HEXA-X-II

A holistic flagship towards the 6G network platform and system, to inspire digital transformation, for the world to act together in meeting needs in society and ecosystems with novel 6G services

Deliverable D1.3
Environmental and social view on 6G

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Abstract

This document presents an analysis of the obstacles and uncertainties in achieving environmental, social, and economic sustainability for 6G and for 6G-supported solutions. It offers an initial perspective on societal expectations and feedback, as well as outlining the business models for the remaining three Representative Use Cases (RUCs). Furthermore, it offers an examination of the business ecosystem, identifying key stakeholders, building upon the initial insights on business and revenue models provided in the Hexa-X-II D1.2 deliverable "6G Use Cases and Requirements".

Keywords

6G, Social acceptance, social engagement, environmental/social/economic 6G sustainability, 6G-supported environmental/social/economic sustainability, 6G business models, 6G key stakeholders, challenge, risk, mitigation plan

Executive Summary

This deliverable focuses on the study of peoples' concerns and needs from current and future networks. The aim is to start engaging society from the beginning of the 6G design, listening to their needs and focusing on their concerns in order to design next generation networks that address them. To achieve this, D1.3 starts from the analysis of surveys conducted for existing and future networks. The surveys emphasize the dynamic nature of social acceptability concerning technological advancements, shaped by factors like COVID-19, cultural norms, individual beliefs, ethical considerations, different geographies and perceived societal impact. User preferences in adopting and using technology are mainly influenced by environmental awareness, curiosity, facilitating conditions, and perceived satisfaction.

In parallel, the challenges, the risks and the mitigation strategies to meet environmental, social and economic sustainability aspects related to all stakeholders for each Hexa-X-II Representative Use Case (RUC) are identified. The aim of this analysis is to be proactive so as to ensure that 6G will have a positive effect in peoples' lives, be prepared and identify ways to balance conditions that may limit the contribution of 6G or 6G environmental, social and economic sustainability handprints[3], or allow the sustainability footprints[4] to grow larger.

In the context of Hexa-X-II, **challenges** refer to difficulties or resistance that may prevent realization of the sustainability handprints [2] and achieve minimization of the sustainability footprints [3].The analysis revealed that the main environmental, social and economic challenges (shared within different and more than one Use Cases - UCs) include:

- Designing and implementing resource-efficient communication systems, including both materials and energy.
- Ensuring backwards compatibility and interoperability on hardware and software levels for e.g., maximizing the usage of existing infrastructure.
- Design for circularity, i.e., design hardware to be durable, easily upgradable, able to be disassembled, recyclable, reusable, and modular; etc.
- Strategic deployment planning and network architecture by balancing flexibility, interoperability, and capacity requirements, also while optimizing the choice between terrestrial (TN) and non-terrestrial network (NTN) elements.
- Identifying and using environmentally friendly materials in the production of 6G devices and infrastructure to reduce environmental impact.
- Promoting sustainable and efficient spectrum usage and sharing.
- Maximizing the adoption of renewable energy sources and the integration of smart grid technologies depending on the country and the respective regulations.
- Comprehensive lifecycle assessments are pivotal to understand the hotspots in a product or system, but simpler and applicable methodologies are needed to be used more broadly.
- Social engagement and building trust in the use of the new technologies while taking into account cultural and regulatory aspects of all countries.
- Increasing network investments due to e.g., increased amount of data, and infrastructure costs for digital inclusion.
- Building new business models, e.g., new types of collaborations, contracts and financial flows, and incentives for attracting large investments for the benefit of the society.

[2] Sustainability Handprints: In the context of Hexa-X-II, the term "handprints" refers to the positive effects enabled by a 6G-enabled solution. These encompass positive first-order, second-order, and higher-order environmental, social, and economic effects that do not only help mitigate and reduce direct negative effects but also generate additional positive contributions to the environment, society, and economy

[3] Sustainability Footprints: In the context of Hexa-X-II, the term "footprint" is defined in alignment with ITU-T L.1480 [L1480], encompassing direct, i.e., first-order negative environmental effects, extended to direct negative social and economic effects. Furthermore, the Hexa-X-II definition of sustainability footprints includes second-order and higher-order environmental, social, and economic negative effects.

Discussing the above challenges within different use cases revealed two cross-sectorial challenges.

The first one refers to the need to balance the sustainability goals, either within the same sustainability axis or among different sustainability axes. For example, energy use from renewable sources vs. materials needed for building e.g., solar generators, and economic costs for the same reasons; digital inclusion vs. low environmental and economic costs; critical situations vs. environmental and economic costs, etc. Further studies of the trade-offs taking into account more detailed UC descriptions, conditions, implementation approach and technology enablers is needed.

The second cross-sectorial challenge is related to the need for engaging society both during the design of the solutions but also during their deployment and use. Awareness and consensus of the targeted sustainability goals as well as guidelines, good practices and regulations that promote the targeted sustainability goals and their balance are required.

Analyzing further the challenges, the authors identified potential related risks. In Hexa-X-II, **risks** refer to both the likelihood of not realizing the UC sustainability handprints and of sustainability footprints becoming larger than initially estimated. Risks also include the likelihood of the UC resulting in not yet identified footprints. The most common risks related to all sustainability axes are:

- New possibilities to become so pervasive/successful, that will demand increased consumption of energy and other resources, and thus economic costs as well.
- Reduced exploitation of the new technologies either due to e.g., their capabilities, humans' reluctance to use or distrust of new technologies, high cost of ownership or other economic factors, resulting in environmental and economic costs that could have been avoided.
- Recycling processes may struggle to adapt to the fast-paced technological evolution and the increasing complexity of devices.
- Regions with less developed waste management infrastructure, or access to recycling facilities may struggle to handle the disposal and recycling of electronic devices. This can lead to improper disposal practices, such as open burning. Toxic e-waste dumping in developing countries may also increase.
- Digital division due to devices / services affordability / high costs
- Affordability of the spectrum for the national stakeholders
- Fragmentation of ecosystem: several regional 6G standards
- Lack of interoperability and compatibility on all levels among stakeholders that could collaborate for e.g., sharing economic costs.
- Limitations or restrictions in the way spectrum is authorized, used or managed in different regions/countries.

Mitigation strategies were also studied for each risk. A **mitigation strategy** is a plan to reduce or eliminate the impact of a potential risk. The plan should take into account what technical decisions / technologies can be applied on the 6G blueprint for avoiding the risk but also recommendation to stakeholders outside of the ICT sector, e.g., policy makers. The identified mitigation strategies mostly refer to:

- Smooth inclusion of digital/remote services (e-health, remote education, teleworking, Digital Twins, etc.) in society's current practices and lives so as to allow people with different backgrounds to adapt.
- Education and awareness with clear messages about the new services benefits and risks from their extensive use (within all the sustainability axes).
- Modular design of the devices and the network equipment that allows re-use and circularity.
- Security and privacy by design as well as transparency in Artificial Intelligence (AI)/ / Machine Learning (ML)-based mechanisms that support decision-making processes.
- Standardization activities that will ensure interoperability across different stakeholders.
- Business models that allow collaboration among stakeholders.

This analysis is based on Hexa-X-II D1.1 "Environmental, social, and economic drivers and goals" work, where some of the challenges were already discussed according to the literature review, and builds on top of Hexa-X-II D1.2 "6G Use Cases and Requirements", where the representative Use Cases are described and analysed, including the sustainability handprints and footprints. The stakeholders that could apply the mitigation strategies for the benefit of all stakeholders are also discussed within this report, complementing the 6G ecosystems.

Table of Contents

List of Tables

List of Figures

Acronyms and abbreviations

Term	Description
6G	Sixth-Generation Technology for Wireless Communications
AI	Artificial Intelligence
B2B	Business-to-Business
B2C	Business-to-Consumer
DSP	Digital Service Provider
DT	Digital Twin
E2E	End-to-End
EMF	Electromagnetic Field
ESG	Environmental, social, and governance
ETNO	European Telecommunications Network Operators
EU	European Union
GHG	Greenhouse Gases
ICT	Information and Communication Technology
IMT	International Mobile Telecommunications
IoT	Internet-of-things
IPR	Intellectual Property Rights
JCAS	Joint communication and sensing
KVI	Key Value Indicator
MINETAD	Ministry of Energy, Tourism, and Digital Agenda
ML	Machine Learning
NGOs	Non-Governmental Organizations
NR	New Radio
NTN	Non-Terrestrial Networks
PPDR	Public Protection and Disaster Relief
QoS	Quality of Service
R&D	Research and Development
ROI	Return on Investment
RUC	Representative Use Case
SDG	Sustainable Development Goal
SNS JU	Smart Network and Services Joint Undertaking
SW	software
TN	Terrestrial Network
UC	Use Case

US	United States
USD	United States Dollars
WHO	World Health Organization
WP	Work Package

Definitions

Term	Description
Challenge	Challenge is the situation of being faced with something with known end point that is difficult to achieve, needs great effort in order to be done successfully and therefore tests the subject's (person's or technology's) ability. In the context of Hexa-X-II, challenges refer to difficulties or resistance that may prevent the Use case (UC) sustainability handprints[4] and minimization of the sustainability footprints[5] and therefore jeopardizing the potential 6G benefits for environmental, social or economic sustainability.
Risk	The term 'risk' is often associated with the possibility that an undesirable outcome and/or effects may occur due to external factors that acts as a hindrance and has not been taken into account when outlining the challenges. The future outcomes after a risky situation are perceived as something unpredictable and uncontrollable. In Hexa-X-II, risks refer to both the likelihood of not realizing the Use Case (UC) sustainability handprints and of sustainability footprints becoming larger than expected. Risks also include the likelihood of the UC resulting in not yet identified footprints. In order to identify the risks, one needs to analyse further the challenges, and describe what could go wrong so that the UC does not meet the sustainability handprints, or the sustainability footprints grow larger.
Mitigation strategies	A mitigation strategy is a plan to reduce or eliminate the impact of a potential risk. The plan should take into account what technical decisions / technologies that can be applied on the 6G blueprint to help avoiding the risk not to meet environmental, social and economic sustainability targets, i.e., reduce the probability that the undesired outcome happens, or managing it in terms of reducing the undesirability of the outcome but also recommendation to stakeholders outside of the ICT sector, e.g., policy makers.
Sustainability Handprints (as defined in Hexa-X-II D1.2)	In the context of Hexa-X-II, the term "handprints" refers to the positive effects enabled by a 6G-enabled solution. These encompass positive first-order, second-order, and higher-order environmental, social, and economic effects that do not only help mitigate and reduce direct negative effects but also generate additional positive contributions to the environment, society, and economy
Sustainability Footprints (as defined in	In the context of Hexa-X-II, the term "footprint" is defined in alignment with ITU-T L.1480 [L1480], encompassing direct, i.e., first-order negative environmental effects, extended to direct negative social and economic effects. Furthermore, the Hexa-X-II definition of

[4] Sustainability Handprints: In the context of Hexa-X-II, the term "handprints" refers to the positive effects enabled by a 6G-enabled solution. These encompass positive first-order, second-order, and higher-order environmental, social, and economic effects that do not only help mitigate and reduce direct negative effects but also generate additional positive contributions to the environment, society, and economy

[5] Sustainability Footprints: In the context of Hexa-X-II, the term "footprint" is defined in alignment with ITU-T L.1480 [L1480], encompassing direct, i.e., first-order negative environmental effects, extended to direct negative social and economic effects. Furthermore, the Hexa-X-II definition of sustainability footprints includes second-order and higher-order environmental, social, and economic negative effects.

Hexa-X-II D1.2)	sustainability footprints includes second-order and higher-order environmental, social, and economic negative effects.

1 Introduction

In order to provide useful technologies and infrastructure we need to keep in mind the needs and the concerns of the end-users. Moreover, a technology needs to be sustainable and also promote sustainability, both in economic terms as well as other values related to the environment and the social aspects, so as to attract also the other stakeholders' interest. We need technology innovators and researchers to investigate new solutions, infrastructure providers and operators to support the telecommunication means, policy makers to regulate the process and its interoperability with past and future technologies and many more.

The objective of Hexa-X-II is to design a system blueprint aiming at a (environmental, social and economic) 6G platform, that should meet the future needs of serving and transforming society and business. Sustainability aspects are considered towards two directions: a) making 6G sustainable and b) 6G for sustainability, i.e., including the means that will allow 6G to support solutions that will promote sustainability in different verticals. Moreover, sustainability within Hexa-X-II are based on three pillars: a) environmental, b) social and c) economic sustainability.

1.1 Objective of the Document

The aim of this document is to set the grounds for social acceptance and provides the analysis of the challenges and risks to meet environmental, social and economic sustainability for the 6G technology, networks and solutions. Potential improvement strategies (in the technical design and in the policies and practices) are further proposed so as to increase the sustainability benefits of 6G solutions and services while limiting unwilling and unexpected effects. Eventually, this will allow the involved stakeholders to be prepared and act proactively for such cases and thus, ensure 6G sustainability and 6G for sustainability.

The document starts with the analysis of existing and ongoing surveys on advanced communication services collected from citizens. Their feedback highlights some of the challenges and the risks to meet the three sustainability types (see Definitions section for more details). The footprint and handprint sustainability analysis for each representative Use Case (RUC) in Hexa-X-II D1.2 [HEX223-D12] also prepared the grounds for identifying more such challenges and risks. The proposed mitigation strategies involve technical decisions or technologies that can be applied on the 6G blueprint to help avoiding the risk not to meet environmental, social and economic sustainability targets and/ or recommendations to stakeholders outside of the ICT sector, e.g., policy makers.

A Stakeholder analysis of all representative UCs (three in D1.2 and three in this deliverable) are taken into account for verifying that challenges and risks have been investigated for all involved parties. This analysis is then complemented by highlighting stakeholders that have the expertise for realizing them, i.e., which could decide on and apply the mitigation strategies for the benefit of all.

1.2 Structure of the Document

This document is structured as follows: Section 2 aims at providing an understanding of the concerns in society regarding current and future networks. It focuses on existing and ongoing surveys on society's acceptance of the advanced communication services. Section 3 gives details related to the business models for the three remaining RUCs, i.e., Cooperating Mobile Robots, Network Assisted Mobility, Human Centric Services[6]. Section 4 presents the methodology followed for the identification of the challenges, the risks to meet environmental, social and economic sustainability and the mitigation strategies. It, furthermore, summarizes them providing also information of the representative UCs where we came across each risk. The extended Use Case (UC)-based analysis of challenges, risks and mitigation strategies can be found in Annex 1.

Section 5 addresses all the 6G ecosystem, expanding towards all directions (technical, business, sustainability and value related aspects). Finally, conclusions are drawn in Section 6.

[6] the other representative use cases were analyzed in Hexa-X-II D1.2 [HEX223-D12]

2 Develop an Understanding of Society's Expectations and Needs Regarding Networks

As part of the Hexa-X-II project, our ambition is to reach an initial understanding of society's expectations and needs regarding networks. We want the next generation of networks to enable a more sustainable development of the world, thereby including these aspects from the start of the development process. Thus, it is essential to start by having a comprehensive vision that allows us to grasp the general expectations of individuals in a constantly evolving world, marked by crises and technological advancements. Faced with these global phenomena, individuals' behaviors are inevitably heavily influenced. In order to launch a new generation of networks, it is therefore crucial to understand society's expectations and adopt a dialogue-based approach between the telecom ecosystem and representatives of the society. This chapter explores this perspective.

Examining the Debates Surrounding 5G Technology

In analyzing the controversies surrounding the implementation of 5G technology, one cannot help but observe a prevailing narrative that portrays the digitalization of society as an unavoidable phenomenon to which the population must adapt [BZ22]. However, it should be noted that, long before the introduction of 5G, parts of society have been reluctant to the increasing digitalization of everyday life.. The aim of this first section is to present an assessment of the discussions surrounding 5G technology. Nevertheless, clarifications need to be mentioned. Firstly, these debates bring to light both negative and positive perceptions of the network. Moreover, these controversies primarily focus on 5G, but it often serves as a vector: the public associates it with the broader digital sphere and consequently tends to project its criticisms onto 5G [Noc22]. Hence, what sets this 5th generation apart is that its introduction has sparked some strong reactions, even before its widespread international implementation. Lastly, it is crucial to acknowledge these debates because these weak signals still carry significance and can generate strong opposition within society: hence, it is essential to build 6G with society and for society. There exists a difference in the reactions depending on the region of the world; nevertheless, on a global scale, these controversies seem to revolve around similar themes: health, environment, security, and democracy. The different elements constituting those perspectives are detailed below.

The first theme refers to possible health concerns related to the use of wireless technologies. The negative effects highlighted notably include exposure to electromagnetic fields [Del20]. Although the World Health Organization (WHO) and several governmental authorities have concluded that there are no substantiated health effects below international Electromagnetic Field (EMF) limits, public concern about EMF exposure from 6G may arise [EC22]. Several factors contribute to this lack of trust, and having a clear communication with society on this subject can help mitigate it.

Next, the question of the environmental impact of 5G throughout its value chain is also raised. This includes increased metal extraction, terminals production, dependence on energy resources, and energy consumption [Cho20]. The end-of-life of equipment is a central issue as it often requires changing mobile phones to benefit from 5G although some initiatives have been put in place, notably by vendors, to recycle old phones. Finally, the increased performance enabled by 5G is criticized for its potential role in increasing mobile usages (rebound effect).

The security impact arises from concerns about the use of personal data and increased vulnerability to cyberattacks [EC20]. These questions arise particularly due to improved localization capabilities and parallel development of artificial intelligence. Furthermore, society's increasing dependence on this network, if 5G is widespread or globally deployed, raises questions of state sovereignty and country resilience in the event of a widespread outage.

Finally, the democratic aspect, although less prominent than the previous ones, also raises some concerns. In this regard, what is criticized is the fact that the network deployment did not undergo any national consultation or discussion, despite affecting everyone. In some countries, democratic demands are quite vivid, for example in France and Switzerland, while in others, like the Scandinavian countries, challenges to the government are much rarer due to a higher trust in governments [OEC22]. For instance, in Switzerland, elected officials at the local level have encountered resistance from national authorities in their attempts to enforce moratoria on 5G deployment [Car20], showing a certain imbalance of power which tends to be criticized.

These concerns expressed by the public manifest concretely in increased tensions, sometimes leading to acts of vandalism, as observed throughout Europe from 2020. The proliferation of fake news about 5G only fuels these strong sentiments towards the network [SA20].

One may wonder why the previous generations of networks did not seem to attract the same number of controversies. It is essential to note that those generations have received a certain amount of criticism, however, 5G sets a precedent in this regard. The public's perception of this network has been heavily influenced by contextual factors such as the COVID-19 pandemic, climate change, and globalization of trade [Noc22]. In addition, social media have played a major role in spreading information, including fake news and conspiracy theories, such as those linking the spread of COVID-19 to the deployment of 5G [AVD+20].

These factors shed light on the distinctive nature of the opposition to 5G.

Social Acceptability

In the discourse surrounding the introduction of new technologies like 5G, the concept of social acceptability frequently emerges as a topic of discussion. Social acceptability, often interchangeably referred to as 'social acceptance', is not encapsulated by a singular, universally acknowledged definition.

In Hexa-X-II, the term is used according to the following definition: "a condition that results from a judgmental process by which individuals (1) compare the perceived reality with its known alternatives; and (2) decide whether the “real” condition is superior, or sufficiently similar, to the most favorable alternative condition" [Bru92]. However, this term is increasingly criticized, for two main reasons. First, it implies a top-down approach, where projects are imposed on society without real discussion, and where public reception only comes into play after the completion of the technology creation process. Then, it simplifies the complexity of the issues by reducing them to a binary situation of "in favor of" or "against". Yet, the question of "why?" remains central to the challenges of a technology that ideally should provide solutions to previously identified problems and added value to consumers.

Hence, as part of Hexa-X-II, we want to promote a more nuanced reflection and a better understanding of the social impacts of projects. This involves transparency, effective communication and engagement in a meaningful dialogue with society. The complexity of the issues at stake and the analysis of all aspects of the project need to be considered beyond mere acceptance or rejection. It is imperative to adopt a broader perspective when examining the behavioral outcomes arising from the implementation of a new technology. By embracing a macro lens, we can shed light on these behaviors and identify overarching patterns.

2.1 Analysis of Previous Surveys on Advanced Communication Services

Building on the analysis of trends in environmental, social, and economic sustainability outlined in Hexa-X-II D1.1 [HEX223-D11], this chapter delves into the analysis of the available surveys on innovative network services, exploring global perspectives on citizens’ attitudes and concerns towards technological advancements, with an emphasis on trustworthiness and digital inclusion.

The European Commission's strategic focus for 2019-2024 centers on building "a Europe fit for the digital age," aiming to empower citizens, businesses, and governments in leveraging the benefits of the digital environment [EC19]. This strategy is structured around three pillars. The first pillar 'Technology that works for the people', encompasses investments in digital skills, cybersecurity measures, and the rapid deployment of ultra-fast broadband. Moving to the second pillar, 'A fair and competitive digital economy', focuses on adapting EU rules to the digital economy and strengthening online platform accountability. Lastly, under the third pillar, 'An open, democratic and sustainable society', efforts are directed towards reducing carbon emissions in the digital sector and enhancing citizens’ control over their data.

In order to keep up with the accelerating pace of the dynamic evolution of the digital communications landscape, numerous government and private institutions engage in conducting opinion surveys to understand the public perception of the evolving digital environments. This chapter seeks to contribute insights into the social dimensions of advanced telecommunication services by examining some of these surveys, conducted by Deloitte [DEL22], EY [EY22], Ipsos [IPS20] and Traficom [TRA20]. These surveys were selected for their focused examination of cutting-edge telecommunications. In addition to those, two studies [Mak23] & [Cha22] focusing on the French territory will be presented: they offer insights on digital services on a more local scale. By centering on these specific surveys, the objective is to obtain a better understanding of citizens' attitudes, concerns, and needs in this technological domain. This careful selection ensures that the derived data and insights directly align with the evolving landscape of the telecommunications industry.

2.1.1 Post-pandemic survey of US consumers

To investigate consumer attitudes towards the "digital life," **Deloitte's Center for Technology, Media & Telecommunications** [DEL22] conducted a survey in the first quarter of 2022 involving 2,005 US consumers. The report has been summarized by showing statistics related to the expectation of 5G in various aspects of digital life, including devices (technology, entertainment, smart home, smartphones), connectivity (home internet and mobile), virtual experiences (work, school, and healthcare), wearables (fitness trackers and smartwatches), and the challenges associated with managing one's digital life. The respondents were categorized into generational groups and tech-adopter cohorts to provide a detailed understanding of various consumer segments. The survey was conducted post the era of COVID-19, revealing a shift in people's lives concerning their utilization of digital services.

When it comes to 5G service, in general, 48% of respondents expressed that the 5G service surpassed their expectations somewhat or significantly, while an additional 44% stated that it met their expectations. Dissatisfaction was minimal, with only 8% users reporting discontent. Notably, early adopters exhibited even higher satisfaction levels, with 72% indicating that 5G somewhat or significantly exceeded their expectations.

The pandemic brought about a substantial shift towards remote work and learning, with remote work evolving from a necessity during lockdowns to a preferred option for many. An overwhelming 99% of individuals who worked from home in the past year expressed appreciation for various aspects of the experience, for example work from home eliminated the need for commuting, enhanced comfort within the home environment, lowered risks of contracting COVID-19 or other illnesses and improved concentration on work tasks. The challenges, like juggling family or household responsibilities while working, dealing with unstable home internet services and working extended hours, have significantly diminished compared to before, as workers accumulate more experience, networks and devices are optimized, and there is reduced competition for bandwidth.

Virtual health care visits also gained popularity during the pandemic, with consumers using smartphones and wearables to manage health and fitness. Virtual medical experiences have seen an increase in satisfaction, with 92% of consumers expressing both very and somewhat satisfied responses. The primary advantages of virtual visits include convenience, a decreased risk of illness transmission, and ease in finding appointment slots. However, consumers also noted persistent challenges, such as the absence of face-to-face connection, difficulties in collecting vital signs, and technology-related issues.

On the other hand, while consumers strive to master their digital lives, challenges persist in addressing privacy concerns, controlling screen time, and managing technological complexities. A third of the respondents acknowledged falling victim to some form of hacking or scam, with 17% experiencing such incidents two or more times.

