background (BG) | Foreground (FG) | KERs | 3rd Party Software used