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 D1.1
Environmental, social, and economic drivers and goals for 6G

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Abstract

In addition to technical advancements, the development of 6G networks is also driven by the three dimensions of sustainability. Environmental, social, and economic sustainability are considered up from the planning phase and aim to create more environmentally friendly and energy-efficient technologies that promote accessibility, security, and new business opportunities. Hexa-X-II will design a system blueprint aiming at the sustainable, inclusive, and trustworthy 6G platform that should meet the future needs of serving and transforming society and business. This deliverable comes with the first considerations of drivers and goals for 6G regarding sustainability and their impact on the design of the 6G system.

Keywords

6G, sustainability, environment sustainability, social sustainability, economic sustainability, use cases, 6G design

Disclaimer

Executive Summary

This first deliverable from Work Package 1 (WP1) “Environmental, social, and economic drivers and goals for 6G” describe the foundations for the design of a sustainable, inclusive and trustworthy 6G. Sustainability has become the cornerstone for the development of new system and applications and will be a driver for the design of 6G. Sustainability can be considered under three different angles:

- Environmental sustainability, ensuring the preservation of natural resources and ecosystem
- Social sustainability, aiming at the well-being of all individuals and communities; Inclusion and trustworthiness are two important aspects.
- Economic sustainability, targeting long-term economic growth while respecting the conditions for environmental and social sustainability

This report presents the drivers and goals for 6G inspired by these three interconnected pillars of sustainability, to be used as a baseline for Hexa-X-II to deliver a system blueprint of the 6G platform.

Several stakeholders have provided their own view on sustainability and provided guidelines, including governmental and intergovernmental organizations, standardization bodies and industry fora, and regional initiatives and projects. A comprehensive state-of-the-art of the different stakeholders, as well as their visions and guidelines, is presented, setting the frame for Hexa-X-II own drivers and goals. A unified set of terminologies is also provided as a common ground. Several sustainability goals, including those set by the UN, are to be met by 2030, when 6G is expected to be available. The aim is to provide social and economic value without compromising the ability of future generations to meet their own needs.

Not only environmental, social, and economic sustainability aspects are inseparable and have direct and indirect impacts on one another, but several trade-offs can also arise between different sustainability factors within each aspect. Assessing the environmental impacts of a new technology requires a holistic, life cycle assessment (LCA) approach to different footprints along with their respective indicators and proxies. An ecological 6G design should incorporate environmental sustainability considerations in the planning, architecture, and operation of networks. This requires a fundamental shift in the way equipment and devices are designed, produced, consumed, and disposed of action, as well as action from all stakeholders. Such considerations include the adoption of circularity practices, avoidance of hazardous substances, enhancement of energy efficiency and overall energy consumption through cloudification and automation, and the reliance on ecological energy sources, and design of modular and durable equipment.

Social sustainability can be influenced by several factors including resources availability, gender equality, health and wellbeing, IT education, safety, inclusivity, justice, etc. In the context of 6G networks, these factors can be reduced to two main categories: a) digital inclusion, i.e., making 6G networks and services available and accessible. This requires better network coverage, capacity, and equal exploitability. b) trustworthiness, i.e., moving forward with a network design that can address security and data privacy concerns. A socially sustainable 6G must prioritize cybersecurity and safeguard end-users' privacy, involve human oversight in AI-based approaches to ensure accountability and foster trust, improve availability, flexibility, adaptability, as well as non-discriminatory practices.

Economic sustainability operates at corporate, ecosystem, and societal levels in order to ensure sustainability while making profitable business decisions, promoting collaboration and innovation, achieving prosperity and growth, and transitioning away from harmful practices. Having this in perspective, 6G should be designed to solve major sustainability challenges and prepare for mitigating risks while ensuring economic viability through sustainable business model innovation, open value configurations and sharing of economy models, and user densities accommodation among other.

As a starting point for the project, Hexa-X-II identified an initial set of use cases, relying on the use cases delivered by Hexa-X project and selecting a subset of seven use cases. These use cases can be categorized into three dimensions: sustainability-driven use cases, technology-centric use cases, and vertical use-cases. The use cases envisioned for 6G will be further identified and developed in the coming deliverable from Hexa-X-II,

D1.2, with a new methodology to ensure that the proposed use cases will address end user needs and solve existing problems.