In essence, this survey conveys that despite numerous available measures to safeguard consumer data, many individuals have not embraced these security protocols. Although 71% took at least one step, typically prompted by mobile operating systems, only 21% implemented four or more measures. Even among those who experienced two or more breaches, the average number of protective measures taken was merely three.

Despite the prevailing concerns surrounding the deployment of 5G technology and advanced telecommunication services, consumers readily recognize and appreciate the positive influence that their devices and virtual experiences have on their lives. This acknowledgment underscores the growing significance of technology in enhancing various aspects of daily living. Furthermore, it reflects consumers' evolving attitudes towards striking a balance between their digital and physical worlds with a heightened sense of intentionality. This desire for equilibrium highlights a nuanced approach where individuals aim to leverage the benefits of technological advancements while remaining mindful of maintaining a harmonious coexistence between their digital and tangible realities.

2.1.2 Online survey of global enterprises

The **EY Reimagining Industry Futures Study** [EY22] derives from an online survey capturing perceptions of 5G and the Internet of Things (IoT) among 1,018 global enterprises. The survey was conducted by EY Romania between November and December 2021, and encompassed respondents from various industry sectors and regions. The results incorporated only the input of those participants who identified themselves as "moderately knowledgeable" or higher regarding IoT or 5G initiatives within their organizations.

The survey delved into executives' perspectives and intentions concerning emerging technologies, with a particular emphasis on IoT and 5G-based IoT. Key themes explored encompassed spending intentions on emerging technologies, Industry 4.0 use cases facilitated by 5G, and businesses' attitudes towards suppliers and collaborative ecosystems. The survey report also presents supplementary insights and recommendations grounded in enterprises' adoption of 5G-IoT and the dynamic transformations within their relationships with 5G-IoT providers.

The Study highlighted enterprises turning to 5G to address immediate business challenges resulting from the COVID-19 pandemic and associated global disruptions. Process optimization took precedence for 49% of respondents, surpassing the 28% favouring advanced 5G applications involving virtual or augmented reality. A notable 85% of respondents attribute their heightened interest in 5G to the repercussions of the global health crisis, a significant increase from 52% in the previous year's study. Supply chain disruptions motivate 80% of respondents to pursue 5G solutions, while 71% cite a focus on environmental, social, and governance (ESG) issues as a contributing factor. Despite these aspirations, there remains room for progress: 37% express concerns that current use cases from 5G and IoT vendors do not adequately address their business resilience and continuity requirements, and 47% believe today's use cases do not align with their sustainability objectives.

In conclusion, the study underscores a notable enterprise pivot to 5G, primarily driven by the urgent business challenges arising from the COVID-19 pandemic, with a strong emphasis on process optimization.

2.1.3 European 5G survey

Ipsos [IPS20], a prominent market research company, conducted a 5G survey for ETNO (European Telecommunications Network Operators' association). The online survey, conducted in August 2020, at the very beginning of 5G becoming available, engaged 7350 respondents distributed across 23 European countries. As 5G emerges as a transformative technology in cellular communication, its deployment across multiple European markets has generated concerns and strong resistance among certain citizens. This survey aims to provide an accurate and impartial representation of the public opinion regarding 5G.

The key findings from the survey are as follows:

1. **High Awareness, Low Understanding:** While almost all Europeans are aware of 5G, only one in four claims to have a good understanding of the technology. This highlights a significant gap between awareness and comprehension.
2. **Attitudes:** Younger Europeans tend to exhibit a more positive attitude toward 5G, while older individuals are often neutral. Positive attitudes strongly correlate with a better understanding of 5G.
3. **Uncertainty and Myths:** Approximately 50-60% of Europeans express uncertainty regarding certain 5G myths, with one in five individuals appearing to believe in these myths.
4. **Impact of Information Sources:** The number of information sources and the level of being informed significantly influence attitudes toward 5G. Information from government and telecom operators is highly trusted, while social media and advertisements are the least trusted channels.
5. **Perceived Advantages:** Higher speed and increased capacity are the most recognized benefits of 5G over 4G. Europeans with a better understanding of 5G know that it enables new technologies and possibilities.

Briefly put, this survey underscores a significant awareness-understanding gap about 5G among Europeans, with younger individuals displaying more positive attitudes, uncertainty prevailing over certain myths, the pivotal role of information sources influencing perceptions, and a correlation between awareness and knowledge in recognizing 5G's advantages.

2.1.4 Survey of Finnish consumers

In late summer 2020, the **Finnish Transport and Communications Agency** (Traficom) conducted a consumer survey [TRA20] on ICT sector services and devices, as well as consumers' interest in environmental issues. The survey aimed to support the Ministry of Transport and Communications' strategy on ICT sector, climate, and the environment. Conducted by IROResearch Oy, the survey interviewed 2,000 individuals aged 15 or above by telephone. The survey addressed views on environmental impact, service usage, device replacement frequency, and device recycling.

The respondents predominantly recognize the positive environmental influence of prolonging the use and recycling of various terminal devices, such as smartphones as shown in Figure 2-1 below. Furthermore, the reduction in travelling resulting from the widespread adoption of remote meetings is perceived as a positive contribution to environmental sustainability. The survey reveals that 55% of the participants express some level of interest in acquiring more information about the environmental impact of the ICT sector, while only the minority of the population show less interest in this regard [TRA20].

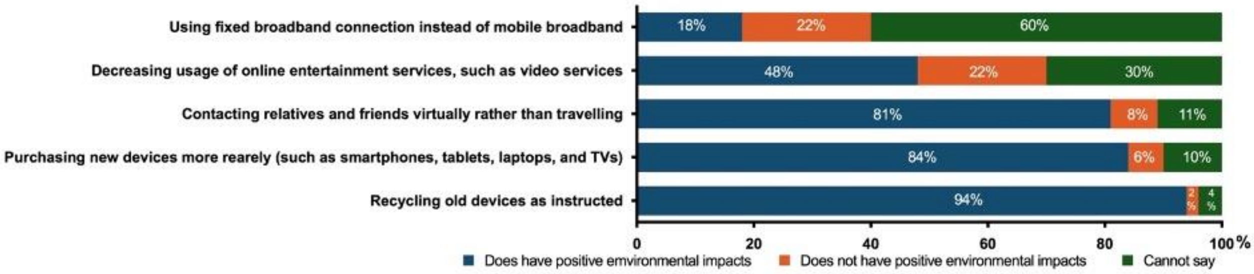

Figure 2-1: Consumers views on whether the choices made by them have positive environmental impacts [TRA20]

The findings of the survey underscore that the respondents possess a commendable level of awareness regarding the environmental impact of ICT devices, reflecting a collective inclination toward responsible behaviour. This trend is particularly heartening as Finland actively pursues its environmental goals. However, there is a limited segment of the population that requires additional information regarding how the service life of digital devices and services affects the environment and climate. The importance of providing reliable, easily understandable, and current information becomes increasingly apparent in the context of everyday life becoming more digitally integrated.

In summary, this survey highlights widespread recognition of the positive environmental impact of device use and recycling, particularly smartphones, reflecting commendable awareness; however, the need for additional information on digital devices' service life impact emphasizes the importance of accessible and current information in an era of increasing digital integration.

The above-mentioned four surveys underscore the dynamic nature of social acceptability concerning technological advancements, influenced by diverse factors such as COVID-19, cultural norms, individual beliefs, ethical considerations, and perceived societal impact. Technology adoption and usage behavior are chiefly shaped by environmental awareness, curiosity, facilitating conditions, and perceived satisfaction, highlighting the multifaceted nature of user preferences. Additionally, the surveys indicate the potential effectiveness of public environmental awareness campaigns in dispelling misconceptions, emphasizing the eco-friendly nature of advanced telecommunication technologies, and its minimal impact on privacy and the ecological system. Recognizing these challenges, the Hexa-X-II project is diligently addressing some of the privacy and ecological shortcomings and assessing the EMF exposure from new technology components with the aim of creating a 6G platform characterized by sustainability, inclusivity, and trustworthiness.

2.1.5 French Perspectives on digital services: Examining Public Perception in a Local Context

2.1.5.1 Citizen consultation on the environmental impact of digital technology

To continue on the subject of the environment, a consultation organized by Make.org at the initiative of Orange France in 2023 [Mak23], focusing on reducing the environmental impacts of digital technology, offers some insights for 6G. Participants were invited to answer the following question: "Together, how can we reduce the environmental impacts of digital technology (equipments, internet usage, mobile, video…)?". In order to do so, they could submit proposals and vote for proposals that had been made by other participants. This consultation gathered nearly 170,000 participants located in France, and the submitted proposals received over 2.6 million votes, participants being able to vote for several propositions, without limit. The voted proposals identified major topics related to the environmental impact of digital technology, which will be detailed below.

The first topic concerns environmental sustainability. The central idea that reached consensus is the use of digital devices for a longer duration. As previously mentioned, a criticism addressed to 5G is the environmental impact caused by the need to invest in a new mobile phone compatible with 5G. This proposal reflects a genuine public demand for increased durability of digital devices, as well as the role of operators in offering incentives for consumers to keep their equipment and extend its lifespan. Thus, the idea of "making devices upgradable to avoid buying new ones" received wide approval. This translates into the technological ecosystem's ability to produce equipment capable of adapting to sector developments.

The second topic, directly related to the use of mobile networks, concerns telecommunications offers and services. The idea of adapting offers to customers' actual mobile data consumption is one of the mechanisms mentioned. Specifically, this involves offering bonuses or financial advantages to customers who do not use all the data included in their plans. This idea is linked to the incentivizing role of mobile operators, who, according to a large portion of participants, should act on their customers' mobile data consumption by regulating their offers. However, the idea of "charging data based on consumption" is controversial, as well as billing customers based on their internet activities and putting an end to unlimited plans. Here, it is important to highlight the fact that some technological practices are so deeply embedded in usage that, for many, the idea of reverting to previous habits is inconceivable. Thus, contradictions abound: on one hand, there is a desire for a technology that is more environmentally friendly; on the other, the steps required to be taken by consumers represent a leap that is still too significant to undertake.

Lastly, the topic related to network infrastructure and data centers highlights the idea of not developing 5G, which strongly divides participants. On this same theme, nearly half of the participants voted in favor of the proposal "we must already refuse the preparation of 6G," raising real questions about the future of the network.

***2.1.5.2** Study on the perception of facial recognition*

A study on the perception of facial recognition [Cha22], although not specifically addressing the perception of 5G, is also relevant in assessing individuals' reluctance towards the introduction of new technology. This study focuses on perceptions of facial recognition technology. The study is based on peoples' reaction when asked to participate in an experiment with "smart gates" in two high schools in southern France. The opposition to the experiment resulted in the experiments being canceled but the reasons of the opposition offered valuable insights for the study. One salient point revealed by this study is the comparison with other equally criticized technologies mentioned by the respondents, such as video surveillance and "intrusive" technologies like biometrics or drones. The objections mainly revolve around anti-security opinions, a prevalent theme in the debate similar to 5G.

This study allows us to draw more general conclusions that can apply to other technologies such as 6G or digital technology as a whole:

- Field studies are necessary to understand broader issues.
- It is essential to take citizens' demands seriously and provide concrete and well-supported explanations to justify the implementation of criticized technologies.
- People tend to think by analogy and compare new technologies to others that are more familiar to them.

- Societal context is crucial: pre-existing tensions in the technology's implementation area (whether related to technological subjects or not) can increase stakeholders' sensitivity to a particular technological issue, hence fostering dialogue with them is necessary.
- A bottom-up and localized approach must be prioritized as it allows for a better understanding of controversies.
- New technologies tend to become politicized [Agg21]. Companies must stop fearing public debate and must engage in it.

These two studies provide us with an important insight into people's expectations in terms of digital technology, and more specifically, the networks of the future. However, they are conducted on a local scale in France, and are not representative of all stakeholders at the European scale or worldwide.

This part of the chapter offers a comprehensive overview of consumers' perspectives on new technologies and networks. The intricate nature of these perceptions adds to the difficulty in comprehending them. It is therefore essential to go one step further, using a complete societal dialogue approach on a country-by-country basis. Various methodologies will be detailed in the next section.

In the synthesis of the surveyed data and studies on advanced telecommunication services, HEXA-X-II distills the essence of these insights, extracting critical observations that can profoundly influence the trajectory of 6G development and implementation. By analyzing public acceptance and addressing minor concerns surrounding 5G and potential 6G developments, the surveys offer a comprehensive understanding of the landscape. This synthesized knowledge serves as a significant input for the advancement and integration of 6G technology, guiding its evolution and integration into future landscapes.

2.2 Societal Dialogue

The Significance of Employing Societal Dialogue

The notion of dialogue encompasses various contexts, including economic, political, and organizational levels within a country or company. Here, we will focus on the concept of societal dialogue specifically in the context of implementing 6G technology.

According to common usage, social dialogue encompasses the entirety of interactions, consultations, and negotiations among employers, employees, and occasionally the government. Nevertheless, our objective in this deliverable is to present a more expansive and societal perspective that more closely resonates with the notion of dialogue as understood within the realm of participatory democracy. Societal dialogue can thus be defined as an inclusive and collaborative communication process among different stakeholders in society, such as citizens, civil society organizations, businesses, academics, government institutions, and advocacy groups. Its primary objective is to foster mutual understanding and seek constructive solutions to complex social issues.

Public consultation, defined as a "two-way relationship in which citizens provide feedback to government" [OEC01] can be considered as a form of societal dialogue, and is increasingly favored by democracies today, especially at EU level [EUR23].By encouraging the participation of diverse actors with varying perspectives and interests, societal dialogue aims to address concerns, facilitate new insights, and promote collaboration in tackling societal challenges. In the specific case of introducing 6G, adopting a societal dialogue approach can prove advantageous. By engaging stakeholders early on, there is a possibility to address their concerns and expectations, thereby mitigating potential controversies and opposition.

To organize the dialogue effectively, a chronological framework can be followed [PT07]:

1. Defining the context: This involves establishing the objectives, identifying the key issues, and determining the relevant stakeholders. This initial step helps create a shared understanding among decision-makers and stakeholders.
2. Selecting and planning the appropriate dialogue methodology: Considering the predetermined objectives and issues, the most suitable approach for facilitating the dialogue should be chosen and carefully planned.
3. Gathering data and expertise: Understanding the interests, fears, and desires of participating stakeholders is crucial to define the data corpus. This step helps identify potential themes for discussion and ensures the selection of legitimate experts.

4. Mobilizing stakeholders and providing necessary information: Engaging and informing stakeholders about the dialogue process in advance, as well as raising awareness, informing and training them on the corpus of data related to the chosen topics are essential. This step ensures their active involvement and familiarity with the overall subject matter.
5. Facilitating and moderating dialogue workshops: Creating a conducive environment for open exchange and constructive positions is vital. Participants should feel comfortable expressing their perspectives, building proposals, and seeking consensus. Clearly defining the workshop methodology is crucial to align with the dialogue's objectives.
6. Analyzing, evaluating, and reporting on the dialogue: After the workshops, a comprehensive analysis of the discussions should be conducted. Intermediate results can be collected during the process, leading to a final report that draws conclusions and establishes an action plan.

By following this structured approach to societal dialogue, the implementation and deployment of 6G can benefit from stakeholder input, ensuring a more inclusive and informed decision-making process.

If we examine the aforementioned studies, they highlight, on one hand, a rather insufficient level of societal knowledge regarding 5G, and on the other hand, a desire for more information regarding the environmental impact of digital technologies. Consequently, in the context of introducing a new technology, it is crucial for ecosystem actors to recognize the importance of transmitting and sharing information with various stakeholders. Legitimately, the societal dialogue approach, inspired by participatory democracy initiatives, wherein time is dedicated to information sharing and a thorough understanding of the issues, can emerge as a relevant strategy.

Applications of societal dialogue methods

To explore the concept of societal dialogue further, it is worth examining its applications in the context of the introduction of a new technology. France serves as a particularly relevant example, as many French cities have embraced this approach to gather public opinions on the implementation of 5G. Cities like Rennes, Nantes, and the collectivity of Corsica have engaged citizens, elected officials, and other stakeholders through citizen consultations.

In certain cities, alternative terms such as "citizen conference" in Paris and Strasbourg, or "citizen debate" in Lille, are used instead of citizen consultations. This demonstrates the diverse formats employed to foster societal dialogue. Similarly, some cities establish online platforms for participants to submit proposals, while others prioritize face-to-face interactions through workshops involving a limited number of individuals. Those approaches can be very qualitative: in those cases, the choice is that of an in-depth method, aiming at exploring complex perceptions. The insights gathered from these consultations are not strictly limited to 5G but can entail broader perspectives linked to digital technology. Concrete actions resulting from these efforts can go as far as the creation of a citizen's digital council in Rennes, or dedicated monitoring bodies meant to oversee 5G deployment in Paris and Lille.

In contrast, some cities have opted for a moratorium, intending to delay 5G deployment to allow for thorough examination and potential requests to the government for regulatory measures. While not strictly a form of societal dialogue, this approach represents an intermediate stance where local authorities seek to slow down 5G implementation in specific territories.

On a broader scale, when examining the European landscape, the identification of such initiatives becomes increasingly arduous. Numerous countries have issued citizen consultations, yet these consultations primarily revolve around technical considerations (e.g., validating the allocation of specific frequency bands for 5G technology). However, when scrutinizing the societal dimension, only a select few nations emerge as examples. Notably, in 2017, Spain spearheaded a public consultation initiated by its Ministry of Energy, Tourism, and Digital Agenda (MINETAD), comprising a comprehensive questionnaire of 25 inquiries to which participants were invited to provide their insights [MIN17]. Diverging from the aforementioned consultations conducted within French urban centers, this initiative took place well before the actual implementation of 5G, with the explicit aim of determining the trajectory of Spain's forthcoming 5G National Plan. Furthermore, this consultation distinguishes itself by the extensive array of stakeholders who actively engaged in the process.

The combination of these factors renders France a particularly suitable field for embarking on a societal dialogue process. The fervent opposition surrounding the implementation of 5G, coupled with the consequential political measures taken, has compelled us to choose this specific geographic region as the site for an initial qualitative study.

Following this societal dialogue dynamic, and with the aim of testing a first animation method, we have initiated a series of workshops in France on the theme of future networks. The process of engaging in this dialogue, as previously explained, presents a notable complexity, particularly for organizations who do not hold political roles.

The following findings provide an initial glimpse into individuals' perceptions towards a potential 6G network. Starting with a qualitative approach with a small sample of people allows for exploring the breadth of perspectives on a complex subject like 6G. This approach does not allow for representativeness, nevertheless, it could subsequently be complemented by a quantitative approach. Here, we intend to go beyond a mere study; it represents an active exchange and a co-construction with various stakeholders: employees, public authorities and consumer customers.

There was a total of 6 workshops, each one of them gathering 8 participants. The first phase of the workshops consisted in an acculturation time where participants were provided information on networks and specifically on 6G extracted from 2 main sources: Hexa-X's publicly available document [HEX21-D11] and Orange's White Paper on 6G [Ora22].

The method used was Edward De Bono's Six Thinking Hats: this method encourages participants to adopt different ways of thinking (emotional, creative, pessimistic, optimistic) represented by different colored hats.

These workshops revolved around 3 main themes:

- What is a network and why do we need a new network every 10 years?
- 6G: How to reconcile ethics and performance?
- 6G and technology: use cases (based on Hexa-X use cases)

From these first 6 workshops, preliminary insights have been gathered.

Participants have notably expressed genuine appreciation for this approach. Moreover, this feedback has brought forth thought-provoking questions that will serve as a foundation for further development. In the upcoming deliverable, we intend to provide a comprehensive analysis of these results. To enhance the validity of our findings, additional dialogue sessions will be conducted, complementing the initial testing phase. This will allow for greater credibility and significance to the outcomes obtained.

Through these workshops, certain themes have emerged that align with elements highlighted in existing quantitative studies. Notably, these themes touch upon the criticism of the rapid advancement of new technologies [YOU23] [IPS23] and the relevance of a new generation of networks, as previously discussed in the Make.org study [Mak23]. This resonance further strengthens the importance of our research and its alignment with existing scholarly discourse.

In summary, this chapter highlights the significance of soliciting societal feedback. The introduction of a new network generation can trigger diverse and, at times, vehement reactions from individuals, necessitating a comprehensive understanding of their fears, concerns, expectations and needs in advance. The adoption of this approach by multiple European nations would lend greater credibility to propose use cases that resonate with the population. Consequently, the identified opportunity is to replicate this methodology in other geographic regions to increase the representativeness of these findings, followed by their weighting through a quantitative study.

3 Business models for 6G ecosystem

6G is expected to enable new business around different use cases resulting in new business models for 6G ecosystems. Hexa-X-II use case families and representative use cases for the families have been presented in [HEX223-D12] together with business models for three of the representative use cases, namely “seamless immersive reality”, “real time digital twins” and “ubiquitous network” use cases. Hexa-X-II D1.2 presented a business modelling methodology that consist of three steps for each use case: 1) ecosystem business model canvas, 2) stakeholder analysis, and 3) ecosystem pie for visualisation of the ecosystem level business model.

This chapter presents business models for three remaining representative use cases from [HEX223-D12], namely “cooperating mobile robots”, “network assisted mobility” and "human centric services”, using the business modelling methodology developed in [HEX223-D12]. The results are presented in the following sub-sections. For details about the business modelling methodology, please see Chapter 5 of [HEX223-D12].

3.1 Cooperating Mobile Robots

The Cooperating Mobile Robots representative use case considers autonomous robots which can move, sense their environment and perform productive tasks. They can communicate with each other, other machines and humans to contribute to common objectives. The use case considers robots performing collaborative tasks beyond each robot’s individual capabilities. Table 3-1 presents the ecosystem business model canvas for cooperating mobile robots. The value proposition of the use case is to offer improved efficiency, quality, security, flexibility, and reliability from collaborative mobile robots conducting complex tasks in a coordinated manner. Table 3-2 presents the key stakeholders of the use case including an analysis of the stakeholders. Finally, Figure 3-1 presents the ecosystem pie visualisation of the use case that shows the ecosystem value proposition and key stakeholders’ contributions to the ecosystem.

Table 3-1: Cooperating mobile robots Business Model Canvas

Supply Side	Ecosystem Value Propositions	Demand Side
• **Stakeholders/key partners:** suppliers / providers of robots / cobots (sector specific: manufacturers / rental companies); network infrastructure provider; network operator (public/private network); modem chipset manufacturer and provider; providers of programs/software (for collaborative robots); system integrators; "space stakeholders" • **Resources:** high-quality local network; robots; platform; sensing and monitoring	• **Value proposition:** Improved efficiency, quality, security, flexibility and reliability from collaborative mobile robots conducting complex tasks in a coordinated manner. • **Value co-creations:** Co-creation and enabling a total solution for robots, machines and humans to efficiently conduct tasks through the exchange of information using the network. • **Value capture:** Higher efficiency and economies of scale through collaborative automation for all involved	• **Customer segments:** different campuses (area with buildings) including e.g., manufacturing sites; hospitals, harbors/airport/cargo handling/logistics centers, construction sites (temporary factory); construction/campus management company; manufacturer; constructor; construction rental companies.

capabilities; IoT devices; compute resources; Artificial Intelligence (AI) algorithms; data and access to data; domain specific competence; funding; design processes; intellectual property rights (IPR). • **Activities**: Coordination and cooperation between stakeholders and robots; research and development (R&D); design; manufacturing; deployment; sales; operation maintenance; circular business; sustainability / life cycle /ethical management; authentication; development software (SW) solutions; production of devices; design and operation of networks; integration of solutions;	(including moving production back to Europe); safer environment to work in (safety). • **Value co-destruction:** Lack of collaboration due to interoperability challenges between components hindering innovation and the ability to achieve economies of scale for the solutions. People losing skills to conduct tasks and solve problems and high dependency on robots. • **Partnerships:** robot providers and software providers (compatibility) for system partnerships; production site and robot providers; network providers and data center service providers; network providers and operators.	• **Stakeholders/key partners:** manufacturers; co-workers of cobots; • **Customer relationships:** dedicated customer sale and care for the account; business-to-business (B2B); support for the solutions. • **Channels:** digital channels for all instrumental information exchange between seller and customer; key account manager (human channel)

Outcomes

- **Benefits:** higher resource efficiency and productivity of processes; cost savings from same solution used in multiple factories; high precision leading to less waste; improved safety for workers; new business from developing and manufacturing robot/cobots; improved reuse of resources; productivity processes (construction as manufacturing); opportunity for automizing production and produce closer to customer; setting up factory rapidly; allowing remote operations; potential environmental and social benefits from bringing production to Europe.
- **Revenues (revenue streams):** solutions as a service; whole solution from one major player that partners with others; paying per robot; building owner invests in building with the robots and rents the facility as a service/contractual agreement; manufacturing (construction, logistics) as a service.
- **Pricing:** as a service (monthly) pricing models; fixed price per component; paid per delivered unit; pricing based on customers' improved efficiency or other values (% of margin).
- **Costs:** Economic and environmental costs from the manufacturing of robots; people are replaced by robots **-** people need to learn new skills; coordination of robots for energy/charging; back up for robots in case of failures; high upfront investment from the deployment of the whole system (phased approach needed).