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Acronyms and abbreviations

Term	Description
AI	Agenda Item or Artificial Intelligence
BEREC	Body of European Regulators for Electronic Communications
CEN	European Committee for Standardization
CENELEC	European Electrotechnical Committee for Standardization
ETSI	European Telecommunications Standards Institute
GESI	Global Enabling Sustainability Initiative
GSMA	Global System for Mobile Communications Association
ICT	Information and Communications Technology
ITU	International Telecommunication Union
SBTi	Science Based Target initiative
SDG	Sustainable Development Goal
SG	Study Group
SME	Small and Medium Enterprises
UN	United Nations

1 Introduction

Environmental, societal, and economic sustainability are three interconnected pillars that form the basis for sustainable development. A legitimate and successful development and implementation of 6G technologies must respect all three pillars and cater to and balance the expectations from stakeholders (6G stakeholders are introduced and described in chapter 5.).

Environmental sustainability aims to preserve natural resources and ecosystems. It refers to the responsible and efficient use of natural resources and the protection of ecosystems and biodiversity, to maintain their health and productivity over time. It involves reducing waste, pollution, and the overuse of natural resources, and ensuring that human activities do not harm the natural environment. Environmental sustainability also aims to create a healthy and safe environment for people to live in, by minimizing the negative impact of human activities on air, water, and soil quality. Achieving environmental sustainability often requires a shift towards renewable energy sources, the use of eco-friendly products and practices, and the implementation of policies and regulations that promote sustainable development. Moreover, a change in production methods is needed to overcome this challenge; one that 6G can meet.

Social sustainability involves ensuring that social structures and institutions are inclusive, non-discriminatory, and promote equal access to opportunities and resources. Social sustainability also aims to foster a sense of social cohesion and community, by promoting social trust, cooperation, and shared values. Especially digital inclusion and trustworthiness are important topics. Achieving social sustainability often requires the development of policies and programs that address social inequalities. Social sustainability is a vital component of sustainable development, which seeks to ensure the well-being of both current and future generations.

Economic sustainability involves developing economies that are resilient, adaptable, and inclusive, while also ensuring that economic growth does not come at the expense of the environment or social equity. It refers to the ability of an economy to support the well-being of its people and its ability to maintain its functions over time. Economic sustainability aims to achieve long-term economic growth and stability by creating conditions that allow businesses, individuals, and communities to thrive. Achieving economic sustainability often requires balancing economic, social, and environmental concerns in decision-making processes, and incorporating sustainable practices into economic systems and policies.