Table 3-2: Coordinated mobile robots Stakeholder Analysis

Stakeholder	Description	Role	Value proposition	Activities	Resources

Suppliers/providers of robots/cobots	Providers of robots and cobots	Supplier	Provide robots, which are collaborating, using network infrastructure, for different segments, building new business opportunities.	Research, design, manufacturing (outsourced), sale/distribution,	Design processes. IPR, knowledge. People. Own factories - or outsourcing expertise.
Network infrastructure provider	Vendor of network infrastructure equipment.	Supplier	Provide infrastructure enabling communication and sensing for cooperating robots, for different purposes and customers. Extract synergy effects, keep installed base maintained and up to date.	Develop and deploy network infrastructure that support communications and sensing. Research, design, manufacturing, outsourcing, sale/ distribution	Design processes, IPR, knowledge, people, own factories, outsourcing expertise, scaling capabilities
Mobile network operator (public/private network)	Provider of local / wide area connectivity services.	Supplier	Provide communication and sensing for running cooperating robots in the target area, where investment and costs in network can be justified by the use and users, and what they pay for deploying and running the network.	Operate local / wide area network. Handle relationship with network owner/financer - and users, access rights of network. Authentication.	Local / wide area active (and passive) network. Network operation and support.
Modem chipset manufacturer and provider	Manufacturer of the modem chipset	Supplier	Provide modems, which are integrated into different devices/equipment with e.g. the right form factors.	Research, design, manufacturing (outsourced), sale/distribution.	Design processes, IPR, knowledge, people. Own factories - or outsourcing expertise.
Providers of software for collaborative robots	Provider of software and applications needed for the robots to function.	Supplier	To provide software for robots to collaboratively conduct tasks enabling e.g. efficient and automatic choice of network "paths"	Design and development, sales and distribution, management of access / licenses, etc.	Algorithms, application, IPR and copyright, experts, vertical domain knowledge
System integrators	Integrators of components from different providers.	Supplier	Offer system-level solutions by recombining, reconfiguring, and handling many types of components. cost-efficiently.	Combine components into solutions. Design and deploy final solutions for robots. Contract, customer relationship	Expert knowledge, large portfolio of customers and certified tested components
Manufacturer	Company that operates the manufacturing site where the robots are located.	Customer	Improve manufacturing and process efficiency by means of collaborative robots	Define processes and manufacturing activities, define requirements, operate robots	Site, infrastructure, other manufacturing machinery and devices
Co-workers of robots	People working with robots	Customer	Improve process efficiency in collaboration with robots	Operate robots, work with robots	Skills, know-how.

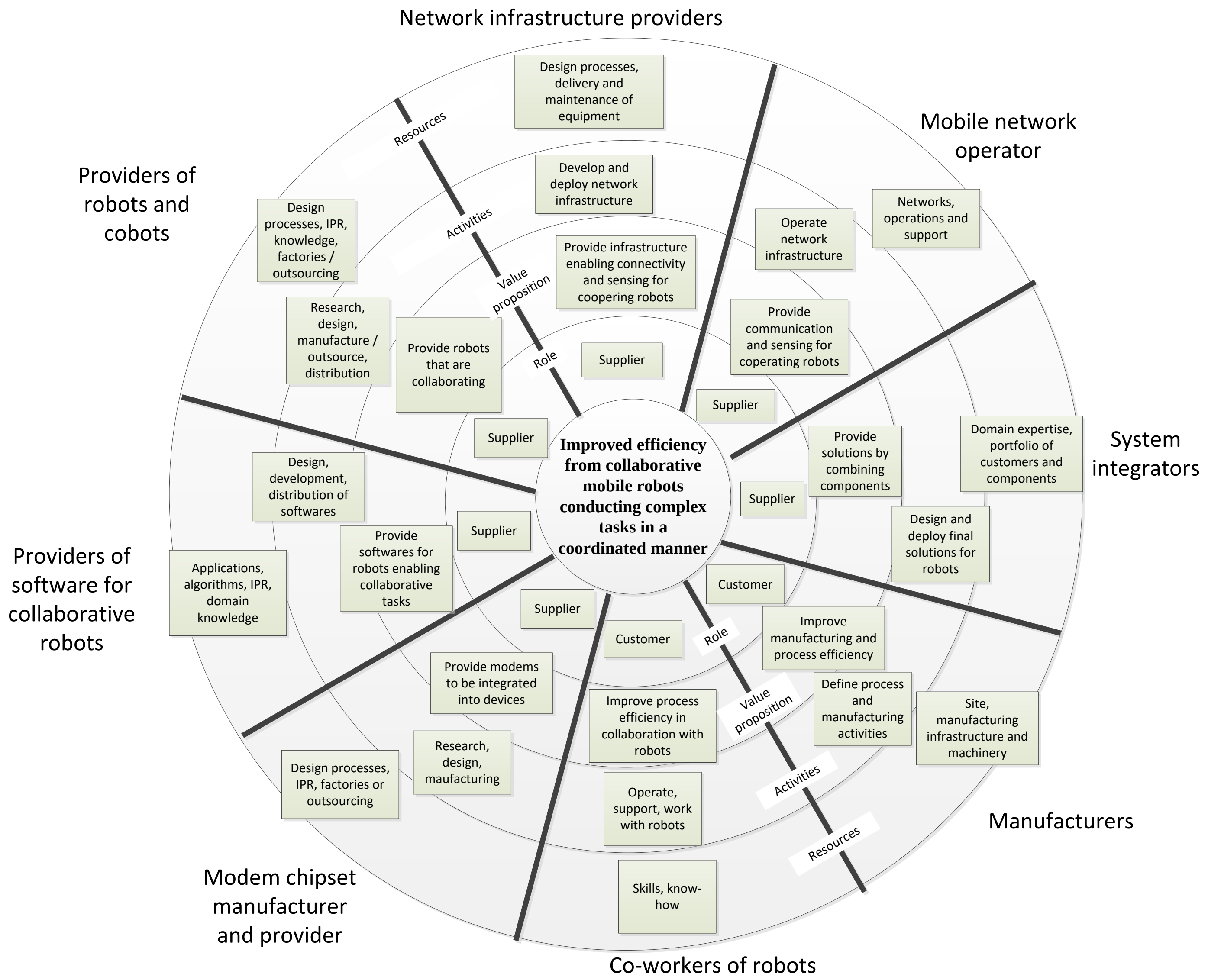
Network infrastructure providers
Design processes, delivery and maintenance of equipment
Develop and deploy network infrastructure
Provide infrastructure enabling connectivity and sensing for coopering robots
Supplier
Mobile network operator
Networks, operations and support
Operate network infrastructure
Provide communication and sensing for coperating robots
Supplier
System integrators
Domain expertise, portfolio of customers and components
Provide solutions by combining components
Supplier
Design and deploy final solutions for robots
Manufacturers
Site, manufacturing infrastructure and machinery
Define process and manufacturing activities
Improve manufacturing and process efficiency
Customer
Co-workers of robots
Skills, know-how
Operate, support, work with robots
Improve process efficiency in collaboration with robots
Customer
Modem chipset manufacturer and provider
Design processes, IPR, factories or outsourcing
Research, design, maufacturing
Provide modems to be integrated into devices
Supplier
Providers of software for collaborative robots
Applications, algorithms, IPR, domain knowledge
Design, development, distribution of softwares
Provide softwares for robots enabling collaborative tasks
Supplier
Providers of robots and cobots
Design processes, IPR, knowledge, factories / outsourcing
Research, design, manufacture / outsource, distribution
Provide robots that are collaborating
Supplier
Resources
Activities
Value proposition
Role
Improved efficiency from collaborative mobile robots conducting complex tasks in a coordinated manner

Figure 3-1: Cooperating mobile robots Ecosystem Pie

3.2 Network Assisted Mobility

Network Assisted Mobility considers vehicles (cars, drones, etc.) that rely on 6G network nodes and devices for localization of connected and unconnected objects. Networks observe the physical environment and aggregate data to supporting the vehicles with different levels of autonomy and modes of operation. Table 3-3 presents the ecosystem business model canvas for network assisted mobility use case. The value proposition of the use case is to offer optimized mobility by reducing negative externalities such as accidents, pollution, and traffic congestion through situational awareness obtained with 6G network and devices. Table 3-4 presents the key stakeholders of the use case including an analysis of the stakeholders. Finally, Figure 3-2 presents the ecosystem pie visualisation of the use case that shows the ecosystem value proposition and key stakeholders' contributions to the ecosystem.

Table 3-3: Network-assisted mobility Business Model Canvas

Supply Side	Ecosystem Value Propositions	Demand Side
• **Stakeholders/key partners:** car / drone / vehicle manufacturers, mobile network operators, network infrastructure vendors; modem chipset manufacturer and provider; cloud companies, sensor providers, authorities (incl. transport and communication regulators), transport and logistics companies; insurance companies; software providers; integrators. • **Resources:** infrastructure (roads, sensors, cameras, networks, etc.), cars / drones / vehicles and resources used for producing them; algorithms; data; standards and protocols; sensors and devices. • **Activities**: collecting and processing of data; offering of situational awareness information; development, manufacturing and deployment of equipment/vehicles;	• **Value proposition:** Optimized mobility by reducing negative externalities such as accidents, pollution, and traffic congestion through situational awareness obtained with 6G network and devices. • **Value co-creations:** Improved efficiency and safety including energy efficiency improvements/reduced traffic congestion through collecting and sharing of information about the moving objects and operational environment to optimize the paths. • **Value capture:** Reinforced role in modern society for transport sector; improved safety in city environment. • **Value co-destruction:** interoperability issues; compatibility; quality and amount of data; privacy issues; algorithms used for optimizing operations; liability issues/safety; trust in people/machines; problems from more mobile objects (rebound effect). • **Partnerships:** Many partnerships: car manufacturers with cloud companies and sensor manufacturers; car manufacturers with authorities.	• **Customer segments:** drivers/consumers; transportation/logistics/delivery companies (public/private). • **Stakeholders/key partners:** end users/citizens (including pedestrians); public authorities; transport and logistics companies; cities (urban planners), • **Customer relationships:** alliance for implementing systems (B2B); subscription from end customers (business to consumer (B2C)); digitally. • **Channels:** digital channels for reaching final users

development of standards and protocols; operations of transportation (governance).		

Outcomes

- **Benefits:** Make transportation more efficient by reducing its negative externalities such as accidents, pollution and traffic congestion; improved safety; less Greenhouse Gases (GHG) emissions; improved comfort.
- **Revenues (revenue streams):** from transport companies to providers of situation awareness data (or both ways); consumer subscribes to a service; insurance companies' role from reduced traffic accidents; two-sided where vehicle providers and transport companies pay to offer free service to users; free service for data providers; cities pay for providers for reduced environmental footprint; car manufacturers to pay for sensor providers; situational awareness provider pays for algorithm providers.
- **Pricing:** Alternatives: based on usage; pricing of other related digitalized services.
- **Costs:** high density urban networks**;** blame game/liability issues; legal challenges; risks from technology (Artificial Intelligence - AI).

Table 3-4: Network-assisted mobility Stakeholder Analysis

Stakeholder	Description	Role	Value proposition	Activities	Resources
Vehicle manufacturers	Entity manufacturing and providing vehicles for assisted mobility.	Supplier	To allow use of device and its core functions to be applicable in any location, connecting seamlessly to any network, to part of a mobility scenario.	Design and development, sales and distribution, service management.	IPR. Research, manufacturing, marketing and sales, support
MNO	Network operators providing communication and sensing functionality.	Supplier	Offering high-density network communication and sensing required for urban mobility of vehicles.	Operate local / wide area network. Handle relationship with network owner/financer - and users, access rights of network. Authentication.	Local active (and passive network). Human operation and support.

Network infrastructure providers	Infrastructure providers for communication and sensing infrastructure	Supplier	Offer communication and sensing network infrastructure to enable mobility	Develop and deploy network infrastructure that supports both communication and sensing. Research, design, manufacturing (outsourced), sale/distribution.	Design processes. IPR, knowledge. People. Own factories - or outsourcing expertise. Scaling capabilities
Cloud companies	Entity hosting the applications enabling mobility scenarios. Low latency requirements demand edge functionality.	Supplier	Cost- and energy efficiency computing, close to edge when needed;	Asset optimizing, deployment and management, optimizing use of servers and installations, maintenance, sales and customer relationships, energy optimizing activities	Physical assets, capital, capital investors. Servers, cooling installations, contracts for green and cost-efficient energy, licenses for platform SW
Modem chipset manufacturer and provider	Manufacturer of the modem chipset	Supplier	Provide modems, which are integrated into different devices/equipment with e.g. the right form factors.	Research, design, manufacturing (outsourced), sale/distribution.	Design processes, IPR, knowledge, people. Own factories - or outsourcing expertise.
Software providers	Providing AI enabled applications	Supplier	Enables mobility functionality through applications, e.g., efficient and automatic choice of network "paths"	Design and development, sales and distribution, management of access/licenses etc.	Algorithms, application, IPR and copyright, experts, vertical domain knowledge
System integrators	Entity that combines resources and components into one end-to-end network service or system, according to a predefined service-level agreement.	Supplier	Integrating different components into a functioning system, by combining and configuring different parts. Carries the risk of a functioning system according to a predefined Quality of Service (QoS).	Design and deploy systems. Contracting, and customer relationship. Risk/revenues portfolio management.	Expert knowledge. Best practice processes. Sufficiently large portfolio of customers to carry risk. Portfolio/stock of ready/certified/tested components.
Authorities	Governance bodies regulating how to implement and operate mobility services.	Customer	Predictable market environments. Perceived legitimacy from policy makers.	Follow market evolution, desired and non-desired market situations. Suggest, handle process, and act on regulatory mandate.	Mandate and decision rights. Expertise. Regulatory means. Legitimacy.
Cities	Governing body in a city.	Customer	Use data generated by network assisted mobility to develop and offer digital city	Coordinate or assist service development and infrastrcuture	City infrastructure and expertise. Mandate for

			services. City can act also as a local regulator.	deployment. Digitalize city services.	suggestions and decisions. Finances.
Drivers	Person driving a vehicle and subscribing to a mobility service.	Customer	Improve their driving value by reducing accidents, traffic, etc, by means of assisted mobility. To be able to pay for a service, so that specific parties can extract the benefits from the service without hazzles	Assess advantages of service, decide to subscribe, manage subscriptions, manage relationship with service provider(s)	Vehicle. Ability to pay/financial resources.
Transport and logistic companies	Private or public firms owning and/or operating transport services.	Customer	Optimize their processes and improve their mobility efficiency	Transport service design and planning, digitalize and optimize transport services by means of assisted mobility	Vehicles. Customer base. Employees. Ability to pay/financial resources.
Other road users	People using the roads (excluding drivers), including pedestrians, cyclists, kick bikes, unprotected road users.	Customer	Improve their road user value by means of coordination, safety and information offered by the networks.	Providing and use of data	Usage data

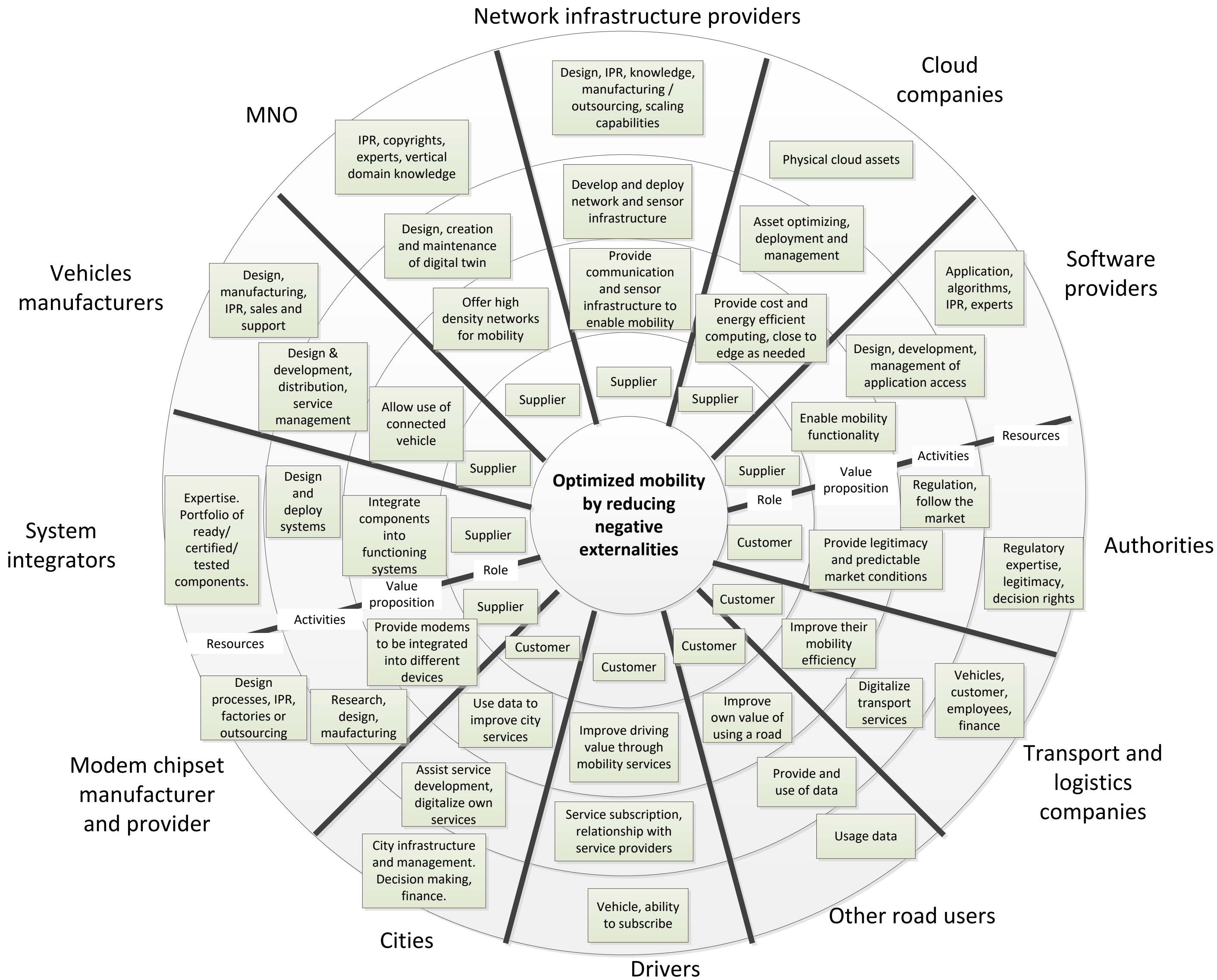

Figure 3-2: Network-assisted mobility Ecosystem Pie

3.3 Human Centric Services

Human Centric Services focuses on humans at the centre where trusted services are offered in trusted environments where privacy and reliability are key characteristics. Human centric services include a range of safety and wellbeing-oriented services including precision healthcare services, safe environments and public safety service during events. Table 3-5 presents the ecosystem business model canvas for human centric services use case. The value proposition of the use case is to offer improved safety and wellbeing through non-intrusive and trusted monitoring and response using sensors and network. Table 3-6 presents the key stakeholders of the use case including an analysis of the stakeholders. Finally, Figure 3-3 presents the ecosystem pie visualisation of the use case that shows the ecosystem value proposition and key stakeholders' contributions to the ecosystem.

Table 3-5: Human-centric services Business Model Canvas

Supply Side	Ecosystem Value Propositions	Demand Side
• **Stakeholders/key partners:** mobile network operator; network infrastructure providers; domain specific service providers (e.g., health); modem chipset manufacturer and provider; authorities; sensing device providers. • **Resources:** monitoring equipment of public and private domains; devices, service, applications, and software. • **Activities**: sensing / monitoring of humans/environment; privacy preservation / trust building; distribution of sensors to users;	• **Value proposition:** Improved safety and wellbeing through non-intrusive and trusted monitoring and response using sensors and network; • **Value co-creations:** Trust building, public-private sector collaborations and co-creation between local service providers (such as caretakers) and the system supporting local service provisioning. • **Value capture:** Savings for society through different early warnings (e.g., natural disasters, personal health) and improved safety and security services. • **Value co-destruction:** Balance between being monitored vs. improved safety; misuse of and access to material (videos); non-transparency; institutional barriers from availability of data; lack of compatibility of data and devices; • **Partnerships:** network operator and provider of human centric services; parties in the specific domain (e.g., healthcare); private-public-partnerships	• **Customer segments:** humans/end users (the elderly, children, …); consumers; hospitals; healthcare providers/institutions; schools; insurance companies; safety/security companies; • **Stakeholders/key partners:** humans/end users (the elderly, children, …); consumers; hospitals; healthcare providers/institutions; schools; insurance companies; safety/security companies; • **Customer relationships:** order online; via "prescription" from professionals; domain-specific client relationship; customers can be consumers or institutions (individuals, schools, care-places) • **Channels:** digital channels; human dialogue (appointments);

Outcomes

- **Benefits:** improved safety and feeling of being safe in familiar and non-familiar environments; less stress from security concerns; improved efficiency of enabling more care services with same (limited) resources; new business opportunities for local providers (e.g., caretakers) to expand service coverage and customer base.
- **Revenues (revenue streams):** Alternatives: Fixed yearly fee per government, private companies, non-governmental organizations (NGOs) giving basic service. Additional fee for end-users based on usage. Revenues from data streams.
- **Pricing:** Alternatives: differentiated by age/condition/responses; based on risk level; based on potential savings;
- **Costs:** Infrastructure investments; service development investments; privacy and security; environmental and economic costs of sensors (waste); intrusion; overwhelming of data;

Table 3-6: Human-centric services Stakeholder Analysis

Stakeholder	Description	Role	Value proposition	Activities	Resources
Network infrastructure provider	Vendor of communication network infrastructure.	Supplier	Provide network infrastructure with the requirement of trusted environments, building new opportunities for different customers segments and human needs.	Research, design, manufacturing (outsourced), deployment and distribution of network elements.	Design processes. IPR, knowledge. People. Own factories - or outsourcing expertise.
Mobile network operator	Provider of local / wide area connectivity services.	Supplier	Provide communication services for trusted environment, which can be justified by the use and users.	Invest and operate local /wide area networks. Handle relationship with network owner/financer - and users, access rights of network. Authentication.	Local / wide area active (and passive network). Human operation and support.
Sensor device providers	Providers of sensors of different types	Supplier	Provide robust and predictable installations of specific sensors/equipment and make available trustworthy monitoring data.	Research, design, manufacturing (outsourced), sale/distribution.	Design processes. IPR, knowledge, experts. Domain-specific knowledge.
Modem chipset manufacturer and provider	Manufacturer of the modem chipset	Supplier	Provide modems, which are integrated into different devices/equipment with e.g. the right form factors.	Research, design, manufacturing (outsourced), sale/distribution.	Design processes, IPR, knowledge, people. Own factories - or outsourcing expertise.

Domain specific service providers (e.g., health)	Providers of the human centric services.	Supplier	Provide specific services for human needs, combining different components together.	Design and development of application, distribute and operate specific services.	Algorithms, application, IPR and copyright, experts, vertical domain knowledge
Authorities	Governance bodies regulating the operations.	Customer	Provide predictable market environments, legitimacy and trust by policy-making decisions.	Follow market evolution, desired and non-desired market situations. Suggest, handle process, and act on regulatory mandate.	Mandate and decision rights. Sector-specific regulation expertise. Legitimacy.
Humans/end users	People using the human centric services.	Customer	Improve own safety and wellbeing conditions utilizing a non-intrusive and trusted monitoring system	Use services, exchange information, react to provided information. Give feedback to suppliers.	Time, motivation, perceived benefits from services
Safety/security company	Companies providing safety/security services.	Supplier	Improve service offer by using human centric infrastructure and applications	Define service requirements, adoption of services and applications, react /improve their services	Expertise. Trusted brand.
Healthcare institution	Organizations where the human centric services are used (e.g. elderly care homes).	Customer	Provide healthcare services with improved precision, efficiency and coverage by a non-intrusive and trusted monitoring system, and related applications	Operate trusted human-centric services, ensure data is correct, analyze data and react to service information	Domain specific expertise, mandates for health services, budgets: financial and resources,

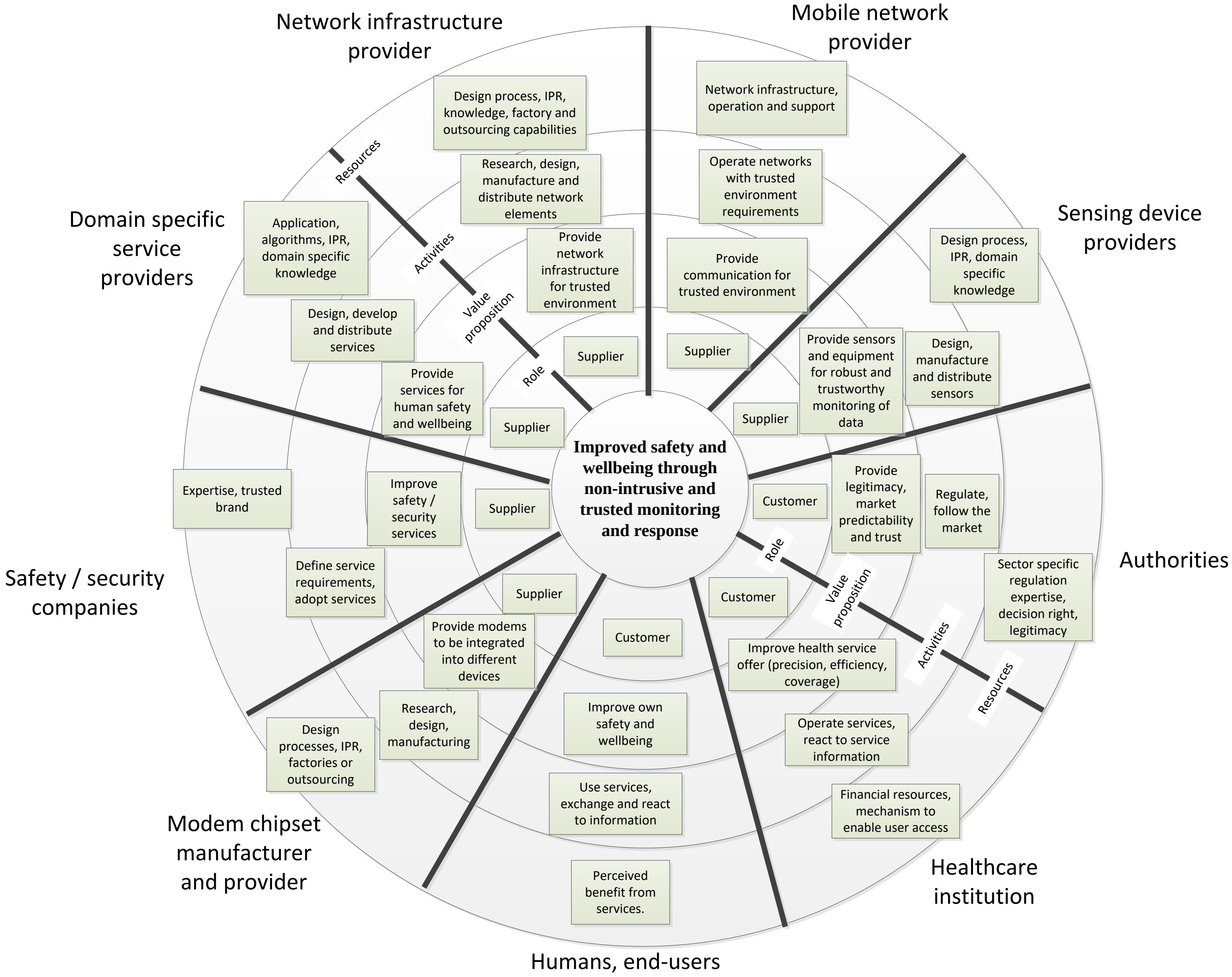

Figure 3-3: Human-centric services Ecosystem Pie

4 Preparedness for 6G Environmental, Social and Economic Sustainability

To deliver a positively impactful and sustainable technology, it is required to predict the potential shortcomings, the challenges and the risks; and to identify strategies to mitigate them. Not all stakeholders of a technology experience the same challenges and risks and not all can use the same strategy to mitigate them. However, identifying as many potential challenges and risks as possible in advance allows for the preparedness needed both from a technical/design point of view and from the sustainability and the exploitation perspectives.

Hexa-X-II studies the challenges and risks at use-case level using the analysis on handprint and footprint on the three sustainability pillars, presented in [HEX223-D12]. For each of the representative UCs the **challenges**, defined as the difficulties or resistance that may prevent the realization of the UC sustainability handprints and minimization of the sustainability footprints; are pointed out. For each challenge, multiple **risks**, defined as likelihood of not realizing the UC sustainability handprints and of sustainability footprints becoming larger than expected, are further identified and design-level solutions are provided. **Mitigation strategies** associated to each risk are proposed, taking into account both the technical/designing and the policy/best practices perspectives. The mitigation measures were also complemented with indications of stakeholders that may have the knowledge and the expertise to realize them, i.e., define further and apply them for the benefit of all.

In this section we provide a summary and conclusions of the above studies. Detailed analysis of the challenges, the risks, the mitigation strategies and the involved stakeholders (impacted or capable of applying the mitigation measures) for the representative UCs are presented in Annex 1 (Annex 1.1 to Annex 1.6). Annex 1.7 summarizes the results and the main outcomes on a risk basis approach.

4.1 Environmental Sustainability

The development and deployment of 6G networks ushers in a new era of connectivity with transformative use cases. To ensure the environmental sustainability of these use cases, a holistic approach encompassing different environmental challenges that require technical and design-level solutions as well as a comprehensive assessment of environmental risks and mitigation strategies is imperative.

4.1.1 Challenges

One significant challenge lies in developing **resource-efficient communication systems**, aiming to optimize material, water, and end-to-end (E2E) energy consumption during the manufacturing, usage, and end-of-life phases. This involves employing materials with minimal environmental impact and implementing energy-efficient transmission protocols. While efficiency of resources is a key consideration, it must be aligned with a **sustainable overall management of resources** and strategic choices considering holistic approaches to environmental impacts and full life cycle analysis of devices and equipment. That way, we can avoid suboptimizing by focusing on a single life cycle stage or shifting environmental impacts from one part of the system to another.

Relying on **renewable energy sources**, integrating smart grid technologies, and investing in renewable energy infrastructure across the entire ICT ecosystem are key to reduce the GHG emissions.

The adoption of **circular design** principles, focusing on ensuring the durability and recyclability of hardware components, and making them easily upgradable, demountable, recyclable, reusable, and modular is crucial at design level to minimize environmental impacts. Drought and water scarcity in some regions poses multifaceted challenges to component manufacturing, data centres and water-intensive cooling systems, overall infrastructure, and operations. Extreme temperatures can cause physical damage to the ICT infrastructure leading to hardware failures or system damage which can cause data loss. Furthermore, extreme temperatures increase energy demand for cooling. Other water-related risks, like wildfires, can also disrupt operations and data security. Meeting corporate sustainability goals necessitates a shift toward water-efficient technologies, and **resilient physical infrastructure** and disaster preparedness measures in the face of drought-related uncertainties.

Environmental challenges arise at every stage of the supply chain, and achieving sustainability outcomes depends on the **engagement of various stakeholders** including raw material suppliers, component and device manufacturers, infrastructure providers, software developers, network operators, service providers, end users, and regulatory bodies. Collaborative efforts are crucial to establish a sustainable supply chain that promotes a positive environmental impact through shared commitments and eco-friendly practices. Monitoring and auditing the entire value chain to ensure responsible material sourcing, implementation of sustainable processes and waste reduction strategies, efficient transportation and packaging practices, compliance with environmental and ethical standards, as well as advocating for the lowest environmental footprint, are pivotal actions.

Innovative business models emphasizing infrastructure sharing, circularity, and other collaborative practices should also be promoted and implemented. To this end, cross-sector collaboration, and the spread of environmental awareness and good practices, contribute to broader environmental sustainability goals and integrates 6G into holistic sustainability initiatives.

Local community engagement is another challenge in aligning 6G with community sustainability goals. Engaging with local communities, and tailoring solutions and deployment plans according to their specific needs and local sustainability requirements can help provide improved experience and quality of service, increase the adoption of the solution, and achieve greater sustainability outcomes.

On the hardware and software levels, a significant challenge is to maximize the use of existing infrastructure without sacrificing efficiency gains, ensuring **backward compatibility** and **interoperability**. This approach avoids the unnecessary manufacturing and deployment of new hardware devices, and network infrastructure. Collaborative and multi-sensing approaches, as well as data fusion approaches, leveraging both network-based and device-based sensors can also be considered to reduce overall manufacturing of sensors and corresponding electronic waste.

Strategic deployment planning and network architecture in 6G balancing flexibility, interoperability, and capacity requirements, while optimizing the choice between Terrestrial Network (TN) and non-terrestrial network (NTN) elements is crucial to balance both performance and sustainability requirements. The goal is to reduce the environmental impact of manufacturing network components and create more sustainable communication infrastructure by limiting the overall resource consumption and electronic waste while ensuring seamless 6G services.

Moreover, ensuring **sustainable spectrum usage** as well as dynamic spectrum sharing allow for flexible and adaptive usage of available frequencies which is pivotal to maximize the efficiency of spectrum resources and sustainability of mobile broadband.

A significant challenge in achieving sustainability goals involves navigating the inherent trade-offs across environmental, social, and economic pillars. It necessitates thoughtful considerations and **holistic approaches** to strike a balance across these dimensions. Comprehensive lifecycle assessments are pivotal to understand the hotspots in a product or system, but simpler methodologies are needed to be used more broadly.

There is a need to reinforce the importance of entire **supply chain transparency**, regulatory compliance, stakeholder engagement, and continuous improvement of standardized methodologies, assessment tools, and holistic frameworks. Furthermore, a general challenge is to maximize the potential positive impacts, or sustainability handprints (as defined in Hexa-X-II D1.2). In order to do that, it will be critical to understand the driving forces for maximizing the uptake as well as any barriers for realization of the potential sustainability handprints for each use case. It is crucial to understand how to balance out all sustainability aspects and when to implement what in order not to provide overcapacity or other capabilities without need for it. Defining the mechanisms that will ensure that digitalization happens only when it can lead to sustainable handprints is a huge challenge.

4.1.2 Risks and Mitigation Strategies

A spectrum of environmental risks arises across diverse use cases. These risks necessitate informed mitigation strategies and collaborative efforts within a vast stakeholders' ecosystem. The multifaceted nature of these risks requires careful consideration and a comprehensive approach to design and implementation. This approach seeks to ensure the responsible and sustainable evolution of 6G technologies, considering their broad-ranging impact on our environment.

The **increased manufacturing** of hardware components due to pervasive success or widespread adoption of new solutions, or business models leading to unintended demand and unprecedented consumption of energy and resources pose significant environmental risks. To counteract the unwarranted surge in hardware manufacturing and energy consumption, it is imperative to implement sustainable business models that prioritize circular economy principles emphasizing device reuse, recycling, and sustainable material choices.

Exploring **innovative business models** such as device leasing or subscription services can also minimize unnecessary hardware demand. Additionally, the implementation of product stewardship initiatives incentivizes responsible manufacturing and disposal practices.

Determining adequate capabilities and Quality of Service (QoS) considering **user-centric approaches** to specific needs and performance metrics, along with legislative measures to prevent "walled gardens" and encourage **standardized hardware and software** interfaces between different manufacturers, as well as improved software upgradability of terminals are crucial steps in limiting these unintended effects and extend usage duration and lifespan.

A key design target for 6G is that it will be more environmentally sustainable than any predecessor. If this goal is met, then another risk factor could arise from a **reduced adoption** of 6G solutions due to limited suitability to specific/complex environments, affordability of the solution on small-scale levels, or reluctance in embracing new ways for living, working, and accessing different services preventing the environmental handprints from being reached. Effective strategies and policies should be established to foster solution adoption in collaboration with organizations and policymakers. Furthermore, organizing training sessions and effective on-the-job demonstrations and tutorials can enhance understanding and uptake of these solutions.

Locally rational, opportunistic decisions may lead to global unfortunate environmental effects. To address this risk, promoting transparency, accountability, and measurability throughout the value chain, and educating stakeholders at all levels on good and sustainable practices are essential mitigation strategies.

The impossible collection of environmental data due to lack of Return on Investment (ROI), stakeholder willingness to pay for the information collected, or other restrictions hinders effective environmental management. Identifying and engaging relevant stakeholders and highlighting the potential benefits they can derive from the collected data is key. Advocating for clear regulatory frameworks can also motivate stakeholders to invest in data collection for compliance or competitive reasons. Providing tax breaks or other financial incentives while fostering collaborations and partnerships between public and private entities to distribute the costs and responsibilities associated with data collection can foster different stakeholders' contributions and initiatives and facilitate data collection for environmental monitoring and compliance.

Additionally, the improper disposal of electronic devices, such as open burning or e-waste dumping, due to **underdeveloped waste management infrastructure**, or recycling processes struggling to adapt to the fast-paced technological evolution and increasing complexity of devices, exacerbates environmental degradation. Designing for circularity helps optimize repairability, reusability and recyclability, while securing a longer lifetime of hardware and software. Minimizing required manufacturing of hardware devices, and network infrastructure should also be leveraged. Only products with fully biodegradable materials can be left in nature. Products made only partially of biodegradable materials should be taken back at the end of their life. Moreover, incorporating recycling strategies into business models are crucial steps for responsible end-of-life management.

The risk associated with increased efficiency in production processes leading to increased production as a **rebound effect** can have unintended environmental consequences. Aligning business strategies with shared industry norms, adhering to taxation regulations, and implementing transparent fee structures are essential to balance growth while ensuring sustainable practices.

Lastly, **increased spare-time travel** and commuting due to remote working, and increased transport of goods due to online shopping and other digital services, contribute to environmental pressures. Organizing education campaigns and awareness about the climate crisis as well as promoting taxation and regulatory policies on travel while encouraging sustainable transportation alternatives are effective strategies to mitigate these environmental risks.

As stated earlier, a comprehensive, use case- specific sustainability analysis highlighting different challenges and design-level solutions, environmental risks and mitigation strategies relevant to particular application scenarios, and identifying corresponding stakeholders involved in implementation of the solution and mitigation can be found in Annex 1.7.

4.2 Social Sustainability

In this section, challenges, risks and mitigation strategies in the context of 6G from the social sustainability perspective are presented.

4.2.1 Challenges

When it comes to technological advances, the most common social challenges (already identified from previous network generations) are those related to **social engagement / technology uptake** and **security aspects.** These challenges, despite being often discussed, always need to be taken into consideration due to their complexity, in terms of factors that may influence human behaviour towards new technologies.

The positive impacts (sustainability handprints) of each use case – and of 6G overall – will only be reached if there is an adoption of the new technology by the end users. **Social engagement / technology uptake** is not only about end-users liking or not liking a technology and finding it useful or easy to use. It is also related to end-users trust and confidence on it or being necessary enough to pay the cost. Other aspects include if one trusts the operations of a new technology and what are the risks they may run into if the technology fails. Availability of the service when they need it, skills needed to use it and people losing their jobs due to automation (e.g., in cooperating robots or network assisted mobility scenarios) can further impact one's decision to use or not use a new technology. Technology health harm (mental or pathological) in peoples [AMJ+11] [Ken23] and/or the environment (air-oriented and animal populations) are also factors that may influence social engagement and technology uptake. Additionally, technology uptake is also related to technology providers concerns with respect to, usually, economic aspects like return on investment and cost of ownership. Decision or policy makers may also play a role in this case towards using or not using a technology depending on security (privacy and trustworthiness) as well as negative impacts on health, environment, job opportunities, democracy and justice, digital inclusion and Sustainable Development Goals (SDGs).

Although **security** is one of the aspects that may affect the social engagement and technology uptake, it needs its own attention. Security often triggers cyber-security discussions, but it is not unusual to also refer to physical security and safety, e.g., when dealing with malfunctioning moving robots or autonomous driving cars that could cause accidents. Breaking down the cyber-security topic, we often come across the challenge of privacy, security by design, authorization to access data (personal or corporate), authentication, anonymization, etc.

Achieving **trustworthiness** is a challenge that poses more questions including: who is accountable if the technology fails?; will the technology be available whenever and wherever needed?; Can the AI-based insights and decision-making be trusted?;, etc. However, trustworthiness is not only about trusting technology; it is also about trusting information providers for the technology, or even the society and the country. This is a very broad challenge, since the lack of trust could be caused by several different factors. For example, depending on who provides the assurances for the performance and the security of the technology as well as who provides and develops or oversees the technology, peoples' and authorities' trust may change. Moreover, trusting an authority today, it does not necessarily mean that one will always trust it; this may change depending on the context, for what people place their trust on and available information of the authority at a given time.

4.2.2 Risks and Mitigation strategies

The above challenges have led to a list of risks, in terms of involved stakeholder and negative outcomes if not properly handled. The most impactful risks are those related to trustworthiness including low trust in technology characteristics or fear of new technology in general, reluctance to change, distrust in one specific stakeholder, or even disinformation. Risks related to trustworthiness also include lack of acknowledgement and control of which data is being measured/used/stored; and data leaks in case of the system being hacked, most prominent in digital twins and personal data-based solutions. Fragmentation of responsibility when using AI-based and autonomous systems, e.g., self-driving cars, in cases of something going wrong / bad decision making is also an often risk related to trustworthiness. Finally, the risk of breached humans' privacy / location information from sensing devices, e.g., cobots' sensors or autonomous cars' sensors has also been discussed.

Another important risk is the one related to the inclusion of new processes and technologies in the value chain. This risk is closely related to the risk of people lacking the knowledge to use the new technologies resulting in stressful conditions, if no additional training is provided, or uneducated workers losing their jobs involving manual, linear, and repetitive tasks from automated processes and robots. In some UCs, the risk of people overusing the technology and digital solutions for e.g., remote work, education, communication, gaming, raises concerns with respect to what effect this may have on peoples' psychology, including e.g., individual isolation and alienation / loss of human physical contact, and overall health, e.g., when immersive reality is extensively used.

Fully relying on technology reveals two more risks; a) that of digital divide due to high cost of new services/devices, IT/digital illiteracy or non-availability of digital services in certain geographical locations and b) vulnerability of people and services if the technology fails or is damaged intentionally or accidentally.

Finally, social engagement / technology uptake challenge may also pose risks in environmental and economic sustainability axis. Limited use of services may result in increased total cost of ownership. Increased total ownership may accordingly jeopardize the affordability of the services, especially for public service providers such as schools, or poorer areas and countries. Limited exploitation of the technology may also result in unnecessary research cost or unnecessary environmental (in terms of e.g., energy and materials) and economic costs for offering more complex network infrastructures.

The first step for mitigating the risk that 6G might not be trusted by end users is that **6G blueprint has to be designed with the aim to be trustworthy**. As stated in [HEX223-D11] (chapter 3.2.1) characteristics of trustworthiness include accountability, accuracy, authenticity, availability, controllability, integrity, privacy, quality reliability, resilience, robustness, safety, security, transparency and usability. Moreover, 6G solutions and networks need to be cyber-secure and respect end user's privacy while AI-based approaches need to be clear, transparent and keep humans in the loop so that accountability, and thus trust, can be maintained. Security by design, trustworthy and explainable AI techniques need to be applied in the 6G blueprint while modularity of technology could support the required flexibility in software and hardware design that would allow to implement suitable strategies, e.g., decoupling devices from the users. Joint communication and sensing (JCAS) services also need to be designed in such a way that require as little data as possible, limiting the possibility to expose humans' personal data, e.g., position.

The second step in the mitigation strategy is to **open a dialogue** with representatives from outside ICT sector and **communicate the design choices** made to make the 6G blueprint trustworthy. Following this, the purpose of trustworthiness needs to be also communicated in the **final standards and applications**. This will be an important task of Hexa-X-II and all its partners in the initial phase.

4.3 Economic Sustainability

This section presents the challenges, the risks and the mitigation strategies in the context of 6G from the economic sustainability perspective.

4.3.1 Challenges

One general challenge facing many use cases for 6G is to develop effective scenarios that can financially benefit the stakeholders in the ecosystem around the use case.

Another challenge facing the 6G deployments is the increasing amount of data accumulating in foreseen use cases. The handling of large amounts of data is costly and resource consuming, leading to economic burden on stakeholders. There is also varying quality/content of data in terms of the economic benefits it can bring to organizations and society. As a result, there is a potential need for new business models and incentives.

Additionally, there are the challenges associated with large investments needed in the infrastructure and use case specific equipment and services for realizing the different use cases, which in the worst case can lead to stakeholders not making profit. Use cases are often imagined by the ICT community developing the ICT solutions, which can lead to developing solutions that are not appealing to the end users, leading to poor interest in the technology once deployed. This calls for early interactions with consumer communities and vertical industry representatives to co-design the actual services to gain social acceptance, which is discussed in Section 2. Operation in the ecosystem of stakeholders calls for new ways of sharing of investments and incomes in the use case specific ecosystems. This challenge of transformation of doing business in an ecosystem requires new types of collaborations, contracts and financial flows in the 6G era, specific to the use cases.

Moreover, there is a challenge to have shared/common standards for the equipment and solutions to avoid the potential lack of interoperability between different systems and services. There are also cyber security related challenges from the increasing reliance on digital technologies. The economic side includes potentially high costs from attacks. Although most uncertain, there are estimates showing that the global cost due to cybercrimes could be as high as 9.5 trillion USD in 2024 [ESE23]. If measured as a country, this would correspond to the third largest economy after the US and China.

4.3.2 Risks and Mitigation Strategies

In the following, we present identified risks and mitigation strategies for 6G from the economic sustainability perspective. First, general risks and mitigation strategies are presented which are relevant for all use cases. After that, specific risks and mitigation strategies identified for specific use cases are presented. The details of the challenges, risks and mitigation strategies of the use cases can be found in the annex.

General Risks and Mitigation Strategies

One general risk is the of lack of legitimacy of stakeholders in the ecosystem, indicating that stakeholder roles/actors are not perceived as a legitimate system component provider for a specific 6G use case in the resulting ecosystem, which can lead to lower demand and less business opportunities. This can be mitigated by building legitimacy and attempting to change attitudes over time by mobilizing roles and actors with “the license to play”. Providers in different roles must express the significance of other roles in the ecosystem and build trust.

Another general risk is the lack of interoperability and compatibility at different levels, which can lead to significant network and service deployment costs in use cases limiting business opportunities. As a result, ecosystems are built around proprietary specifications, which become de-facto standards and suffer from the lack of interoperability across the de-facto standards. As a result, there can be a significant financial dependance on a limited number of service and equipment providers leading to vendor lock-in, and fragmentation of ecosystem with several regional 6G standards. The mitigation strategy for this risk is global standardization and collaboration between standardization organizations, building on existing structures to avoid fragmentation.

Another related general risk is to end up in a “winner-takes-it-all” position and de-facto proprietary standards leading to a lock-in situation, which makes it difficult to attract firms to invest in value creation in the ecosystem. There can be high uncertainty about investments, returns, and sharing of revenues and costs between stakeholders in the use case specific ecosystems. For customers, the current operation and revenues might suffer when implementing new 6G systems. New pricing models for differentiated services can be difficult to implement. Mitigation strategies for these involve the reinforcement of European key priorities including e.g., sovereignty and competition, and the development of new business models that enable new types of investments in networks and use-case-specific services accepting alternative financing and operating parties to be involved.