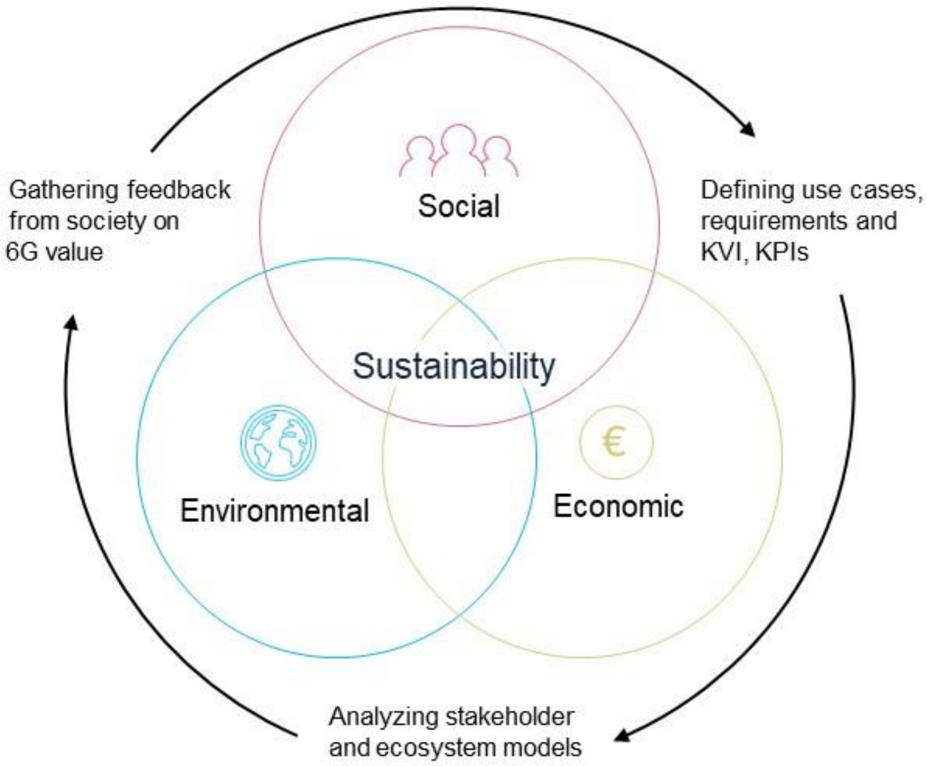

Figure 1-1: The three Pillars of Sustainability

Together, these three pillars provide a framework for creating a sustainable future that meets the needs of both present and future generations. These before mentioned three pillars of sustainability have thus to be a basis and must be considered when designing 6G. 6G is the next generation of communication system building on top of 5G. Beyond the technical challenges future 6G must tackle, it is important that also sustainability is embedded in the conception of the technology. The aforementioned three pillars of sustainability have thus to be a basis and must be considered when designing 6G. This first document of WP1 of HEXA-X-II aims at providing drivers and goals for 6G regarding those three pillars of sustainability.

The organization of this deliverables is as follows. Chapter 2 begins with a review of existing guidelines and works on sustainability within the United Nations (UN), in European Union (EU) and in global organizations related to the Information and Communication Technologies (ICT). Chapter 3 provides an overview of the most up-to-date definitions of environmental, social, and economic sustainability. Chapter 4 outlines the current trends observed in the various sustainability domains. As 6G is expected to be launched in the early 2030s, chapter 5 considers goals and drivers with a vision being a decade ahead from now and examines the impact of these identified drivers and goals. The implications for potential use cases are explored in chapter 6 and a first initial set of use cases for 6G is provided in this chapter. Chapter 7 proposes some initial aspects that must be considered by the design of the 6G system. Finally, we conclude in chapter 8.

This deliverable provides the first work on “Sustainability Guidelines for 6G Design”. This is the Hexa-X-II Work Package (WP) 1 outcome towards all other WPs within Hexa-X-II. Our next steps in WP1 are a deep dive into the use cases and use cases families in our next deliverable D1.2 entitled “6G use cases and requirements” which is planned for December 2023

2 Existing Work and Guidelines on Sustainability

This chapter aims to provide an overview of the main existing actors, and their guidelines and works concerning sustainability. These actors or entities that set goals for sustainability affect also 6G. Additionally, this chapter summarizes work in governmental and intergovernmental organizations, standardization and industry associations as well as regional projects and research initiatives.

Chapter 2.1 presents work from governmental and inter-governmental entities such as the United Nations (UN) [1] and its related entities like the Intergovernmental Panel on Climate Change (IPCC) [2] and the UN Framework Convention on Climate Change (UNFCCC) [3], the European Union (EU) [4], the Body of European Regulators for Electronic Communications (BEREC) [5] and the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) [6].

Chapter 2.2 adds summaries of works from Standardization Organizations like the International Telecommunication Union (ITU) [7], the European Telecommunications Standards Institute (ETSI) [8] and the 3rd Generation partnership project (3GPP) [9].

Chapter 2.3 provides a look on Industry Associations and their work on sustainability. Among the cited entities there are the Global System for Mobile Communication Association (GSMA) [10], the Next Generation Mobile Network Operators (NGMN) [11] and the Next G Alliance (NGA) [12].

Finally, chapter 2.4 cites regional or other miscellaneous initiatives, such as the Hexa-X project [13], the Nine Planetary boundaries concept [14], the Doughnut Economy principle [15] and the butterfly diagram for circular economy [16].

All these actors or entities are, either, more generic or domain-specific to the telecommunications industry. They can influence and set directions and visions. Some entities may affect decisions directly, for instance the EU Smart Networks and Services (SNS) and 6G research program [17] set specific expectations for sustainability goals.

2.1 Governmental and Intergovernmental Work

This chapter presents some key work from governmental and intergovernmental Organisations.

2.1.1 United Nations (UN) Sustainable Development Goals (SDGs)

United Nations' Sustainable Development Goals (UN SDGs) – are 17 goals adopted by all UN member states in 2015 during the meeting in Paris, as part of the Agenda 2030 for Sustainable Development. These 17 goals are further specified into 169 targets, and a high number of indicators which are mainly defined from the perspective of the different member countries. They follow the Millennium Development Goals (MDGs) adopted in 2000 to reduce extreme poverty by 2015. Under the motto "leave no one behind" the aim is to meet the needs of the present without compromising the ability of future generations to meet their own needs [18].