One general risk is about the radio spectrum for 6G, which involves many economic sustainability related aspects. The potential lack of globally harmonized spectrum for 6G can lead to lost business opportunities and increased cost in different use cases limiting the deployments. Potential local/national/regional differences in the way the spectrum is made available and priced could result in ecosystem fragmentation and thus increased costs and lack of scaling. The potential restrictions about the way spectrum is managed in different regions/countries may risk the provision of the required capacity in the different use cases in 6G devices not achieving economies of scale in production. The mitigation strategy for this is to ensure timely availability of new harmonized regional or global spectrum for 6G use across low/medium/high frequency bands to facilitate the economies of scale for development of 6G ecosystem for 2030 target deployment.

Use Case Specific Risks and Mitigation Strategies

Use case specific risks and mitigation strategies from the economic sustainability perspective are presented next. More details can be found in the Annex.

Seamless immersive reality use case is foreseen to face the risk of unequal uptake of services due to financial aspects related to the digital divide impacting nations' welfare and future economic prospects. This risk can be mitigated by global, open standards and interoperability to minimize the risk of vendor lock-in and testing and experimentation with users to find killer applications. Another risk is service monopoly and vendor lock-in from the selection of gear and services for the use case, which can be mitigated with global and open standards and interoperability. Another risk is the potential high cost of applications and equipment, which can further become obsolete fast. Mitigation strategy involves user groups to clearly express their expectations on equipment and applications for the providers.

Cooperative mobile robots use case could face the risk of people losing jobs, which could result in an economic impact on people/cities/nations. This can be mitigated by promoting training and continuous learning. Also, the risk of overestimating the market interests and customers' willingness to pay for the use case are present. Mitigation for this risk involves new financing incentives, models, and ecosystems for the use case to share revenues and costs within the ecosystem.

Realtime digital twins and network-assisted mobility use cases face the risk that including new technologies into existing devices and infrastructures (such as cars) is costly and complex. This risk can be mitigated with deploying standardized solutions step-by-step, covering most beneficial areas and cases first after identifying and assessing together with users and customers, where the challenges and benefits are higher.

Network assisted mobility use case faces the risk of difficulties to agree on data and other key elements due to interoperability challenges of multiple big companies in the industry (e.g., car manufacturers, IT companies), which can lead to market fragmentation and lack of economies of scale. This risk can be mitigated with promoting global standardization to support common solutions. This use case also faces the risk of too many dependencies between road infrastructure, networks, and devices (e.g., vehicles), which makes it difficult to reach global, wide-area solutions. Mitigation strategy for this risk involves understanding the dependencies across many domains together with mobilizing the interest and participation from other domains (e.g., road, vehicles).

Realtime digital twins use case faces the risk of sector-specific and use case specific systems becoming "black-boxes", which limits the ecosystem stakeholders' ability to further improve and innovate, limiting the business opportunities. Mitigation strategies include developing transparent systems with modular architecture including simpler interfaces. There are also cyber risks resulting in financial risks and the need for data quality control. This can be mitigated with standardized secure solutions.

Ubiquitous network use case faces the risk of sustainability footprints being larger than expected and/or sustainability handprints not happening. These can be mitigated with creating new ecosystems with new roles and funding models, promoting infrastructure sharing to reduce costs, enhancing market predictability by regulation and standardization, ensuring supply of adequate inexpensive spectrum, and creating affordable satellite connection for the most remote areas.

Finally, human centric services use case faces the risk of stakeholders, who could be interested in investing and providing human centric services, are not trusted. This can lead to demand not taking off, and innovation and new business not being created. Mitigation strategies for this risk include relevant stakeholders to leverage on and get legitimacy to act in the local context and to conduct pilots and early experiments to demonstrate trust in stakeholders. Another risk is that service provisioning is not able to adapt to the standards and regulatory regime within the vertical domain in question (e.g., health), where requirements are high. This can be mitigated with close interaction with the domain in question. There is also the risk of capacity demanding services leading to outages and failures, and that the demand does not take off. This can be mitigated by assuring service levels, extensive testing before deployment, and agreed requirements to KPIs/testing before live deployment. Finally, there is a risk of generating false/malicious data that could lead to financial loss for stakeholders involved. As a mitigation strategy, a reputation mechanism could be introduced.

5 Business Ecosystem and Key Stakeholders

Hexa-X-II envisions the future by six 6G use-case families, with six representative use-cases [HEX223-D12]. The use-cases have been the main tool to identify all potential stakeholder roles, those already existing and new. Their role in an ecosystem, their struggles, and potential benefits from being part of the 6G ecosystem were systematically elaborated. The rich lists of 6G use-case stakeholder roles were fed into the analytic work of 6G use-case ecosystem business modelling where three of them were presented in [HEX223-D12] and the remaining three in Section 3. The roles of stakeholders were further analysed when providing assessments of sustainability challenges, risks, and mitigation strategies in Section 4. When identifying key stakeholders, we assumed roles that may hold a stake in a future **6G ecosystem**, and where actors such as firms, governmental bodies, or citizens, may populate the role. Thus, the term key stakeholders is not referring to a few significant stakeholder roles but embraces most roles that are relevant for 6G use-cases.

The list of 6G stakeholders were then grouped, based on characterization of their stake, to three categories, namely business, sustainability, and spectrum. Stakeholders can be part of a business ecosystem, with emphasis on providers and customers. The sustainability aspects of 6G development and deployment add new stakeholder roles to the ecosystem, such as people who are unintentionally affected by 6G or agents who can decide or act to affect the 6G evolution. Not the least, future generations and our planet Earth should be seen as holding huge stakes in our 6G use-cases. Finally, there are stakeholder roles connected to 6G spectrum.

Summary of the key stakeholders roles based on above categorization is presented in Table 5-1 and Table 5-2, for the first two categories, and for the third one in [HEX223-D11]. The long lists of stakeholder roles and actor examples for each 6G use-case can be found in Annex 1.

Table 5-1 Key 6G business ecosystem stakeholder roles

Key 6G business ecosystem stakeholder roles	
Continuation of existing:	**Emerging or reinforced:**
Provider of network infrastructure, Network operator, End-user, Customer, System integrator, Cloud provider, Regulators	Provider of equipment / applications / components on the user/customer side, Providers of sensors, Providers of Industrial 6G devices, Modem chipset manufacturer and provider, Providers of sensing capabilities, Provider of domain specific services, Provider of indoor network, Provider of local network, Building owners, Non-governmental organizations, Provider of energy and energy infrastructures, Innovators, Financial party,

Table 5-2 Key 6G ecosystem stakeholder roles for sustainability

Key 6G ecosystem stakeholder roles for sustainability	
Stakeholder roles and examples of specific actors *affected* by sustainability risks:	**To be mobilized for strategic risk *mitigation*:**
Provider of network infrastructure, Network operators, End User Equipment providers (e.g., smartphones, robots, industrial 6G devices), 6G service providers End-user (e.g., consumer, patient, doctor, earth-quake survivor, the rescuer, the security staffer, content creator, child, elderly, caretaker, employee, pedestrian, future generations)	Provider of network infrastructure, Network operator, User Equipment provider, Other parties in the supply chain or ecosystem (raw material, components, logistic, content, power supply), Solution (domain specific) providers, Technology developers, Global and local regulatory and competition bodies (industry, climate), Governmental bodies,

Customer (e.g., consumer, employer, employee, factory, insurance companies, local/central politicians, domain specific entities) Entities in the environment where use-case is deployed, not involved in use-case (e.g., pedestrians, employees) Entities not in 6G use-cases at all (e.g., other users of power or material, cities affected by waste) Nations, economies, markets, industries	Non-governmental organizations, Vertical industry alliances, End-user alliances, Telecommunication and Vertical certification bodies, Customers (large and influential private and public customers), Telecommunication industry associations, Standard setting organizations, Investors, Research and academic institutions,

Business ecosystems' expansion with 6G

The *business modelling* of potential future 6G use-case ecosystems filtered out the most important stakeholder roles. Ecosystem stakeholder roles that already mentioned in e.g., the 5G ecosystem [HFF+21] [5G PPP23] are the provider of infrastructure equipment and network operator, the consumer as end-user and also subscriber. However, professional entities, such as employers, factory owners, or health care institutions, more often populate the subscriber or customer stakeholder roles. The system integrator, cloud provider, and not at least innovators are also well-established stakeholder roles, however, may become even more prominent in a modular 6G architecture.

Stakeholder roles that are reinforced in the 6G use-case ecosystems are the providers of equipment to users and customers, and the accompanying applications, e.g., equipment for immersive communication experiences, robots, and moving vehicles. Providers of components that enables all kind of equipment to connect are also becoming more significant. Not the least, new stakeholder roles and characteristics are emerging in the use-cases where sensing capabilities are relevant, e.g., providers of sensors, infrastructure with sensing capabilities, and operators of sensing capabilities.

Several of the 6G use-cases are very localized, indoor, or in areas currently with low coverage. To address such circumstances, it can be assumed that the network operator stakeholder role provides both local/private and wide-area networks. However, the 6G use-cases illustrate a situation with more differentiated needs for networks, which in turn could lead to a split of the network operator stakeholder role into sub-roles. Moreover, calls for more differentiated networks introduce new ways to finance them. Thus, new stakeholder roles have emerged, such as building owners and new financing actors populate the subscriber role, such as non-governmental organizations. Finally, in all 6G use-cases energy efficiency is imperative, and providers of energy and energy infrastructures will probably emerge as a prominent 6G stakeholder role.

How, and if, the 6G ecosystem and 6G use-case ecosystems will emerge and evolve is uncertain. The uncertainty is partly due to challenges and risks in the hands of different stakeholders. In the literature on technology evolution [BJC+08] and business ecosystems [GC14], the positions of, and tensions between stakeholder roles and actors are a major source for both failure and success. It follows that, to reach the imagined 6G future, which is guided normatively by sustainability values, it is important to identify and address those stakeholder roles and actors who can contribute to mitigate the risks.

Risk assessment of the 6G use-cases

The *full risk assessment* of the 6G use-cases considers stakeholder roles that are *affected* by risks, and those that may be influential *mitigating* them, for more details see Annex 1. The stakeholder roles affected by 6G risks overlap with the more familiar roles from the 6G ecosystem, such as providers of network operations, users, and customers. For instance, network operators investing in new 6G use-cases are hugely affected by market failures. Again, the actors that populate the roles can be more varied. This variation is, and should be, an expected consequence of a focus on sustainability, e.g., focus on inclusion or protection of certain groups should expand our understanding of who a user and customer may be.

The envisioned 6G user

The user may be a human, or a human overseeing a machine using 6G services. Thus, the potential *user* of 6G-enabled equipment and services can e.g., be a private or professional, she can be the patient or the doctor, the farmer or the application owner giving agricultural recommendations, an earth-quake survivor or the rescuer, poor or affluent, the human in a crowd or the security staffer, content user or producer, the person who operates/own or configures a robot, she can be in rural or central locations, a child and elderly or the caretaker. In many situations a user is supposed to use some form of 6G equipment for a period; in other situations, the equipment may be embedded in a body or a thing. One person can be many types of users in parallel, and in turn a user is affected by many 6G sustainability risks.

Indirect 6G user impact

In several of the representative 6G use-cases, people are affected, even though they are not actively taking part in 6G use-case scenarios. This is an implication of the rich use of sensors and sensing capabilities in both public and more private areas. For instance, pedestrians will unintentionally be part of the environment that is sensed in public areas where mobility is network-assisted. If 6G sensing and monitoring capabilities are used to capture e.g., earthquakes or flooding in rural areas, people may by chance be monitored. On a factory floor, or other indoor locations where collaborative robots and digital twins are used, employees, clients, and customers, could be on the floor and somehow affected by risk events. Moreover, in some risk scenarios, non-6G users may be affected if 6G services consume a disproportionate share of available energy or 6G-waste is not handled in sustainable ways. For example, heating, lighting, and cooking in homes could suffer from expensive energy caused by energy demanding 6G deployments.

Customers and innovators as stakeholders

The *customer*, or the actor that fills the role of paying for a service may vary in 6G use-cases and thus be affected by risks. For instance, customers such as factories and hospitals could perceive lower benefits because of risks associated with energy-consumption or low demand; for instance, those that finance future 6G solutions may be insurance companies, local politicians, central domain specific entities within health, or central governments via national budgets. Private companies may find it beneficial to invest in 6G use-cases, e.g., for educational or health purposes. Thus, such customers with initial willingness to pay for a service could suffer from 6G risks, such as dysfunctional market mechanisms or non-collaborative ecosystem players. The 6G use-cases are addressing the functioning and well-being of local and global communities, and thus, these stakeholders could also suffer from the realization of 6G use-case risks. As a part of the more varied presence of stakeholders in 6G use-cases, innovators are also important. Innovators are large and small developers of hardware and software, but also entities that will use 6G to achieve sustainability goals and who would suffer from risks such as delayed take off or privacy breaches. Thus, there are many examples of future actors populating the user and customer stakeholder roles; specific 6G use-cases will need to uncover those that can extract the benefits but also who would suffer in the event of risks.

Risk mitigation

The stakeholder roles who are important to mobilize to *mitigate* risks go beyond those already introduced as relevant in the 6G ecosystem business modelling. Still, it is important to also mobilize the well-established stakeholder roles such as providers of infrastructure, networks, and equipment to address e.g., risks from competition and lack of standardization. In turn, investors need to consider how to consolidate and support the necessary scale in future 6G deployments. Sustainability is a normative and political topic, and governmental and political institutions on all levels may also have a say, and regulating and competition bodies should be convinced to use their means to shape a sustainable 6G evolution. Non-governmental organizations may play a role alongside governmental bodies, in particular for environmental sustainability. In a technological evolutionary process such as for 6G use-cases, vertical industry alliances, and organized user groups can be influential both to confirm their needs and ability to allocate budgets, and to work precautionary to avoid negative effects, e.g., 5G-ACIA or 5G-AA. 6G use-cases can be domain specific, for instance within health, mobility, or manufacturing and domain specific entities should be approached to mitigate risks. This could be the certifier of health equipment and solutions, urban planners, or road authorities.

Building a resilient 6G

Providers of network infrastructure devices and network operations, and other competing providers, may be tempted to capture market shares or do not have sufficient legitimacy to be taken seriously in the market. In this case, larger private and public customers can act as pioneers and help building trust and enable a market take-off in a societal-critical domain. The telecommunication industry associations also have an important role to play to leverage the playing field, for instance GSMA, NGMN, and TM-forum. These associations have also a role in promoting harmonization, interoperability, standards; even certification can be advanced by for instance GCF (Global Certification Forum). Standard setting organization will have a role to play – e.g., ITU, 3GPP, ETSI, and IEEE – and 6G use-cases will require an even stronger focus on the interplay between the standard focus in these organizations. Not the least, starting as soon as possible, it is important to mobilize research and academic institutions in developing and building belief in the realization of 6G use-cases, as technological, social, and business innovations.

The Hexa-X-II project has carried out a systematic identification of key 6G stakeholder roles. One observation is that some are new or reinforced with 6G. A next step in the analyses will be to stabilize the 6G stakeholder roles building on those already known from the 4G and 5G era.

6 Conclusions

This deliverable aimed at preparing technology innovators to foresee challenges and unintended situations that may jeopardize the environmental, social and economic sustainability impact of 6G and 6G solutions. To this end, the deliverable started with the analysis of existing and ongoing studies of how society feels about existing and future networks, the identification of their needs as well as their concerns that would prevent them from trusting and exploiting the new technologies. Moreover, the business models study, initiated within Hexa-X-II D1.2 deliverable [HEX223-D12] for Seamless Immersive Reality, Realtime Digital Twins, and Ubiquitous Network representative UCs, was complemented by the business models study for the Cooperating Mobile Robots, Network Assisted Mobility and Human Centric Services representative UCs.

In the process of supporting the design of 6G networks and being prepared for unintended situations, the authors studied the representative UCs and identified the challenges that one needs to overcome in order to deliver the sustainability handprints and restrict the impact of sustainability footprints more than initially estimated. The authors also identified the risks posed by these challenges in case they are not properly addressed and that may impede the sustainability goals of 6G and 6G solutions. The analysis of the challenges and the risks for each representative UC made clear four main outcomes:

a) Many challenges and risks are shared between different UCs: these include challenges and risks related to trustworthiness; the early engagement of the stakeholders for ensuring the exploitation of the proposed solutions; the energy, spectrum and materials re-use and circularity; the need for cost-effective infrastructure and services, aiming at affordability and limiting the possibility of the digital divide; the need for new business models that will allow sharing of infrastructure and service costs as well as the need of shared investments for service provision and digital inclusion for the benefit of society even in areas with dispersed populations.
b) There is a holistic challenge of studying and balancing the trade-offs across the environmental, social and economic sustainability axis or even for balancing risks within the same sustainability axis. For example, an environmentally friendly solution in terms of e.g., energy use from renewable sources may increase environmental cost, in terms of materials needed for building e.g., solar generators, and economic costs for the same reasons (potentially resulting in fewer end-users capable of exploiting the solution and thus, digital division). Another example is that the use of networks without fulfilling the digital inclusion goal can maintain both low environmental and economic costs. Accordingly, emergency healthcare or Public Protection and Disaster Relief (PPDR) situations may not allow the use of environmentally and economically friendly solutions because of their criticality, requesting e.g., increased coverage and capacity of the network. Therefore, there is an increased need for studying the trade-offs between not only the KPIs of the solutions but also between the sustainability goals targeted by the solution. In order to address this, one needs to detail not only the use case and the context / conditions for which the solutions are designed but also the exact implementation approach and the technology enablers that will be used.
c) There are cross-sector challenges and risks, i.e., challenges of one sustainability axis, e.g., peoples' distrust in technology or reluctance in using the technology coming from the social sustainability axis, that may pose risks in another sustainability axis, e.g., unnecessary environmental cost in terms of materials usage for building antennas and economic costs for building the infrastructure.
d) The last cross-sectorial challenge is related to the need for societal engagement both during the design of the solutions but also during their deployment and use. Awareness and consensus of the targeted sustainability goals as well as guidelines, good practices and regulations that promote the targeted sustainability goals and their balance are required.

Mitigation strategies were grouped into two categories: those related to the design of the 6G blueprint, i.e., technical aspects, and those related to policies, regulations and standardization. The stakeholders that have the know-how, the authority and the capabilities to apply the mitigation strategies were also defined and complemented the business ecosystem of 6G networks and solutions.

The next step in Work Package 1 (WP1) is to perform a deeper analysis of the challenges, the risks and the mitigation strategies. These need to be compared also with the targeted list of minimum Key Value Indicators (KVIs) to be considered when a 6G UC / solution is designed. The balance between the different sustainability pillars, depending on the context of the UC and the possible implementation approaches needs to be also considered in the following phases.

Annex 1 Hexa-X-II representative UCs analysis on sustainability

Annex 1.1 Seamless Immersive Reality – Representation Use Case 1 (RUC-1)

Annex 1.1.1 Environmental Sustainability

In the context of seamless immersive reality, addressing environmental challenges needs a **multifaceted approach focused on energy efficiency, and responsible waste management**. Firstly, the design of energy-efficient algorithms and low-power hardware is critical due to the high computing and data processing demands of extended reality technologies. This includes adhering to circular economy principles by creating hardware that is more durable, upgradable, demountable, recyclable, reusable, and modular. Additionally, **sustainable resource management** is also a priority, with a focus on the environmental impacts throughout the lifecycle of devices and equipment.

In order to reduce excessive energy and resource consumption in immersive reality environments, it is essential to **integrate comprehensive and holistic environmental impact assessments** into development processes and ensure **transparency and measurability in the entire value chain** to enhance accountability and identify contributors to environmental footprints. Systems need to be adaptable to **renewable energy sources**, through strategies like decentralization and demand shifting. **Collaboration with international organizations and industry stakeholders** is vital in regions with underdeveloped waste management systems, to prevent improper disposal practices such as e-waste dumping. This collaboration needs to extend to industry associations, academic institutions, and environmental NGOs, supported by regional and global governing bodies setting standards and regulations.

Innovative business models like device leasing or subscription services can mitigate hardware waste, complemented by product stewardship initiatives promoting responsible manufacturing and disposal. Stakeholders across the board, including telecom operators, technology suppliers, supply chain partners, and end-users, play a crucial role in implementing these strategies, thereby ensuring the sustainable growth of immersive reality technologies.

Table 6-1: Environmental Sustainability risks and mitigation strategies (RUC 1)-

Ecosystem / Stakeholders	Risks	Mitigation Strategies	Stakeholders who can mitigate the risk
▪ Private individuals ▪ Governments ▪ Technology developers and suppliers ▪ Network operators ▪ Local communities ▪ Global community ▪ End-users ▪ All other consumers and users of same and different product and services ▪ Other people and consumers in different locations ▪ Investors and providers in other locations.	New possibilities to become so pervasive/successful, that will demand for exaggerated levels of energy/resources	Integrate environmental impact assessments into development processes to anticipate and address global consequences.	Tech developers, suppliers, and telecom operators
		The need for transparency and measurability throughout the value chain, to minimise the total footprint, and identify the largest contributors for mitigation strategies to be applied/built.	Supply chain partners: raw material suppliers, component manufacturers, logistics providers, tech providers, investors, end -users adopting the technology
		Build the system in ways for them to be flexible and adaptable to renewable energy availability (e.g., decentralization, demand shifting)	Tech developers, suppliers, and telecom operators
	Locally rationally decisions favouring opportunistic approaches in immersive reality development leading to global unfortunate effects	Conduct user education campaigns to promote responsible usage and awareness of environmental impacts.	Industry associations, academic institutions, environmental NGOs, in collaboration with technology suppliers
		Encourage applications that promote physical activity and positive environmental behaviours. Monitor and adjust strategies based on evolving user behaviour patterns	Institutions which can help with financial incentives and mechanisms
		Establish take-back and recycling programs to ensure responsible disposal of end-of-life devices. Encourage manufacturers to use recyclable materials	Regional and global governing bodies for climate and environment (e.g., setting standard to markets, certification, legacy, regulations)

	Regions with less developed waste management infrastructure, or access to recycling facilities may struggle to handle the disposal and recycling of electronic devices. This can lead to improper disposal practices, such as open burning or e-waste dumping	Collaborate and coordinate with international organizations and industry stakeholders to establish global development of immersive reality applications guided by environmental sustainability approaches.	Industry associations, academic institutions, environmental NGOs, in collaboration with technology suppliers
			Regional and global governing bodies for climate and environment (e.g., setting standard to markets, certification, legacy, regulations)
	Business models supporting immersive reality may inadvertently drive excessive demand and generate hardware waste	Prioritize circular economy principles in business models emphasizing device reuse, recycling, and sustainable material choices.	Telecom operators and technology suppliers
		Explore innovative business models such as device/HW leasing or subscription services to minimize unnecessary hardware demand	
		Implement product stewardship initiatives to incentivize responsible manufacturing and disposal practices within the immersive reality industry	Supply chain partners: raw material suppliers, component manufacturers, logistics providers, tech providers, investors, end -users adopting the technology

Annex 1.1.2 Social Sustainability

Apart from the 2 major challenges presented in Section 4.2, i.e., **social engagement / technology uptake** and **security (including privacy, security by design and trust)**, the analysis of this representative UC revealed a few more challenges:

- **Low mental health and well-being**: Immersive reality can positively impact people's lives depending on when, where and how it is used. For example, immersive reality in educational contexts could benefit students visiting remote museums and cultural events that they may not afford to physically visit, it could even be exploited in rural areas where the population is low, and the teachers are not enough. However, balancing the digital representation of a person with one's physical activities' is a challenge, especially if the digital interaction feels like a real one. Overusing immersive reality could then pose risks for the individuals in terms of e.g., individual isolation and alienation (i.e., loss of human physical contact). Depending on the used equipment risks could focus only on mental health or on physical well-being as well.
- The need to **balance equipment costs and technology capabilities**: Usually a new technology is much more expensive than technology that is available for some time or depending on the purpose the technology is going to be used there are different required capabilities. However, costs and affordability of the technology may lead to equality issues between individuals or even countries with varying income. This is a challenge that needs to be addressed; otherwise, it may rise risk both for the technology and / or infrastructure provider well as for the customer (buying person/authority/end-user).
- The need for **security, privacy, resilience, and trustworthiness** are common for all technological advancements offered over networks, but in some cases this challenge may be more critical than others. Immersive reality is one of these cases. Depending on the implementation of a service and the domain for which it is provided, a large number of personal data are collected and stored. In educational context this could be for performance analysis of the student or the teacher or even for continuation of the teaching process; in entertainment contexts it could be for gaming continuation, preferences for insightful ads or more. Building a resilient and trustworthy system for handling such information and ensuring that only the authorized people have access to this information is of paramount importance.
- **Fear of digital divide, digital inequalities depending on access, information technologies (IT) literacy and economic status**: although immersive reality can largely benefit digital inclusion in education, professional environments, health and more; accessing it, having the knowledge to use it or paying for the necessary personal equipment is not straightforward for the entire population. This highlights the challenge of overcoming the fear of the new and the digital divide this may lead to.