As a foundation for life on Earth four of them address Environment (i.e., 6, 13, 14 and 15); eight of them address Society (i.e., 1, 2, 3, 4, 5, 7, 11 and 16); four address economy (i.e., 8, 9, 10 and 12) and the 17th goal is what binds it all together, i.e., "Partnerships for the goals".

The UN SDGs are organized according the three pillars of sustainability as follows.

Environment

- SGD 6: Clean water and sanitation – Ensure availability and sustainable management of water and sanitation for all
- SDG 13: Climate action – Take urgent action to combat climate change and its impacts
- SDG 14: Life below water – Conserve and sustainably use the oceans, seas and marine resources for sustainable development
- SDG 15: Life and land – Protect, restore, and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss

Society

- SDG 1: No poverty – End poverty in all its forms everywhere
- SDG 2: Zero hunger – End hunger, achieve food security and improved nutrition and promote sustainable agriculture
- SDG 3: Good health and well-being – Ensure healthy lives and promote well-being for all at all ages
- SDG 4: Quality education – Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all
- SDG 5: Gender equality – Achieve gender equality and empower all women and girls
- SDG 7: Affordable and clean energy - Ensure access to affordable, reliable, sustainable, and modern energy for all
- SDG 11: Sustainable cities and communities – Make cities and human settlements inclusive, safe, resilient, and sustainable
- SDG 16: Peace, justice and strong institution – Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels

Economy

- SGD 8: Decent work and economic growth – Promote sustained, inclusive, and sustainable economic growth, full and productive employment and decent work for all
- SDG 9: Industry, innovation, and infrastructure - Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation
- SDG 10: Reduced inequality – Reduce inequality within and among countries
- SDG 12: Responsible consumption and production – Ensure sustainable consumption and production patterns

Overall

- SDG 17: Partnerships for the goals – Strengthen the means of implementation and revitalize the global partnership for sustainable development

For details on the 17 goals with their 169 targets and 231 indicators, see [18] [18]. The Stockholm Resilience Centre has visualized them well as a wedding cake [19], see Figure 2-1.