The analysis of these challenges revealed the risks listed in Table 6-2.

The most impactful risks, in terms of how many stakeholders are impacted from them, are those related to either end-users or authorities not exploiting the capabilities coming from the immersive reality technology due to costs, reluctance in using new technologies and security/privacy aspects.

Different approaches have been proposed for addressing these risks. Risks related to privacy concerns need to be tackled at a technical / designing level exploiting security-by-design principles, strict authentication / authorization mechanisms, and anonymization techniques where possible. Privacy and security risks can also be minimized raising proper awareness of the population that will use the technology in terms of both the added value the technology brings but also in terms of security threats and how to recognize or avoid them. Another, equally important, mitigation strategy comes from the policy-makers and the regulators (with the support of the technology providers) in terms of e.g., defining the maximum information that can be collected and used depending on the purpose of the immersive reality system, who can access them, how, why, what is the preservation policy and what are the minimum corrective measures in case of a breach, etc.

Table 6-2: Social Sustainability risks and mitigation strategies (RUC 1)

Ecosystem / Stakeholders	Risks	Mitigation Strategies	Stakeholders who can mitigate the risk
Building owners; content providers; Government, local councils, administrations, etc.; security and spectrum regulators; Owner and decision maker for the use of sensoring equipment; Shareholders, investors; subscribers (persons or firms); end-user (private or company)	People reluctance (people not liking the changes) in using new technology on education process	▪ Advertise more the added value; ▪ Co-construction of the solutions / UCs (incl. user friendly / technology agnostic approaches)	▪ Technology providers ▪ Domain experts
Government, local councils, administrations, etc.; security regulators; Owner and decision maker for the use of sensory equipment; Shareholders, investors; subscribers (persons or firms); end-user (private or company)	People worried about privacy / trust issues in the new technology; Lack of acknowledgement and control of which data is being measured/used/stored;	▪ Security by design ▪ Educate the end-users on the system security applied; ▪ Educate the population on the benefits and risks of these UCs	▪ Technology providers ▪ Domain experts
Company structures; governmental authorities; building owners; content providers; Government, local councils, administrations, etc.; security regulators; Shareholders, investors; subscribers (persons or firms); end-user (private or company)	Potential risks for trustworthiness in case of hacking	▪ Training / explanation of the new technologies; ▪ Education and awareness on the benefits and risks of the technology. They need to be easily accessible and friendly (e.g., not relying on 50 pages documents that no one will read)	Technology providers
Employees / end-users; Government, local councils, administrations, etc.; Shareholders, investors; subscribers (persons or firms); end-user (private or company)	Lack of skills to properly use the technology	Training how to use the new technologies	Employees; policy makers;
Technology providers; network providers; building owners; Government, local councils, administrations, etc.;	Environmental impact and cost impact for building a technology that is not used (social vs.		

spectrum regulators; Owner and decision maker for the use of sensory equipment; Shareholders, investors; Financing actor/sponsor of content and applications, e.g., education; Public building access owners; Infrastructure equipment provider; Innovators (developers of e.g., XR, HW/SW components); Network (operator) providers; Sensor providers	Environmental/Economic sustainability)		
Subscribers (persons); End-user (private)	Devices attached to face/head challenge people's concern on how they look/appear	Device look & feel	Technology providers
technology providers; network providers; funding authorities; Shareholders, investors; Financing actor/sponsor of content and applications, e.g., education; Public building access owners; Infrastructure equipment provider; Innovators (developers of e.g., XR, HW/SW components); Network (operator) providers; Sensor providers; Artificial Intelligence-based application provider; Provider of access to immersive experience application	Cost impact for research, more complex network infrastructures offering technology not being used		
Lower income end-users; Government, local councils, administrations, etc. from poorer countries; Lower income subscribers (persons or firms)	Too expensive equipment to be used from all, leading to digital divide	▪ Come up with ways to decrease cost as fast as possible to enable unserved sectors of the population; ▪ Governmentally supported / funded services	Policy makers; governments; funding authorities;
	Equipment becomes too expensive for the end-users or the public administrations that offer the	Co-funding of the devices needed for the immersive solution (e.g., educations)	public sector

	immersive services (e.g., educational services) in poor areas		
	the total cost of ownership for e.g., the school is too high, cannot be afforded	▪ When designing a device, take into account the cost, not only the performance; ▪ Develop less-costly alternatives which do not perform incredibly well, but are able to fulfil the essential use cases; ▪ Modularity of technology; ▪ Explore new business models, e.g., rental devices; ▪ Re-use the devices and fight against planned obsolescence; ▪ Decoupling devices from the users	Device producers; Technology providers
Government, local councils, administrations, etc.	Risk of deciding not to use the technology out of fear for digital divide	▪ Raise awareness of measures taken to avoid digital divide ▪ Open discussions for identifying the reasons the factors that could lead to digital divide and how to avoid it	Technology researchers and providers
subscribers (persons or firms)	Potential risk for individual isolation and alienation (i.e., loss of human physical contact)	Making sure content companies call in the experts (e.g. health specialists) to design adequate services	Content companies
End-user (private or company)	Potential risk for enhancing manipulation (proteus effect: representation of avatar may influence behaviour and attitude)	Raise awareness of the negative impacts in mental and physical health due to technology overuse	Technology providers to the society Society to end-users
Employees / end-users	Personal information made available to third parties without consent (e.g., hacking, unregulated businesses)	Tight and clear regulations on data creation, use, storage, and sharing; clear definition of the data collected and why	Policy makers
Government, local councils, administrations, etc.	Lack of acknowledgement and control of which data is being measured/used/stored.	Anonymisation of data, and protection of identity	Technology providers

Patient, children,	Manufacturers / providers are "rationally" trying to minimize cost and burdens from sustainability requirements, challenging privacy concerns	Tight and clear regulations on data creation, use, storage, and sharing; clear definition of the data collected and why	Technology providers Regulators

Annex 1.1.3 Economic Sustainability

In addition to the general challenges identified in Section 4.3, we can identify specific challenges for the seamless immersive reality use case, which are presented next. One economic sustainability challenge in seamless immersive reality representative use case is to **develop effective scenarios that can financially benefit** from immersive reality devices and services and for which there will be customers willing to pay. An example of this is creating an interoperable seamless immersive reality based real-time digital twin of a construction site, which accounts for the real needs of the customer.

Another challenge is to **have shared/common standards for the equipment and solutions** to allow wide-spread adoption of the seamless immersive reality services and equipment and avoid fragmentation. This is critical for the financial success of the seamless immersive reality use case since too limited usability of potentially costly special purpose equipment and services will not fly. This calls for stakeholders to agree on standards, including old and new stakeholder across the ICT and also from the vertical target sectors, where the use cases are deployed. A challenge is **not knowing your customers / end users** resulting in the difficulty of making new meaningful/useful services (social consequences; should be done by knowledgeable people/experts). Especially, the challenge of **not having the developer community to join the ecosystem** can lead to use cases not having the right use case specific content, which has financial implications. There is a challenge that immersive experiences will require extensive amounts of data/content/material and potentially requires a lot of effort for creating custom-made content, which again is costly.

One challenge is the potentially **large investments needed in the infrastructure** to support moving/mobile users of immersive experience. Unevenness of demand over the day can lead to over dimensioning of the infrastructure and leaving resources unused at some times, which is costly. Another challenge is to come up with **ways to decrease cost** as fast as possible to enable unserved sectors of the population to enjoy seamless immersive reality.

In addition to the general risks and mitigation strategies identified in Section 4.3, we have identified specific risks and mitigation strategies for the seamless immersive reality use case, which are presented in Table 6-3 together with involved stakeholders.

Table 6-3: Economic Sustainability risks and mitigation strategies (RUC 1)

Ecosystem / Stakeholders	**Risks**	**Mitigation Strategies**	**Stakeholders who can mitigate the risk**
Network operators	Investment in the network needs a clear demand for the immersive reality service and the availability of service and device ecosystem to fulfill the demand. There are financial risks of network deployment with requirements on different resources (benefits vs. costs).	New financing incentives/models/ecosystems for the new services need to be developed for sharing revenues and costs within the ecosystem.	Operators, infrastructure vendors, service providers, users, and other stakeholders in ecosystems
Equipment and service providers	There can be fragmentation in terms of services, equipment, chipsets, and spectrum, which calls for coordination of standards development. Lack of standards HW and SW (content) can hinder content ecosystem (innovation). There can be a lack of interoperability between different SW and HW components provided by different stakeholders. The communication data models between device providers are not harmonized (e.g., message format). As a result, service and device production is not scaling and becomes too costly.	Standards and spectrum harmonization need to be sought together with developing certification regimes. Stakeholders need to align about functionality. Regulatory requirements need to be established on EU level on interoperability. User groups need to be clear on their expectations and requirements for interoperability.	Operators, User associations; regulatory bodies, user groups
Network operators, service providers	There can be unequal uptake of services due to financial aspects related to digital divide impacting nations' welfare and future economic prospects. Too much reliance on immersive experience scenarios can put too much pressure on investment and reduce diversification.	Global and open standards and interoperability are needed to minimize the risk of lock-in (information to be exchanged). Testing and experimentation with users are needed to find killer application and situations.	User groups, vendors, standardization bodies

	There can be too high threshold to start using the services from users' slow adoption or unwillingness to change current habits and user patterns.		
Service and equipment providers	Service monopoly might occur for the immersive experience service as well as vendor lock-in from the selection of gear and services for the use case. There is possible gatekeeper role for virtual worlds controlling access to immersive services (e.g., lectures).	Global and open standards and interoperability are needed to minimize risk of lock-in.	User groups, vendors, service providers, standards bodies
End users, customers	Costs of applications and equipment including network and devices can be high and they can become obsolete fast.	User groups need to express clear expectations on equipment and applications for the providers of the equipment and services.	User groups, vendors, service providers

Annex 1.2 Cooperating Mobile Robots – Representation Use Case 2 (RUC-2)

Annex 1.2.1 Environmental Sustainability

The use-case "cooperating mobile robots" predominantly offers handprint gains in terms of social sustainability, e.g., in supporting workforce in dangerous, burdensome and/or repetitive tasks, but also in environmental and economic aspects. Several challenges arise from the implementation of this solution and need to be addressed to minimize environmental footprints and maximize handprints.

The use case envisions – among other objectives – an **increased production flexibility**. This higher flexibility may necessitate a greater number of collaborating robots, potentially highly specialized, both in operation and provisioning. Increased number of robots in turn may lead to **increased material usage and resource allocation** in (robot) production, **increased energy consumption in operation, and e-waste formation** at the end-of-life. To counteract, a careful analysis up-front is necessary considering a scenario-specific analysis of new/additional robots and their corresponding environmental footprint. Ensuring the **sustainability of the entire supply chain** and establishing transparency and traceability among the different suppliers to guarantee **compliance with sustainability standards** is pivotal.

Furthermore, the use-case envisions reaching an **increased resource efficiency** (both in energy and materials used) in production processes. While this is a valid scenario objective, it will likely not be fulfilled in every production scenario, since already today and in the past, a minimum of resource (energy/material) allocation is an economically viable goal. Also here, a detailed analysis of the **scenario-specific gains (handprints) and costs (footprints)** will help to identify those cases which predominantly lead to environmental gains. On the other hand, and a possible challenge here, an increased resource efficiency during production may lead to an overall increase in production. While this is not directly a threat, it might still pose a challenge as it requires the additional production capacity to be (environmentally) sustainable by itself. A responsible balancing between additional production and considering its associated footprints is the best way forward.

Table 6-4: Environmental Sustainability risks and mitigation strategies (RUC-2)

Ecosystem / Stakeholders	**Risks**	**Mitigation Strategies**	**Stakeholders who can mitigate the risk**
▪ Manufacturers; 6G industry device providers (robots) ▪ Local communities, people, and others there ▪ Nations, economies, markets, ICT industry - consumers/citizens (stagnation of modern society) ▪ Provider of 6G services ▪ Other sectors/industries	Running expectedly more robots may consume more resources and energy than in reference scenario	Provide tailored and optimized solutions for specific industries	Tech developers and telecom operators
	Benefits (handprint) might not be met at full scale due to not sufficiently wide adoption (niche)	Establish targeted market expansion and stakeholder engagement and promote the capabilities of robots and cobots.	Industry players, research institutions, suppliers, and operators
	Manufacturers/providers are "rationally" trying to minimize cost and burdens from sustainability requirements, leading to material overuse, emissions, and waste; locally rationally decisions (opportunistic) are leading to global unfortunate effects	Shared industry norms; business models; taxation.	Industry associations, regulatory bodies, tech developers.
			Regional and global governing bodies for climate and environment (e.g., setting standard to markets, certification, legacy, regulations)
	Regions with less developed waste management infrastructure, or access to recycling facilities may struggle to handle the disposal and recycling of electronic devices. This can lead to improper disposal practices, such as open burning or e-waste dumping	Establish incentivized take-back programs as well as monitored and assisted collection of robots using	Tech developers and telecom operators
		Conduct user education campaigns to promote responsible usage and end-of-life treatment as well as awareness of environmental impacts.	NGOs, local authorities, industry associations, regulatory bodies,
		Work to achieve cleaner energy (fossil-free energy, according to local/regional/global agreed criteria)	Power companies, investors in power companies, regulators, governmental with incentives

Annex 1.2.2 Social Sustainability

The 2 major challenges of **social engagement / technology uptake** and **security (including safety – from human-to-machine interactions, privacy, security by design and trust)** and the respective risks presented in Section 4.2, apply also in the cooperating mobile robots representative UC. The analysis of the UC uncovered 3 more challenges:

- **Support workers performing tasks beyond their capabilities that risk their lives (e.g., carrying large weights, working in dangerous environments) vs. job losses**: Robots are already used for performing arduous tasks in risky, for humans, environments, e.g., heavy lifting in the manufacturing, logistics, etc. or performing simpler tasks in dangerous environments, e.g., within mines. Cooperating mobile robots can support workers further since they are envisioned to have the capacity of synchronizing and collaborating with each other. Such a functionality can support workers well-being as well as other goals such as efficiency and effectiveness of performing each task. On the other hand, substituting workers with robots will limit the available jobs for uneducated workers. Balancing the two aspects is a challenge that if it is not properly addressed can create a number of risks (see the first 4 risks of Table 6-5).
- **Balance new processes with existing processes**: Introducing a new process for a task that is envisioned to be beneficial in terms of efficiency and effectiveness is not always easy or straightforward. Study of the benefits it introduces is needed while it is also necessary to take into account the time needed to get used to it or to combine it with existing processes. When the new processes involve the use of new devices (e.g., robots or even software controlling the robots in this UC), this may increase the employees stress for e.g., not making mistakes or quickly adapting to it (especially if the new process requires IT experience that an uneducated worker may or may not have). Moreover, maintenance procedures of the devices may also jeopardise the volume of benefits coming from the new process.
- **Balancing real human interaction with robot-human interaction**: Exploiting robots that can act autonomously for everyday repetitive tasks, e.g., in smart living environments, can be efficient and effective but attention is needed for balancing humans' psychological factors, e.g., human alienation from the extensive use of technology and thus, limitation of interactions between real humans.

Table 6-5 summarises the identified risks related to these challenges and suggests mitigation strategies. Risks related to security/privacy, safety during human-to-machine interactions and the need for new skills when processes start to include cooperating mobile robots need to be further studied and be taken into account during the design of the robots, the sensors they will use, the processes for which they will be used and the mechanisms that will empower the robots coordination (both for the cooperative tasks and the robots maintenance procedures). In parallel, policy-makers and standardization groups should engage in dialogue with non-ICT stakeholders that could help in the design of policies and procedures that will support a smooth transition from current practices to new procedures through e.g., parallel use of digitalized/robot-supported and non-digitalized processes, continuous training in new technologies, informative webinars / workshops of the benefits and the risks in using cooperating mobile robots as well as data used from cobots that may be relevant to human privacy aspects (e.g., robots localization data with respect to humans in the area they move).

Table 6-5: Social Sustainability risks and mitigation strategies (RUC-2)

Ecosystem / Stakeholders	Risks	Mitigation Strategies	Stakeholders who can mitigate the risk
employees	Rendering roles obsolete: may eliminate job roles involving manual, linear, and repetitive tasks	policies for smooth transition from current practises to new, robot-supported processes, e.g., parallel use of the processes for x period	▪ Policy-makers; ▪ Stakeholders with human sciences expertise
	Robots and cobots may require human operators to obtain new skills w.r.t. their method of use and maintenance (IT/robots literacy)	▪ training in new technologies; ▪ continuous-training policies ▪ extensive study of current practices and how cooperating mobile robots can be integrated ▪ thorough study of needs depending on the context the cobots will be used and customized (to the needs) design of robots	▪ Manufacturers; ▪ site owners; ▪ employers; ▪ policy-makers; ▪ cobots-supported service providers; ▪ cobots providers
	Risk of increasing employees stress for new process / maintenance procedure/ etc,		
	People's privacy may be breached by unauthorized use of robots' and cobots' sensors	▪ provision for data breaches; ▪ security by design; ▪ education of people wrt. the collected data ▪ design JCAS services that require as little data as possible	▪ Policy-makers; ▪ standardization groups; ▪ JCAS services providers;

Annex 1.2.3 Economic Sustainability

In addition to the general challenges identified in Section 4.3, we can identify specific challenges for the collaborative mobile robots use case, which are presented next. Collaborative mobile robots representative use case faces the challenge of **scaling of the collaborative mobile robots's solutions** to make the use case economically feasible. Niche solutions/services with small markets for very narrow use cases pose a challenge for the economic success of this use case since their development can be costly. This calls for standardization and the development of generic enough solutions. Collaborative mobile robots will operate with people, which leads to the economic challenge of **educating the people to use the new technology**, which requires effort and causes training costs.

In addition to the general risks and mitigation strategies identified in Section 4.3, we have identified specific risks and mitigation strategies for the collaborative mobile robots use case, which are presented in Table 6-6 together with involved stakeholders.

Table 6-6: Economic Sustainability risks and mitigation strategies (RUC-2)

Ecosystem / Stakeholders	Risks	Mitigation Strategies	Stakeholders who can mitigate the risk
Equipment and service providers, users	Lack of standards HW and SW (content) can hinder the content ecosystem (innovation) and resulting business creation. Lack of interoperability between SW and HW can hinder robots' ability to collaborate. There can be the lack of general accessible and harmonized APIs, common data models and harmonized spectrum. This can lead to vendor lock-in for both equipment and services. As a result, device production does not scale and becomes too costly.	Global standardization needs to be promoted to support common solutions: standards, or de-facto standards (specifications). Existing industry solutions and standards need to be used, e.g., from IEEE. Device chipsets need to be harmonized via standardization. Certification regimes need to be developed for devices.	Operators, Infrastructure providers/vendor, UE/device providers, industry associations: GSMA, NGMN, TM-forum, GCF (global certification forum), customer association (e.g., 5G-ACIA), ITU, 3GPP, ETSI, IEEE.
Employees, nations	Risk of people losing jobs resulting in economic impact on people/cities/nations.	Training and continuous learning need to be promoted.	Governments, employers
Service providers	Overestimation of market interest and customers' willingness to pay for the use case.	New financing incentives/models/ecosystems for the new services need to be developed for sharing revenues and costs within the ecosystem.	Operators, infrastructure vendors, service providers, users, and other stakeholders in ecosystems

Annex 1.3 Network Assisted Mobility – Representation Use Case 3 (RUC-3)

Annex 1.3.1 Environmental Sustainability

Several environmental challenges must be addressed to foster environmental sustainability in the network-assisted mobility use case. A primary concern involves **designing network components with a paramount focus on resource efficiency,** including energy, water, and materials, aiming to curtail the overall environmental impact associated with supporting the technology. Concurrently, the development of **energy-efficient processes for object localization and data analysis** becomes pivotal to minimize energy consumption. To adapt to the dynamic nature of connected vehicles, designing network topologies that can dynamically adjust based on density is essential for optimizing communication and resource consumption.

Another critical facet involves **incorporating only sustainable materials in manufacturing** network devices, aligning with **eco-friendly practices**. This includes implementing **holistic approach to sustainability**, and **strategic decision making aiming to minimize the environmental impact** through responsible sourcing, sustainable material transportation and usage, as well as stakeholders' engagement and transparency throughout the entire supply chain.

Ensuring **compliance with both environmental and EU-recommended EMF limits** is imperative to guarantee that network-assisted mobility solutions not only meet technical objectives but also respect value to human and environment. Furthermore, embracing a **modular design approach** for network devices allows for easy upgrades and repairs, reducing the need for frequent replacements and e-waste generation. **Collaborative efforts with stakeholders across the entire value chain,** including manufacturers, service providers, and regulatory bodies, can establish industry-wide standards for sustainable practices, creating a cohesive ecosystem committed to environmental stewardship.

Table 6-7: Environmental Sustainability risks and mitigation strategies (RUC-3)

Ecosystem / Stakeholders	Risks	Mitigation Strategies	Stakeholders who can mitigate the risk
▪ Tech suppliers and telecom operators ▪ Future generations and planet Earth: citizens, politicians, industries, local governments, cities ▪ Humans in traffic/pedestrians, professional transportation, industries ▪ Raw material providers, industry players, suppliers, telecom operators ▪ Regulatory bodies, industry associations	Reliance on non-renewable energy sources for network operations in some regions may undermine the overall sustainability goals	Invest in cleaner energy	Regional and global governing bodies for climate and environment (e.g., setting standard to markets, certification, legacy, regulations)
		Advocate for carbon taxation and other regulatory policies	Power companies, investors in power companies, regulators, governmental with incentives
	Sub-optimal integration of the assisted network mobility solution in urban planning preventing the achievement of the environmental handprints	Cross-Sector collaboration for ecological and sustainable urban planning and city development	Urban planners, environmental agencies, governments
	Implementation of network-assisted mobility solutions may inadvertently contribute to unanticipated traffic congestion and thus counteracting environmental goals	Continuously monitor and adjust traffic management strategies to minimize congestion and optimize environmental impact.	Telecom operators and tech developers and suppliers
	Irresponsible waste management depending on the different regions, access to recycling facilities, or recycling processes struggling to adapt to increasing device complexity	Establish incentivized take-back programs as well as monitored and assisted collection of end-of-life vehicles.	Tech developers, suppliers, and network service providers
		Raise environmental awareness on ecological and sustainable practices	Industry associations, academic institutions, environmental NGOs, in collaboration with technology suppliers

			Regional and global governing bodies for climate and environment (e.g., setting standard to markets, certification, legacy, regulations)
	Localization, Sensing and reliable compute capabilities might require a lot more energy/power	Work to achieve cleaner energy (fossil-free energy, according to local/regional/global agreed criteria)	Regional and global governing bodies for climate and environment (e.g., setting standard to markets, certification, legacy, regulations)
			Power companies, investors in power companies, regulators, governmental with incentives

Annex 1.3.2 Social Sustainability

Network assisted mobility representative UC introduces the following two additional main challenges:

- **Balancing transportation costs and availability vs. safety of operations**: Automation in vehicles can bring great benefits in e.g., reduced accidents, availability of transportation even in areas with limited professional drivers, transportation costs, etc. On the other hand, relying solely on technology in such cases can also turn extremely bad in cases of malfunctioning, bad AI/ML-based decisions, cyber-attacks, etc. Balancing the two aspects is of paramount importance for avoiding risky situations and including fragmentation of responsibilities.
- **Ensuring network assisted mobility in all areas**: Geographical, demographic or local-policy factors (e.g. spectrum allocation costs) can make business models of operators so unsustainable that sensing technologies (and 6G in general) are not deployed in rural areas, and benefits of Network-assisted mobility do not reach rural population (e.g. continuity of transportation service in rural areas) .