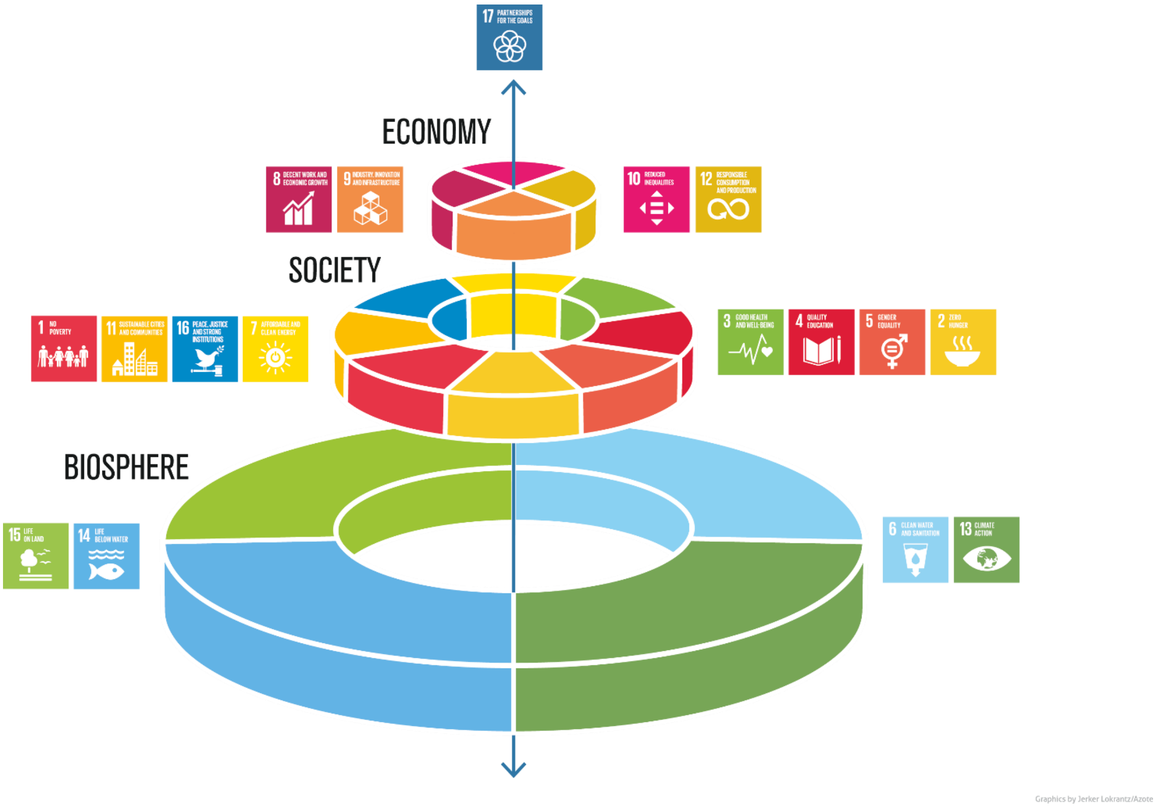

Figure 2-1: The 17 SDGs grouped by Stockholm Resilience Centre (Credit: Azote for Stockholm Resilience Centre, Stockholm University CC BY-ND 3.0.)

The timing when the goals should be reached is the year 2030 which is with the time when 6G is expected to be available in the market. Consequently, 6G cannot as such impact the achievement of the SDGs, but Hexa-X-II can use them to identify the critical sustainability areas. It is also expected that the 2030 goals will be followed by subsequent goals going in the same direction.

2.1.2 United Nations Framework Convention on Climate Change (UFNCCC)

Corporate climate transition has been increasingly in focus during recent years, with several key initiatives gathering companies across sectors. Overall, companies are supposed to reach net zero around 2040-2050, following a 1.5°C aligned emissions reduction pathway corresponding to halving emissions by 2030 [18]. The two main initiatives around net zero and emission reduction are the Science-Based Targets Initiative (SBTi) [20] and the Race to Zero [21] initiatives led by the Climate Champions that are closely linked with the United Nations Framework Convention on Climate Change (UNFCCC)[2].

SBTi is a partnership between CDP, the United Nations Global Compact, World Resources Institute (WRI) and the World-Wide Fund for Nature (WWF). For a company with climate targets, this initiative offers a possibility for a 3rd party validation. Targets are only considered ‘science-based’ if they are in line with what the latest climate science deems necessary to meet the goals of the Paris Agreement – limiting global warming to well-below 2°C above pre-industrial levels and pursuing efforts to limit warming to 1.5°C. All the 3 scopes (defined by the Greenhouse Gas Protocol [22]) need to be included.

The SBTi defines frameworks for both short-term and long-term targets and have so far engaged with over 4000 companies. Their work includes: i) defining and promoting best practice in emissions reductions and net-zero targets in line with climate science; ii) providing technical assistance and expert resources to companies who set science-based targets in line with the latest climate science; and iii) supporting companies with independent assessment and validation of targets.

[2] The Treaty to reduce greenhouse gas concentrations was signed by 154 countries in 1992 as part of the United Nations Conference on Environment and Development (UNCED)

Race to Zero is a global campaign which mobilizes a coalition of leading net-zero initiatives, representing 11,309 non-State actors including 8,307 companies, 595 financial institutions, 1,136 cities, 52 states and regions, 1,125 educational institutions and 65 healthcare institutions (as of September 2022). Race to Zero is led by the Climate Champions. It mobilizes actors outside of national governments to join the Climate Ambition Alliance and was launched at the UN's Climate Action Summit 2019 in Madrid, Spain. An important step forward to provide a foundation to the Net Zero Concept was taken with the publication of the report of the United Nations High-Level Expert Group On The Net Zero Emissions Commitments Of Non-State Entities [23], and the ISO Net Zero Guidelines [24].

The Exponential Roadmap Initiative is one of the Race to Zero members which highlights the importance of technology. It is for innovators, transformers and disruptors and is an accredited partner of United Nations' Race to Zero and a founding partner of the 1.5°C Supply Chain Leaders and the SME Climate Hub [26].

2.1.3 Intergovernmental Panel on Climate Change (IPCC)

The Intergovernmental Panel on Climate Change (IPCC) is the United Nations body for assessing the science related to climate change. The IPCC prepares comprehensive Assessment Reports about knowledge on climate change, its causes, potential impacts, and response options. Through its assessments, the IPCC identifies the strength of scientific agreement in different areas and indicates where further research is needed. The IPCC also produces Special Reports, which are an assessment on a specific issue and Methodology Reports, which provide practical guidelines for the preparation of greenhouse gas inventories [2].

In their latest report, i.e., the Sixth Assessment Report on climate change 2023 [25] published in March 2023, they recognize the interdependence of climate, ecosystems and biodiversity, and human societies. It is observed that more than a century of burning fossil fuels as well as unequal and unsustainable energy and land use have led to global warming of 1.1 °C above pre-industrial levels. This has resulted in more frequent and more intense extreme weather events that have caused increasingly dangerous impacts on nature and people in every region of the world. Limiting human-caused global warming requires net zero anthropogenic CO_2 emissions. Pathways consistent with 1.5°C and 2°C carbon budgets imply rapid, deep, and in most cases immediate greenhouse gas (GHG) emission reductions in all sectors. Achieving and sustaining global net negative CO_2 emissions would reduce warming and exceeding a warming level and returning (i.e., overshoot) implies increased risks and potential irreversible impacts.

In addition to the Sixth Assessment Report, the IPCC finalized the Synthesis Report for the Sixth Assessment Report during the Panel's 58th Session held in Interlaken, Switzerland, 13 - 19 March 2023. Scientists behind the report have noted that there are multiple, feasible and effective options to adapt to climate change. These methods are now available and more affordable than ever.

According to António Guterres, Secretary-General of the United Nations: "This latest IPCC report is a how-to guide to defuse the climate time-bomb. We are at a critical time point where the technology and solutions are available to us in a way like never before (…) but we need to work fast, and together, to make it work." A few examples include enhancing recycling, biofuels for transports, reducing food loss and food waste, Fossil Carbon Capture and Storage (CCS), etc.

2.1.4 European Union (EU)

The European Union introduced several policies to tackle sustainability issues.

European Green Deal

Climate change and environmental degradation are an existential threat to Europe and the world. To overcome these challenges, the EU has introduced a package of policy initiatives, called **The European Green Deal**, which aims to set the EU on the path to a green transition, with the ultimate goal of reaching climate neutrality by 2050. The **European Green Deal** will transform the EU into a modern, resource-efficient, and competitive economy, ensuring:

- no net emissions of greenhouse gases by 2050,
- economic growth decoupled from resource use,

- no person and no place left behind [26]

The European Green Deal is closely linked to the Digital Decade, the EU's digital strategy, to help reach climate-neutrality by 2050[3].

European Accessibility Act

When it comes to social sustainability, one example is "**The European accessibility act**, which is a directive that aims to improve the functioning of the internal market for accessible products and services, by removing barriers created by divergent rules in Member States [27] [28].

Persons with disabilities and elderly people will benefit from:

- more accessible products and services in the market
- accessible products and services at more competitive prices
- fewer barriers when accessing transport, education, and the open labour market
- more jobs available where accessibility expertise is needed

It should also be noted from an economic sustainability perspective that businesses will benefit from:

- common rules on accessibility in the EU leading to costs reduction
- easier cross-border trading
- more market opportunities for their accessible products and services"

General Data Protection Regulation (GDPR)

Another example of social sustainability is the General Data Protection Regulation (GDPR) [29]**.** It is described as the toughest privacy and security law in the world. Though it was drafted and passed by the European Union (EU), it imposes obligations onto organizations anywhere, so long as they target or collect data related to people in the EU. The regulation was put into effect on May 25, 2018. The GDPR levies harsh fines against those who violate its privacy and security standards, with penalties reaching into the tens of millions of euros.

With the GDPR, Europe is signalling its firm stance on data privacy and security at a time when more people are entrusting their personal data with cloud services and breaches are a daily occurrence.

2.1.5 Body of European Regulators for Electronic Communications (BEREC)

Body of European Regulators for Electronic Communications (BEREC) assists the European Commission and the national regulatory authorities (NRAs) in implementing the EU regulatory framework for electronic communications. It provides advice on request and on its own initiative to the European institutions and complements, at the European level, the regulatory tasks performed by the NRAs at the national level.

BEREC published a first report on sustainability "Assessing BEREC's contribution to limiting the impact of the digital sector on the environment" [30]. One of the toughest challenges identified by this report was the lack of available data, as well as the need to adopt a harmonized approach to methodologies and standards for assessing the environmental impact of digital technologies. They then proposed a draft report on implementing a common and harmonized assessment methodology and transparency measures regarding the environmental footprint of electronic communications networks and services (ECN/ECS) in the EU that has been approved for public consultation [31].