Table 6-8 presents the respective identified risks and suggested mitigation strategies, including both technical and policy-related actions.

Table 6-8: Social Sustainability risks and mitigation strategies (RUC-3)

Ecosystem / Stakeholders	Risks	Mitigation Strategies	Stakeholders who can mitigate the risk
Humans, pedestrians, drivers,	privacy risks: localization of people (that do not wish to e.g., be located / have digital footprint) in the context of vehicles understanding the operation environment	▪ correct level of accuracy so that you identify the existence of a person without exposing his personal data / identity; ▪ checkpoint of how we use and combine data and for what purpose ▪ provision for data breaches; ▪ security by design; ▪ education of people of the data collected; ▪ design accurate sensing services exploiting as little information as possible	▪ Providers of mobility solutions (all) ▪ Customers (paying), setting requirements to privacy ▪ Regional and global governing bodies for traffic and mobility (e.g., setting standard to markets, certification, legacy, regulations, licenses) ▪ Sensing service provider ▪ Security / privacy regulators
▪ End-users and citizens with potential benefits (they do not get); ▪ Customers - who pay for a service with expected levels ▪ Providers, who are dependent on quality of others in the ecosystem ▪ Local government, road authorities ▪ Subscriber ▪ End-user: e.g., driver, factory operator	Potential risks for trustworthiness in case of hacking (e.g., leading to more accidents)	▪ training / explanation of the new technologies; ▪ security by design;	▪ Providers of mobility solutions (all) ▪ Equipment providers (e.g., cars, automated guided vehicles, robots) ▪ Provider of sensors
▪ Those directly affected in the traffic scenario where things go wrong ▪ End-user: e.g., driver, factory operator	Potential risks from wrong decisions made by AI/ML	▪ trustworthy AI ▪ explainable AI	▪ Providers of mobility solutions (all) ▪ Customers (paying), setting requirements to privacy ▪ Regional and global governing bodies for traffic and mobility (e.g., setting standard

▪ Decision makers in mobility scenarios - who may have made wrong or weak decisions ▪ Providers - which brand is dependent on well-functioning systems ▪ Local government, road authorities			to markets, certification, legacy, regulations, licenses) ▪ Artificial intelligence-based application provider
Employees (professional drivers)	Decreased job opportunities	training in new technologies; continuous-training policies	▪ Employers / customers, paying for new solutions; ▪ Providers
Humans, pedestrians, drivers,	Fragmentation of responsibility when something goes wrong, e.g. cars crashing	System level governance, regulation and end to end insurance	▪ Providers of mobility solutions (all) ▪ Customers (paying), setting requirements to privacy ▪ Regional and global governing bodies for traffic and mobility (e.g., setting standard to markets, certification, legacy, regulations, licenses)
▪ End-users and citizens with potential benefits (they do not get); ▪ Local government, road authorities ▪ Subscriber ▪ End-user: e.g., driver, factory operator	Digital exclusion of citizens in rural or non- densely populated areas from Network-assisted / Digital divide between rural and urban areas	▪ Accurate financial analyses to proof the improved benefit/cost (benefit-to cost) ratio of implementing Network-assisted mobility solutions in rural areas. Those analyses can support further political decisions. ▪ Hardware/Software solutions developed and massified under the principle of openness and public interest, so that production and installation costs are reduced. (e.g. open RAN, open source, open HW, etc.) ▪ Incentives and compensations to motivate operators to implement Sensing Networks in rural areas.	▪ Providers of mobility solutions (all) ▪ Regional and global governing bodies for traffic and mobility (e.g., setting standard to markets, certification, legacy, regulations, licenses) ▪ Equipment providers (e.g., cars, automated guided vehicles, robots) ▪ Provider of sensors ▪ Policy-makers

Annex 1.3.3 Economic Sustainability

In addition to the general challenges identified in Section 4.3, we can identify specific challenges for the network assisted mobility use case, which are presented next. The network assisted mobility representative use case can lead to the challenge of **generating large amounts of data** to create the physical awareness, which is costly. This will require many data centers/data servers, therefore potentially leading to high lock-in from high costs of switching between data centers/servers. Another challenge is the investment needed for required coverage and quality of networks, which again is costly and calls for ways of investment and revenue sharing in the ecosystem.

In addition to the general risks and mitigation strategies identified in Section 4.3, we have identified specific risks and mitigation strategies for the network assisted mobility use case, which are presented in Table 6-9 together with involved stakeholders.

Table 6-9: Economic Sustainability risks and mitigation strategies (RUC-3)

Ecosystem / Stakeholders	Risks	Mitigation Strategies	Stakeholders who can mitigate the risk
End users, operators, service providers, vendors	Inclusion of new technologies into existing devices and infrastructures (e.g. cars) can be costly and complex.	Standardized solutions need to be deployed step-by-step, covering most beneficial areas and cases first. Identify and assess where challenges and benefits are higher, together with users and customers.	Providers and customers/users.
Vendors of equipment, networks, devices, services	Interoperability challenges of multiple big companies in the industry (e.g. car manufacturers, IT companies) can result in difficulties to agree on data and other key elements leading to market fragmentation and lack of economies of scale.	Global standardization needs to be promoted for supporting common solutions.	Providers, customers/users and standardization bodies.
Operators/service providers, vendors,	There can be too many dependencies between road infrastructure, networks, and devices (e.g., vehicles), which makes it difficult to reach global, wide-area solutions. Solutions with high benefits remain for limited specific usage, which is not economically viable.	Understanding the dependencies across many domains are needed together with mobilizing the interest and participation from other domains (road, vehicles).	Road authorities, vehicle associations (5G-AA (5G-automotive association).

Annex 1.4 Realtime Digital Twins – Representation Use Case 4 (RUC-4)

Annex 1.4.1 Environmental Sustainability

The Realtime Digital Twins Use-Case for 6G carries with it several environmental challenges. One of the main challenges lies in **reducing the environmental footprint** from manufacturing, deploying, and running the necessary equipment including **resource intensive IoT** and sensors among other network components and devices. Moreover, reducing the overall energy consumption required for processing real-time data, Digital Twin generation, data centers, IoT devices, and computing resources, and ensuring a responsible management of electronic waste resulting from discarded equipment is a crucial challenge. To address this challenge manufacturers and providers should mobilize to be sustainable: **Shared industry best practice**, **business models limiting unintended footprint effects, taxation, fees, requirements of circularity** (obligation to take care of returned waste), **nudging mechanisms** to make stakeholders to take decisions which are globally rational should help in this quest.

Another environmental challenge can emerge from a **limited adoption of the technology resulting in a hindering of the potential handprints,** as indicated in Hexa -X-II D1.2, due to a not wide enough application. In particular, low adoption could prevent the reduction of GHG emissions and consumption of natural resources, as well as prevent the expected waste reduction and thwart a sustainable urban development. To address this challenge several steps could be taken. In the design phase, a **comprehensive and sound collection of requirements, needs and data** for each potentially relevant field of application should be performed as there's a risk that limited **suitability to specific/complex environments** could limit adoption. Moreover, to reduce the risk related to reluctance in embracing new working methods, effective on-the-job demonstration and training could be organized and organizations should establish suitable strategies and policies to foster Digital Twin adoption; this should also be supported by policy makers including industry alliances, and governing bodies.

Table 6-10: Environmental Sustainability risks and mitigation strategies (RUC-4)

Ecosystem / Stakeholders	Risks	Mitigation Strategies	Stakeholders who can mitigate the risk
▪ Manufacturers; 6G industry device providers (robots, actuators); employees (HES) ▪ Nation, economies, markets, ICT industry - consumers/citizens (stagnation of modern society) ▪ Provider of any 6G services	Reduced Digital Twin (DT) adoption due to reluctance in embracing new working methods	Effective on-the-job demonstration and training	Employers and organizations responsible for overseeing the workforce,
	Reduced DT adoption due to limited suitability to specific/complex environments	Organizations should establish suitable strategies and policies to foster DT adoption; this should also be supported by policy makers	Organizations and policymakers (regulatory bodies, governments, environmental initiatives, etc.)
		In the design phase, ensure comprehensive and sound collection of requirements/data for each relevant field of application so that DTs can effectively tackle specific needs resulting in a wider adoption	Technology developers, engineers, researchers, and scientists
	Manufacturers/providers are "rationally" trying to minimize cost and burdens from sustainability requirements, leading to material overuse, emissions, and waste; locally rationally decisions (opportunistic) are leading to globally unfortunate effects	Shared industry norms; business models limiting unintended effects; taxation, fees; requirements of circularity (obligation to take care of returned waste); nudging mechanisms to make actors to take decisions which are globally rational;	Industry alliances; governance bodies

Annex 1.4.2 Social Sustainability

Exploiting technologies for Realtime Digital Twins poses two more challenges:

- "Big Brother" scenario due to the wide spread of sensors anywhere; and
- Trade-off between workers well-being and employability.

Irrespectively of the applied domain (e.g., manufacturing, smart cities, network planning or ports), in order to create an accurate digital representation of any combination of processes, products, persons, and functionalities of real-world items; multiple data sources, e.g., databases, sensors, tags, network data, data models, and network connectivity for ingesting these data are required. In cases of Digital Twins for smart cities (single or aggregated DT), this phenomenon becomes more prominent resulting in "Big Brother" scenarios or technology invading in peoples' private lives without necessarily their consensus. This phenomenon needs to be official and properly regulated from policy makers with the support of stakeholders coming from multiple expertise areas in order to avoid related risks.

The 2nd challenge refers to the need of balancing DT benefits with employability issues that may rise including e.g., employers' or employees' reluctance in using the new processes and increased IT expertise for exploiting the new processes and technological advancements.

Associated risks and mitigation strategies are presented in Table 6-11.

Table 6-11: Social Sustainability risks and mitigation strategies (RUC-4)

Ecosystem / Stakeholders	**Risks**	**Mitigation Strategies**	**Stakeholders who can mitigate the risk**
Humans in areas which are monitored by sensors	Potential risks to the privacy in the event of a cyber-attack depending on the digital twin (e.g., in case of smart city operations) and if it involves human information	▪ regulation of which DT can be implemented and the information that can be collected, stored and processed to this end ▪ security by design in IoT devices and digital twins	▪ Privacy regulators, Policy makers and Standardization groups ▪ Certification authorities, laboratories, ▪ Developers of HW and SW system components ▪ Provider of IoT devices and sensors
▪ Employees managing the DT	Manufacturers/providers invading private sphere of their employees managing the DT trying e.g., to minimize cost and burdens from sustainability requirements, to optimize operation and profits, e.g., via micromanaging employees, etc.	Clear regulatory framework; industry norms, shared;	Privacy regulators, Policy makers and Standardization groups
All technology providers incl. e.g., ▪ Infrastructure constructor/entrepreneurs ▪ Content provider (into the SW) ▪ Owner and user of the physical asset/device to be twinned (industry manufacturing tools, buildings...) ▪ Developers of (e.g. XR) solutions to present / manipulate Digital Twins ▪ Developers of HW and SW system components ▪ Provider of component that needs to be twinned: machines, robots, vehicles, etc. ▪ Infrastructure equipment provider	End-users' reluctance in embracing new approaches due to excessive complexity or costs issues	Suitable policies put in place to promote best practice and ensure a smooth transition to new methods of work	Policy makers and Standardization groups

▪ Developers of HW and SW system components ▪ Artificial intelligence based application provider ▪ Private, wide area network provider ▪ Provider passive infrastructure (towers, premises, electricity) ▪ Provider passive infrastructure indoor ▪ Provider active infrastructure indoor ▪ Provider of data network (non-Internet data network) ▪ Local networks provider (Digital Service Provider – DSP). ▪ Provider of sensors			
Workers that will need to start using / managing the DT	Potential impact on employability and labour market - must be studied further	Suitable policies put in place to promote best practice and ensure a smooth transition to new methods of work	Policy makers and regulators
▪ Users of DT application: receiver of data ▪ Users of DT application: creator of content and work items	Digital divide in underserved areas	▪ Accurate financial analyses to prove the improved benefit/cost (benefit-to-cost) ratio of implementing the DT ▪ Incentives to provides and MNO for offering adequate network capabilities	▪ Researchers; ▪ Local network providers; ▪ DT providers ▪ Policy-makers and regulators
▪ Users of DT application: receiver of data ▪ Users of DT application: creator of content and work items ▪ City authorities or providers of public city services	Risk of jeopardizing the resilience of a society in the event of e.g., Smart City DT fails	▪ Early engagement of DT users for proper definition of the needs ▪ Detailed design of the DT on a case by case basis, incl. network requirements	▪ Researchers; ▪ DT providers ▪ Users of DT applications ▪ Network providers

Annex 1.4.3 Economic Sustainability

In addition to the general challenges identified in Section 4.3, we can identify specific challenges for the realtime digital twinning use case, which are presented next. Realtime digital twinning representative use case requires an initial investment which can be large depending on use case. One challenge is to **attract investments** and leading to the question who within the realtime digital twinning ecosystem that should invest in the digital twin or the network. Another economic sustainability challenge is the **lack of needed skills** for which the training is costly. Additionally, an economic sustainability challenges is **data management and data security** and resulting potential financial impacts.

In addition to the general risks and mitigation strategies identified in Section 4.3, we have identified specific risks and mitigation strategies for the realtime digital twinning use case, which are presented in Table 6-12 together with involved stakeholders.

Table 6-12: Economic Sustainability risks and mitigation strategies (RUC-4)

Ecosystem / Stakeholders	**Risks**	**Mitigation Strategies**	**Stakeholders who can mitigate the risk**
Digital twin providers	Sector-specific digital twin systems (e.g., in manufacturing) become "black boxes", which limits the ecosystem stakeholders' ability to further improve and innovate (e.g., the factory floor is left to providers) limiting the business opportunities. Manufacturers may fear that losing control limits market take-off.	Transparent systems with modular architecture need to be developed including simpler interfaces.	Providers of Digital twin systems (components and integrators).
Providers	Lack of standards HW and SW (content) can hinder content ecosystem (innovation). There can be a lack of interoperability between different SW and HW components provided by different stakeholders. Lack of standards and harmonized spectrum leads to increased costs including device production not scaling.	Global standardization needs to be promoted including standardized information exchange.	Operators, Infrastructure providers/vendor, UE/device providers, customer association (e.g., 5G-ACIA, public authorities on behalf of citizens, end-user associations)
Providers	Lack of interconnectivity and difficulty of integration with existing technologies/systems/SW as well as increased demand for storage/servers can result in economic burden. for deployment.	Standardized solutions need to be deployed step-by-step, covering most beneficial areas and cases first.	Providers and those deploying the systems and services.
Providers	Cyber risks resulting in financial risks and the need for data quality control.	Standardized secure solutions.	Providers, standardization bodies.

Annex 1.5 Ubiquitous Network – Representation Use Case 5 (RUC-5)

Annex 1.5.1 Environmental Sustainability

For the ubiquitous network use case a huge challenge is to design and implement a ubiquitous 6G network which is both reaching an **acceptable quality of service and at the same time is optimized to have a minimal environmental footprint.** The challenge includes defining **suitable implementation solutions**, which requires a clear understanding of when and where to provide mobile broadband with terrestrial networks, and when to use non-terrestrial networks (such as satellites and drones) - and to understand what implications this might have on the environment. Another challenge is to build **systems which are flexible enough to provide the different capabilities only when they are needed**, through a balance of different implementation possibilities.

The first challenge can be addressed in the implementation phase by performing assessments for different deployment scenarios. It is crucial to **apply an end-to-end perspective** — including the full life cycle and scope of all parts of the system — to build comparable scenarios. It is then possible to **choose the best solution for different geographical areas**. The spectrum made available for 6G will impact the outcomes of these types of assessments when it comes to providing coverage. The second crucial challenge that needs to be considered in the design work is **not to over-deliver capabilities when not needed or to create lock-in effects,** such as preventing for instance sleep mode solutions for the network. However, also here the end-to-end perspective is important to ensure that **systems remain adaptable and open to incorporating new technologies** or solutions as they emerge.

Table 6-13: Environmental Sustainability risks and mitigation strategies (RUC-5)

Ecosystem / Stakeholders	Risks	Mitigation Strategies	Stakeholders who can mitigate the risk
▪ Employer, employee, consumer, local retailers, artists, ▪ Future generations ▪ and planet Earth (from more pollution) ▪ Local and global communities ▪ Network operators experience huge investment failures in networks. ▪ Infrastructure equipment provider ▪ Non-Terrestrial-Network-Connectivity incl Earth station ▪ Wide area networks provider (CSP, ISP) ▪ Local networks provider (DSP). Local, small-scale	Increased connectivity may not result in less travel/transport in total. Examples: ▪ If people take jobs much further from their homes due to the increased acceptance of working from home, thus may need to fly to their workplace on a regular basis. (i.e., increased commuting, maybe even from car/public transport to airplane) ▪ If people discover places / artists etc., which they want to experience live, and decide to travel more than before. (i.e., increased spare-time travel) ▪ If people do more online shopping because of better connectivity, more products could be ordered from far away instead of from local production. (i.e., increased transportation of goods)	Understand the needs and decide on what is good enough from a capabilities level/QoS.	Providers, Regulators, telcos operators, tech suppliers, local authorities, global organizations, industry alliances, environmental NGOs, (especially for the network architecture part)
			Investors in network infrastructure and operation force consolidation
		Research and assess the full life cycle environmental trade-off/balance of when to build out TN network and when to rely on NTN, to minimize the footprint.	Research institutions, international organizations (ITU, UN, etc.), environmental NGOs
			Local and global political bodies
			Local, regional, global competition bodies
	Environmental data may not be possible to collect. Examples: ▪ If no stakeholder is prepared to make the investment in the infrastructure of sensors due to	Minimize use of scarce materials and avoid hazardous substances.	All supply chain contributors including providers, developers, suppliers, operators, and end-users.
		Minimize use of virgin materials.	Technology designers, raw material providers, developers, engineers, suppliers,

base station operator/owner (radio resource) ▪ Provider of energy infrastructure ▪ End-user ▪ Subscriber (governments, authorities, NGOs, private companies)	lack of willingness to pay for the information collected. (No ROI.) ▪ If countries and/or municipalities are not allowing the equipment needed for the monitoring.	When using biodegradable materials, the whole product should be made from biodegradable materials, or it will in any case need to be taken back, not to cause harm in nature.	Technology designers, developers, suppliers, network equipment providers and operators
		Design for circularity (optimize repairability, reusability and recyclability, secure a long lifetime of hardware and software)	
	Ubiquitous network may not result in better precision farming: ▪ Since precision farming requires advanced equipment, it is not an option for small-scale farming in developing countries due to high cost. ▪ The increased efficiency could be used to increase production/yield instead of minimizing the use of fertilizers and pesticides.	Design of sustainable business models with plans to share passive infrastructure, towers, antennas, and so on.	Providers, regulators, telcos operators, tech suppliers, local authorities, global organizations, industry alliances, environmental NGOs, (especially for the network architecture part)
		Recycling plans as part of the design of sustainable business models: Re-evaluate the idea of letting satellites burn at end-of-life.	Regulators, telcos operators, tech suppliers, service providers, local authorities, global organizations, industry alliances,

Annex 1.5.2 Social Sustainability

The Ubiquitous Network use case focuses on delivering Mobile Broadband connectivity to every human on Earth, leaving no "white zones" and therefore address the goal of digital inclusion. This target is highly dependent of the existence or not of the proper infrastructure with the necessary coverage, capacity and capabilities but there are more challenges to overcome:

- Secure global digital literacy and digital skills: providing a digital service is not enough. It needs to also take into account the specificities for each user group and their know-how.
- Find one global standard solution to the ubiquitous network with agreed core values in a diverse world:
- Create understanding of why ubiquitous network is needed
- Geopolitical challenges

Risks and mitigation strategies for social sustainability in the context of Ubiquitous Network can be found in Table 6-14.

Table 6-14: Social Sustainability risks and mitigation strategies (RUC-5)

Ecosystem / Stakeholders	Risks	Mitigation Strategies	Stakeholders who can mitigate the risk

All end-users	Despite the access to digital ecosystem for everyone, there is a risk not everyone can use the digital service, for example
	▪ deployment costs or devices cost can be too high hindering wider availability of connectivity
	▪ the today (unwillingly) unconnected groups of end-users remain unconnected due to coverage and/or digital knowledge and skills
		▪ Raise digital knowledge and skills through education
		  ▪ for children and young, include in school programs, subsidize schools to have connectivity
		  ▪ for grown-ups not yet connected, create learning hubs in public areas as libraries
		▪ Create strong partnerships agreeing on core values as for example privacy
		▪ Flexibility in software and hardware design that could allow to implement suitable strategies
		▪ Security / privacy by design
			▪ policy makers, local and central legislators
			▪ Providers

	Risk for every society which increases its reliability on technology, that it also increases its vulnerability in the sense that the technology can be damaged (intentionally or accidentally) and cause harm to a society.		
	Risk of the technology being used with harmful purposes		
	The more probable to meet digitally, the less probable to meet in person		
	Risk for digital divide rather than digital bridge for people with functional variation / ageing population / IT literacy if all services are meant to be handled digitally		
	Privacy risks if all services are meant to be handled digitally		
	Risk of anxiety or some related mental issue due to expectation for always being connected and being traceable		

Annex 1.5.3 Economic Sustainability

In addition to the general challenges identified in Section 4.3, we can identify specific challenges for the ubiquitous network use case, which are presented next. Ubiquitous network representative use case faces the challenge to find **new business models and collaborations to make the initial investments** needed for a ubiquitous network economically feasible. and **secure Return On Investment (ROI)** for stakeholders in the ecosystem. The latter incorporates the challenge to **make all parts of the ubiquitous network compatible in a cost-efficient and resilient** way including e.g., Terrestrial Networks, Non-Terrestrial Networks, Local Networks etc., and to **secure cost-efficient maintenance of the network**.
In addition to the general risks and mitigation strategies identified in Section 4.3, we have identified specific risks and mitigation strategies for the ubiquitous network use case, which are presented in Table 6-15 together with involved stakeholders.

Table 6-15: Economic Sustainability risks and mitigation strategies (RUC-5)

Ecosystem / Stakeholders	Risks	Mitigation Strategies	Stakeholders who can mitigate the risk
Infrastructure equipment providers Non-Terrestrial-Network-Connectivity incl Earth station Wide area networks provider (CSP, ISP) Local networks provider (DSP). Local, small-scale base station operator/owner (radio resource) Provider of energy infrastructure End-user- Subscriber (governments, authorities, NGOs, private companies)	Sustainability footprints are larger than expected. ▪ Unforeseen costs appear in the future, through for example legislation, which could risk the profitability for the stakeholders. ▪ Natural disasters, war and hacker attacks make the maintenance of the network more costly than expected. ▪ Ubiquitous network will not be affordable enough for end-users and subscribers, hence not enough uptake, affecting the ROI of the stakeholders that have made the investment. Sustainability handprints do not happen: ▪ Deployment costs become too high hindering wider availability of connectivity for different services and thus not increasing economic resilience. ▪ Reusing of resources (5G) is less favourable from an environmental perspective as regards energy efficiency. With new legislation coming this could imply a major cost in the form of GHG taxes (at least in the European Union). ▪ Costs for creating compatibility between ubiquitous network and other use cases (e.g. in public services) proves too costly and thus not increasing economic benefits for the society.	Create new ecosystems including for example e-commerce companies, multilateral development banks and sustainability funds to finance investments and maintenance. Promote infrastructure sharing to reduce costs. In countries with low or uneven distribution of connectivity a way to attract capital for upgrading and expanding digital infrastructure could be by governments reducing constraints on foreign direct investment. Enhance market predictability by legislation/regulation and standardization. Ensure the supply of adequate, inexpensive spectrum. Create affordable satellite connection for the most remote areas. Recalibrate universal service funds (USFs) to fund deployment of infrastructure in unserved areas.	Infrastructure equipment providers Non-Terrestrial-Network-Connectivity incl. Earth station Wide area networks provider (CSP, ISP) Local networks provider (DSP). Local, small-scale base station operator/owner (radio resource) Provider of energy infrastructure End-user- Subscriber (governments, authorities, NGOs, private companies)

Annex 1.6 Human Centric Services– Representation Use Case 6 (RUC-6)

Annex 1.6.1 Environmental Sustainability

The human-centric use-case for 6G brings with it several environmental challenges, paramount among them being the significant increase in energy consumption. This surge is primarily due to the **widespread deployment of new devices and the intensive use of AI/ML algorithms**, which require substantial computational power.

Additionally, the **material consumption for creating these new devices and establishing the network infrastructure** cannot be overlooked. This not only strains natural resources but also leads to a consequential issue: the disposal of e-waste. As these new devices and network components eventually reach the end of their lifecycle, they contribute to the growing problem of **electronic waste**, posing a serious environmental threat.

Moreover, the **non-compatibility of hardware and software platforms** exacerbates these challenges. When devices and systems are not interoperable, it leads to increased resource consumption, as users are often forced to replace otherwise functional equipment to stay compatible with the latest technology standards, further intensifying the environmental impact of 6G technology.

To address these challenges, a two-pronged approach is necessary. First, **legislation** aimed at preventing "walled gardens" and promoting interoperability is crucial. This can be achieved through **standardized hardware and software interfaces** between different manufacturers, ensuring that devices and systems are more universally compatible, thereby reducing the need for frequent replacements and mitigating e-waste. Second, there is a pressing need for education focused on preventing environmentally unsustainable usage of technology. By informing the public and corporate entities about the environmental impact of their technology choices and usage patterns, it is possible to foster a more **sustainable approach to the adoption and utilization of 6G technology**. This combination of legislative action and **educational initiatives** can play a pivotal role in mitigating the environmental impact of the upcoming 6G era.

Table 6-16: Environmental Sustainability risks and mitigation strategies (RUC-6)

Ecosystem / Stakeholders	**Risks**	**Mitigation Strategies**	**Stakeholders who can mitigate the risk**
▪ Private individuals ▪ Governments ▪ Technology developers and suppliers ▪ Network operators ▪ Local communities ▪ Global community ▪ End-users ▪ All other consumers and users of same and different product and services	Increased resource consumption as well as device production linked to excessive usage of the technology due to cost efficiency and convenience, ease to use and associated increase in resource consumption	Advocate for legislation to prevent "walled gardens" and encourage standardized hardware/software interfaces between different manufacturers.	Device and network equipment manufacturers and network operators Governing bodies (through legislation and subsidies and/or taxes)
		Raise awareness about good practices and the environmental crisis.	Educational institutions, Organizations, environmental NGOs, researchers, suppliers, operators
	Lack of economic incentive to be environmentally sustainable	Foster stakeholders' engagement and collaboration to meet sustainability requirements.	Governmental bodies, environmental NGOs, academic institutions (regulation, standards, awareness campaigns)
			Technology providers, operators
		Education to prevent environmentally unsustainable usage.	Governmental bodies, environmental NGOs, academic institutions (regulation, standards, awareness campaigns)
	Accumulation of electronic waste due to the disposal of outdated or malfunctioning on-body sensors and devices.	Design devices with modular and upgradable parts to extend their lifespan.	Hardware and software developers, engineers
		Implement take-back programs for proper disposal and recycling of electronic components.	Technology developers and Service providers
	Unsustainable material sourcing practices and negative impacts on the supply chain.	Comply with sustainability standards throughout the entire supply chain.	All supply chain contributors, raw material providers, suppliers, technology developers, service providers, operators, end-users

Annex 1.6.2 Social Sustainability

This use case puts the human at the center of a wide range of 6G services. Human-centric services demand the use of trusted environments where privacy and reliability are key characteristics to make the services trustable by the public. The examples highlighted in Hexa-X-II D1.2 deliverable include:

- Precision healthcare;
- Safe environments such as kinder gardens, schools, homes, day-care, workplaces, or hospitals;
- Public safety services during big events.

Due to the nature of the UC, the main challenges are those that are common across all technology-related discussions and already analysed in Section 4.2, i.e., **social engagement / technology uptake** and **security aspects**, focusing a lot on privacy challenges**.**

Risks and mitigation strategies for social sustainability in the context of Human Centric Services can be found in Table 6-17.

Table 6-17: Social Sustainability risks and mitigation strategies (RUC-6)

Ecosystem / Stakeholders	Risks	Mitigation Strategies	Stakeholders who can mitigate the risk
▪ People: children, caretakers, elderly, ▪ Customers/offering services such as safe environments ▪ Network operators: not able to get ROI on investments ▪ Governmental and political bodies who are not able to realize social modernization	Privacy risks from monitoring humans	▪ provision for data breaches; ▪ security by design; ▪ education of people of the data collected	▪ Providers of solutions (all) ▪ Customers (paying), setting requirements to privacy ▪ Regional and global governing bodies for situations where humans are in a vulnerable situation (e.g., setting standard to markets, certification and certification partners, legacy, regulations, licenses)
▪ People: children, caretakers, elderly, ▪ Customers/offering services such as safe environments ▪ Network operators: not able to get ROI on investments" ▪ User groups: Patients, etc.	Potential risks for trustworthiness/safety in case of hacking Systems with many components (complex) increase vulnerability for hacking and data leakage in a complex and hackable system	▪ training / explanation of the new technologies; ▪ Education and awareness on the benefits and risks of the technology. They need to be easily accessible and friendly (e.g., not relying on 50 pages documents that no one will read)	
▪ People: children, caretakers, elderly, ▪ Customers/offering services such as safe environments"	Health risks if you fully and always trust the service, without using traditional approaches, and the system fails	▪ quality assurance; ▪ testing; ▪ certification; ▪ set requirements to standards, certificates etc.	

Annex 1.6.3 Economic Sustainability

In addition to the general challenges identified in Section 4.3, we can identify specific challenges for the human centric services use case, which are presented next. Human centric services representative use case faces the challenge to **develop incentives so that people using smart devices would generate sensing data** once the users leave the area where the data is being gathered for the business case to work.

In addition to the general risks and mitigation strategies identified in Section 4.3, we have identified specific risks and mitigation strategies for the human centric services use case, which are presented in Table 6-18 together with involved stakeholders.

Table 6-18: Economic Sustainability risks and mitigation strategies (RUC-6)

Ecosystem / Stakeholders	Risks	Mitigation Strategies	Stakeholders who can mitigate the risk
Vertical service providers	Stakeholders who could be interested in investing and providing human centric services, are not trusted. This can lead to demand not taking off, and innovation and new business not being created.	In local (national) context, relevant stakeholders need to leverage on and get legitimacy to act. Pilots and early experiments need to be conducted to demonstrate trust in stakeholders.	Governing entities in domains. Domain specific alliances. Citizen alliances. Insurance companies, where relevant. National operators, with a current role as "provider of societal critical infrastructure".
Providers of services and solutions	Service provisioning is not able to adapt to the standards and regulatory regime within the vertical domain (health) where requirements are high.	Close interaction with health domain is needed.	Service providers, health providers, insurance companies, health regulators, health device providers
Network operators, solution providers	Capacity demanding services and demand lead to outages and failures and the demand does not take off.	Levels of services need to be assured. Extensive testing is needed before deployment. Agreed requirements to KPIs/testing are needed before live deployment.	Operators, infrastructure equipment providers, health device providers, SW and application providers, domain specific regulators.
Users, customers	Generating false/malicious data could lead to financial loss for stakeholders involved.	A reputation mechanism could be introduced.	Service providers, users.

Annex 1.7 Environmental, Social and Economic sustainability overview

This section summarizes the results from sections Annex 1.1 up to Annex 1.6 on a risk basis approach in a table format. More specifically, using the risks of each representative UC, the authors have grouped similar risks and summarised them in 3 tables (one for each sustainability axis), aiming at supporting the readers and any future UC to perform the methodology and make sure that the most common risks are taken into account when designing the implementation approach of the UC solution or selecting the technology enablers.

Table 6-19: Environmental Sustainability risks and mitigation strategies

Risks	Mitigation Strategies	Related UCs
Increased manufacturing of hardware components due to pervasive success or widespread adoption of new solutions, or business models leading to unintended demand and unprecedented consumption of energy and resources	▪ Implement sustainable business models that prioritize circular economy principles emphasizing device reuse, recycling, and sustainable material choices limiting unintended effects. ▪ Explore innovative business models such as device leasing or subscription services to minimize unnecessary hardware demand. ▪ Implement product stewardship initiatives to incentivize responsible manufacturing and disposal practices. ▪ Determine adequate capabilities and Quality of Service (QoS) considering user-centric approaches to specific needs and performance metrics. ▪ Legislation to prevent "walled gardens" and encourage standardized hardware/software interfaces between different manufacturers.	All
Reduced adoption due to limited suitability to specific/complex environments, affordability of the solution on small-scale levels, or due to reluctance in embracing new ways for living, working, and accessing different services	▪ Establish suitable strategies and policies to foster the adoption of a solution in collaboration with organizations and policy makers. ▪ Organize training sessions and effective on-the-job demonstrations and tutorials.	▪ RUC-1 ▪ RUC-2 ▪ RUC-4 ▪ RUC-5
Locally rational opportunistic decisions leading to global unfortunate environmental effects	▪ Promote transparency, accountability, and measurability throughout the value chain, and identify the largest contributors to footprint impacts. ▪ Educate stakeholders at all levels on good and sustainable practices.	▪ RUC-2 ▪ RUC-4 ▪ RUC-3 ▪ RUC-6

Impossible collection of environmental data due to lack of ROI, stakeholder willingness to pay for the information collected, or other restrictions	▪ Identify and engage relevant stakeholders and highlight the potential benefits they can derive from the collected data. ▪ Advocate for clear regulatory frameworks that can motivate stakeholders to invest in data collection for compliance or competitive reasons. ▪ Tax breaks or other financial incentives can encourage stakeholders to contribute to environmental data collection initiatives. ▪ Foster collaborations and partnerships between public and private entities to distribute the costs and responsibilities associated with data collection.	all
Improper disposal of electronic devices such as open burning or e-waste dumping due to underdeveloped waste management infrastructure, or recycling processes struggling to adapt to the fast-paced technological evolution and the increasing complexity of devices	▪ Design for circularity (optimize repairability, reusability and recyclability, secure a long lifetime of hardware and software) ▪ Minimal required manufacturing of hardware devices, sensors, and network infrastructure should be leveraged ▪ Only products with fully biodegradable materials can be left in nature. Products made only partially of biodegradable materials should be taken back at the end of their life. ▪ Business models should include recycling strategies as part of the business model.	all
Increased efficiency in production processes leading to increased production	Align business strategies with shared industry norms, and adhere to taxation regulations, and implement transparent fee structures to balance growth while ensuring sustainable practices.	▪ RUC-2 ▪ RUC-1
Increased spare-time travel and commuting due to remote working, and increased transport of goods due to online shopping and other digital services	▪ Organize education campaigns and awareness about the climate crisis. ▪ Promote more taxation and regulatory policies on travel.	▪ RUC-1 ▪ RUC-2 ▪ RUC-4 ▪ RUC-5

Table 6-20: Social Sustainability risks and mitigation strategies

Risks	Mitigation Strategies	Related UCs
Risk for low trust due to the actual technical characteristics of the network in terms of trustworthiness	▪ Design of 6G blueprint with the aim to be trustworthy ▪ Cyber-secure networks that respect users' privacy	All

Fear of new technology in general, reluctance to change, distrust in one specific stakeholder, or even disinformation.	▪ Communicate design choices made to make the 6G blueprint trustworthy with all involved stakeholder incl. e.g., end-users, standardization groups, representatives outside the ICT section, etc. ▪ Advertise more the added value; ▪ Co-construction of the solutions / UCs (incl. user friendly / technology agnostic approaches) ▪ Security by design ▪ Educate the end-users on the system security applied; ▪ Educate the population on the benefits and risks of these UCs ▪ Training / explanation of the new technologies; ▪ Education and awareness on the benefits and risks of the technology. They need to be easily accessible and friendly (e.g., not relying on 50 pages documents that no one will read) ▪ Tight and clear regulations on data creation, use, storage, and sharing; clear definition of the data collected and why ▪ Anonymisation of data, and protection of identity	
Lack of acknowledgement and control of which data is being measured/used/stored;		
Personal information made available to third parties without consent (e.g., hacking, unregulated businesses)		
Potential risks for trustworthiness in case of hacking		
Fragmentation of responsibility when something goes wrong, e.g. cars crashing	▪ System level governance, regulation and end to end insurance	RUC-3
Potential risks to the privacy in the event of a cyber-attack depending on the digital twin (e.g., in case of smart city operations) and if it involves human information	▪ regulation of which DT can be implemented and the information that can be collected, stored and processed to this end ▪ security by design in IoT devices and digital twins	RUC-4
Manufacturers/providers invading private sphere of their employees managing the DT trying e.g., to minimize cost and burdens from sustainability requirements, to optimize operation and profits, e.g., via micromanaging employees, etc.	▪ Clear regulatory framework; industry norms, shared;	RUC-4
People’s privacy may be breached by unauthorized use of robots’ and cobots’ sensors	▪ provision for data breaches; ▪ security by design; ▪ education of people wrt. the collected data ▪ design JCAS services that require as little data as possible	RUC-2
privacy risks: localization of people (that do not wish to e.g., be located / have digital footprint) in the context of vehicles understanding the operation environment	▪ correct level of accuracy so that you identify the existence of a person without exposing his personal data / identity; ▪ checkpoint of how we use and combine data and for what purpose	RUC-3

	▪ provision for data breaches; ▪ security by design; ▪ education of people of the data collected; ▪ design accurate sensing services exploiting as little information as possible	
Lack of skills to properly use the technology	▪ training in new technologies; ▪ continuous-training policies ▪ extensive study of current practices and how cooperating mobile robots can be integrated; ▪ thorough study of needs depending on the context the cobots will be used and customized (to the needs) design of robots	RUC-1; RUC-2; RUC-3; RUC-4
Decreased job opportunities		
Robots and cobots may require human operators to obtain new skills w.r.t. their method of use and maintenance (IT/robots literacy)		
Risk of increasing employees stress for new process / maintenance procedure/ etc,		
Rendering roles obsolete: may eliminate job roles involving manual, linear, and repetitive tasks	policies for smooth transition from current practises to new, robot-supported processes, e.g., parallel use of the processes for x period	RUC-2; RUC-4
Environmental impact and cost impact for building a technology that is not used (social vs. Environmental/Economic sustainability)		RUC-1
Devices attached to face/head challenge people's concern on how they look/appear	Device look and feel	RUC-1
Cost impact for research, more complex network infrastructures offering technology not being used		all
Too expensive equipment to be used from all, leading to digital divide	▪ Come up with ways to decrease cost as fast as possible to enable unserved sectors of the population; ▪ Governmentally supported / funded services	RUC-1; RUC-5
Equipment becomes too expensive for the end-users or the public administrations that offer the immersive services (e.g., educational services) in poor areas	▪ Co-funding of the devices needed for the immersive solution (e.g., educations)	RUC-1
the total cost of ownership for e.g., the school is too high, cannot be afforded	▪ When designing a device, take into account the cost, not only the performance; ▪ Develop less-costly alternatives which do not perform incredibly well, but are able to fulfil the essential use cases; ▪ Modularity of technology; ▪ Explore new business models, e.g., rental devices;	RUC-1

	▪ Re-use the devices and fight against planned obsolescence; ▪ Decoupling devices from the users	
Risk of deciding not to use the technology out of fear for digital divide	▪ Raise awareness of measures taken to avoid digital divide ▪ Open discussions for identifying the reasons and the factors that could lead to digital divide and how to avoid it	RUC-1
Potential risk for individual isolation and alienation (i.e., loss of human physical contact)	Making sure content companies call in the experts (e.g. health specialists) to design adequate services	RUC-1; RUC-5
Potential risk for enhancing manipulation (proteus effect: representation of avatar may influence behaviour and attitude)	Raise awareness of the negative impacts in mental and physical health due to technology overuse	RUC-1; RUC-5
Manufacturers / providers are "rationally" trying to minimize cost and burdens from sustainability requirements, challenging privacy concerns	Tight and clear regulations on data creation, use, storage, and sharing; clear definition of the data collected and why	RUC-1, RUC-4
Potential risks from wrong decisions made by AI/ML	▪ trustworthy AI ▪ explainable AI	RUC-3
Digital exclusion of citizens in rural or non- densely populated areas from Network-assisted / Digital divide between rural and urban areas	▪ Accurate financial analyses to proof the improved benefit/cost (benefit-to cost) ratio of implementing Network-assisted mobility solutions in rural areas. Those analyses can support further political decisions. ▪ Hardware/Software solutions developed and massified under the principle of openness and public interest, so that production and installation costs are reduced. (e.g. open RAN, open source, open HW, etc.) ▪ Incentives and compensations to motivate operators to implement Sensing Networks in rural areas.	RUC-3
Digital divide in underserved areas	▪ Accurate financial analyses to prove the improved benefit/cost (benefit-to-cost) ratio of implementing the DT ▪ Incentives to provide and MNO for offering adequate network capabilities	RUC-1, RUC-4, RUC-6
Risk for digital divide rather than digital bridge for people with functional variation / ageing population / IT literacy if all services are meant to be handled digitally	▪ Create strong partnerships agreeing on core values as for example privacy ▪ Flexibility in software and hardware design that could allow to implement suitable strategies	RUC-5
Risk for every society which increases its reliability on technology, that it also increases its vulnerability in the	▪ Raise digital knowledge and skills through education	RUC-5

sense that the technology can be damaged (intentionally or accidentally) and cause harm to a society.	▪ for children and young, include in school programs, subsidize schools to have connectivity; ▪ for grown-ups not yet connected, create learning hubs in public areas as libraries; ▪ Flexibility in software and hardware design that could allow to implement suitable strategies	
Risk of jeopardizing the resilience of a society in the event of e.g., Smart City DT fails	▪ Early engagement of DT users for proper definition of the needs ▪ Detailed design of the DT on a case by case basis, incl. network requirements	RUC-4
Health risks if you fully and always trust health services, without using traditional approaches, and the system fails	▪ quality assurance; testing; certification; set requirements to standards, certificates etc.	RUC-6
Risk of the technology being used with harmful purposes	▪ Raise digital knowledge and skills through education ▪ for children and young, include in school programs, subsidize schools to have connectivity ▪ for grown-ups not yet connected, create learning hubs in public areas as libraries ▪ Flexibility in software and hardware design that could allow to implement suitable strategies ▪ Security / privacy by design	RUC-5

Table 6-21: Economic Sustainability risks and mitigation strategies

Risks	Mitigation Strategies	Related UCs
Lack of legitimacy where the stakeholder roles / actors are not perceived as a legitimate provider of a specific 6G use case component in the ecosystem, can lead to lower demand and business opportunities.	Build legitimacy and change attitudes over time by mobilizing roles and actors with “the license to play”. Providers in different roles must express the significance of other roles. Operators as national entities must build trust. They need to exchange views and demonstrate understanding with general public.	All
Lack of interoperability and compatibility at different levels can lead to significant network and service deployment costs in use cases limiting business opportunities. As a result, ecosystems are built around proprietary specifications which become de-facto standards and lack of interoperability across the de-facto	Global standardization is needed to avoid fragmentation. Collaboration between standardization organizations is needed building on existing structures.	All

standards. This can lead to financial dependance on a limited number of service and equipment providers (vendor lock-in), and fragmentation of ecosystem with several regional 6G standards.		
Ending up in “winner-takes-it-all” position and de-facto proprietary standard will lead to lock-in, which makes it difficult to attract firms to invest in value creation in the ecosystem. There can be high uncertainty about investments, returns, and sharing of revenues and costs between stakeholders in the use case specific ecosystems. For customers, the current operation and revenues might suffer when implementing new 6G systems. Implementing and gaining acceptance for new pricing models for differentiated services is difficult. Switching costs and network effects end-users.	Reinforcement of policies on European key priorities including e.g., sovereignty and competition, will be needed together. New business models need to be developed to enable new types of investments in networks and use case specific services accepting alternative financing and operating parties (e.g., private networks, local communities, indoor, building owners).	All
Lack of globally harmonized spectrum for 6G can lead to lost business opportunities and increased cost in different use cases by limiting the deployments. Local/national/regional differences in the way spectrum is made available and priced can potentially cause ecosystem fragmentation leading to increased costs and lack of scaling. Also, restrictions in the way spectrum is managed in different regions/countries may risk the provision of the required capacity in the different use cases resulting in 6G-devices (e.g., 6G industrial devices, XR devices) not achieving economies-of-scale in production.	Timely availability of new harmonized regional or global spectrum for Mobile Service across low/medium/high frequency bands can facilitate the economies of scale for the development of the 6G ecosystem in the 2030 deployment target.	All
There can be unequal uptake of services due to financial aspects related to digital divide impacting nations' welfare and future economic prospects.	Global and open standards and interoperability are needed to minimize the risk of lock-in. Testing and experimentation with users are needed to find killer application and situations.	RUC-1
Service monopoly and vendor lock-in might occur from the selection of gear and services for the use case.	Global and open standards and interoperability are needed to minimize risk of lock-in.	RUC-1
Costs of applications and equipment including network and devices can be high and they can become obsolete fast.	User groups need to express clear expectations on equipment and applications for the providers of the equipment and services.	RUC-1

Use case service can become a local, indoor service only if no ways to include wide-area use are found. This leads to fragmentation of devices and solutions which is costly.	Stronger mobile network for indoor use cases needs to be built to offer better coverage especially in indoor buildings. Better integration between indoor and outdoor networks needs to be developed.	RUC-1 RUC-2 RUC-4
Risk of people losing jobs resulting in economic impact on people/cities/nations.	Training and continuous learning need to be promoted.	RUC-2
Overestimation of market interest and customers' willingness to pay for the use case.	New financing incentives/models/ecosystems for the new services need to be developed for sharing revenues and costs within the ecosystem.	RUC-2
Inclusion of new technologies into existing devices and infrastructures (e.g. cars) can be costly and complex.	Standardized solutions need to be deployed step-by-step, covering most beneficial areas and cases first. Identify and assess where challenges and benefits are higher, together with users and customers.	RUC-3 RUC-4
Interoperability challenges of multiple big companies in the industry (e.g. car manufacturers, IT companies) can result in difficulties to agree on data and other key elements leading to market fragmentation and lack of economies of scale.	Global standardization needs to be promoted for supporting common solutions.	RUC-3
There can be too many dependencies between road infrastructure, networks, and devices (e.g., vehicles), which makes it difficult to reach global, wide-area solutions.	Understanding the dependencies across many domains are needed together with mobilizing the interest and participation from other domains (road, vehicles).	RUC-3
Sector-specific use case specific systems (e.g., digital twin in manufacturing) become "black boxes", which limits the ecosystem stakeholders' ability to further improve and innovate, limiting the business opportunities. Fear that losing control limits market take-off.	Transparent systems with modular architecture need to be developed including simpler interfaces.	RUC-4
Cyber risks resulting in financial risks and the need for data quality control.	Standardized secure solutions.	RUC-4
Sustainability footprints are larger than expected (unforeseen costs; natural disasters; affordability challenges) and/or Sustainability handprints do not happen (high deployment costs; challenge of reusing 5G resources; compatibility costs).	Create new ecosystems with new roles and new funding models. Promote infrastructure sharing to reduce costs. Enhance market predictability by regulation and standardization.	RUC-5

	Ensure the supply of adequate, inexpensive spectrum. Create affordable satellite connection for the most remote areas.	
Stakeholders who could be interested in investing and providing human centric services, are not trusted. This can lead to demand not taking off, and innovation and new business not being created.	In local (national) context, relevant stakeholders need to leverage on and get legitimacy to act. Pilots and early experiments need to be conducted to demonstrate trust in stakeholders.	RUC-6
Service provisioning is not able to adapt to the standards and regulatory regime within the vertical domain (health) where requirements are high.	Close interaction with health domain is needed.	RUC-6
Capacity demanding services and demand lead to outages and failures and the demand does not take off.	Levels of services need to be assured. Extensive testing is needed before deployment. Agreed requirements to KPIs/testing are needed before live deployment.	RUC-6
Generating false/malicious data could lead to financial loss for stakeholders involved.	A reputation mechanism could be introduced.	RUC-6

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