2.1.6 Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES)

The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) aims to strengthen the science-policy interface for biodiversity and ecosystem services for the conservation and sustainable use of biodiversity, long-term human well-being and sustainable development [32]. The policy

[3] The EU is a main policy driver with regards to materials efficiency and has been the initiator of the common standard in this area from European Committee for Standardization (CEN), European Electrotechnical Committee for Standardization (CENELEC) and ETSI

framework for the 2030 work programme corresponds to the 2030 Agenda for Sustainable Development, including the Sustainable Development Goals, the biodiversity-related conventions and other biodiversity and ecosystem service processes.

The 2030 work programme initially focuses on three topics

- Topic 1 – understanding the importance of biodiversity in achieving the 2030 Agenda for Sustainable Development,
- Topic 2 – understanding the underlying causes of biodiversity loss and determinants of transformative change and options for achieving the 2050 Vision for Biodiversity,
- Topic 3 – measuring business impact and dependence on biodiversity and nature's contributions to people

The work programme is expected to inform all stakeholders in the implementation of their activities to support the achievement of the post-2020 global biodiversity framework and the 2050 Vision for Biodiversity, as well as other work under multilateral environmental agreements related to biodiversity. The work programme may also inform the implementation of the Paris Agreement with respect to matters related to the links between biodiversity and climate change.

2.1.7 Hexa-X European Project

A clear vision is needed to guarantee digital inclusion and ensure health and safety while working towards environmental goals. The EU-funded Hexa-X project [13] seeks to contribute to shape this vision and develop tools necessary to bring the next generation of wireless communications to Europe and beyond. It will achieve this by working on ground-breaking communication technologies, architectures, and artificial intelligence-enabled networks. This will help secure growth and sustainability while creating the future of wireless communications worldwide.

Sustainability is a central aspect of Hexa-X's 6G vision building on the UN SDGs and adapting them for the ICT sector. It has two facets, namely, 6G for sustainability that focuses on 6G enabling non-ICT sectors to meet their CO_2 emissions targets and sustainable 6G that focuses on a 6G system that is environmentally, socially, and financially sustainable.

On 6G for sustainability, Hexa-X set an ambitious direction by indicating a challenging objective toward enabling reductions of (>30%) CO_2e (CO_2 equivalent) emissions in 6G powered non-ICT sectors of society, when compared with a baseline that does not have 6G applied. At this point this target should be seen as an expression for a high climate ambition but any quantification of 6G impacts would be too uncertain to be meaningful. However, Hexa-X has built substantial knowledge on enabling effects of 6G and applying existing methodologies.

Sustainable 6G includes financial, social, and environmental sustainability. For financial sustainability, a reduction in the total cost of ownership (TCO) of more than 30% is expected. The TCO includes both capital expenditure (CAPEX) and operational expenditure (OPEX). For environmental sustainability, Hexa-X stipulates an energy efficiency enhancement of 90% with respect to the baseline. For both financial and environmental sustainability, a 5G NR SA system is considered to be the baseline. More information regarding the Hexa-X project can be found in [13].

2.2 Standardization Organizations

2.2.1 International Telecommunication Union (ITU)

As the UN agency responsible for ICTs, the International Telecommunication Union (ITU) dedicates substantial work for the development of sustainable technologies, for all its radio communication (ITU-R), standardization (ITU-T), and development (ITU-D) branches. On top of that, the ITU has a dedicated area of action for Environment and climate change, which focuses on defining and recommending sustainable ICTs [33].

There are mainly four activities proposed by the ITU to achieve sustainable ICTs:

1. Promote digital technologies to monitor, mitigate, and adapt to climate change.
2. Reduce e-waste to protect environment and human health.
3. Improve energy efficiency based on digital solutions to reduce carbon emissions.
4. Set the example by greening the ITU itself.

In the following, a brief summary of each of these activities is provided.

Monitoring, mitigation, and adaptation to climate change

As part of its commitment to develop sustainable ICTs, the ITU dedicates study and recommendation efforts to improve and popularize digital technologies to deal with climate change in a threefold approach [34]. Regarding monitoring, the ITU-R's Study Group 7 works on developing science services and systems for remote sensing and space application, with the intention of providing detailed climate data. This enables enhanced monitoring and prediction of climate trends [35].

Concerning adaptation, the ITU's approach on sustainable development also entails using technology to adapt people's lives to current and expected climate change. For example, ITU-D's Study Group Question 6/2 investigates how communication technologies can help to adapt to the climate change [36]. In addition, ITU-T Study Group 5 Question 12/5 focuses on developing standards for sustainable and resilient digital technologies while facing climate change [37].

Finally, regarding mitigation, the ITU-T's Study Group 5 examines and standardizes approaches for evaluating and reducing greenhouse gas emissions of communication and digital technologies [38]. Study Group 5 has been active in the area of climate and circular economy and has developed a high number of standards (a k a Recommendations) over the last decade. From the perspective of Hexa-X-II standards of particular interest include:

- L.1410: Assessment of environmental impacts of ICT goods, networks, and services [39]
- L.1480: Assessment of the GHG emissions impacts of ICT when applied in other sectors [40]
- L.1450: Assessment of the ICT sector footprint [41]
- L.1470: The decarbonization trajectory of the ICT sector [42]
- L.1471: Net Zero guidance for the ICT sector [43]

More recently, ITU-T SG5 has started to develop guidelines for biodiversity.

E-waste reduction

The ITU's perspective on sustainability includes a broad portfolio of activities intended to tackle and reduce the negative effects of e-waste, also known as Waste Electrical and Electronic Equipment (WEEE). This includes the definition of dedicated WEEE policies at the ITU Regional Offices for UN members to raise the global WEEE recycling rate to 30%, among other objectives [44].

Besides, the ITU-T's Study Group 5 (SG5) also works on providing international standards and guidelines to encourage a global circular economy [38].

Energy efficiency

As part of their study and standardization work, the ITU aims at playing a leading role in improving energy efficiency of ICTs throughout that same Study Group 5 [38].

In addition, there is a dedicated ITU-T Focus Group called "Environmental Efficiency for Artificial Intelligence and other Emerging Technologies" (FG-AI4EE), which strives for evaluating the influence of emerging technologies such as AI, augmented/virtual reality, industry 5.0, nanotechnology, etc. [45].

Greening ITU

To encourage the adoption of their proposed standards and guidelines, the ITU is committed to operate with sustainable technology itself. This includes efforts such as digitizing paper processes, virtualizing ICT servers, promoting virtual meetings, etc. [46].

2.2.2 European Telecommunications Standards Institute (ETSI)

The European Telecommunications Standards Institute (ETSI) is a recognized European Standardization Organization (ESO) that creates fundamental standards for ICT, to power digital society, dealing with telecommunications, broadcasting and other electronic communications networks and services. ETSI supports EU strategic objectives, regulatory requirements, and policies. It strives for a sustainable future and promotes the EU Industrial Strategy objectives of becoming more green, digital, and resilient [47]. There are different technical committees which are addressing topics of sustainability. Their work is summarized in the following.

Environmental Engineering committee (TC EE)

Standards for reducing the eco-environmental impact of ICT equipment are developed by TC EE. This involves the following activities:

- Conducting Life Cycle Assessments (LCAs) of ICT goods, networks, and services. (This area of standards is developed jointly with ITU-T SG5).
- Devising approaches for evaluating the energy efficiency of wireless access networks and equipment, core networks, and wireline access equipment, as well as developing efficiency metrics/KPI definitions for equipment and network.
- Establishing network standby modes for household and office equipment.
- Creating a Circular economy standard for ICT solutions.
- Developing power feeding solutions based on high voltages to reduce distribution losses on the distribution and novel storage solutions.

In addition to this, TC EE is accountable for defining the environmental and infrastructural aspects of all telecommunication equipment and its surroundings, which includes equipment installed in subscriber premises. Environmental considerations comprise:

- Climatic and biological conditions.
- Chemically and mechanically active substances.
- Mechanical conditions during storage, transportation, and operation.
- Power supply issues such as power distribution, earthing and bonding techniques.
- Thermal management for equipment and facilities.
- Noise emission of equipment.
- Mechanical structure and physical design.

By referencing existing international standards, TC EE aims to achieve the above-mentioned points wherever feasible. Moreover, TC EE are collaborating with ITU-T SG5 are collaborating to develop technically aligned standards on energy efficiency, power feeding solutions, circular economy, network efficiency KPIs, and eco-design requirements for ICT, with the objective of establishing an international eco-environmental standardization [48].

Access, Terminals, Transmission and Multiplexing committee (TC ATTM)

TC ATTM concentrates on fulfilling the eco-friendly requirements of operational networks and sites, as well as broadband transmission. Its tasks include:

- Developing global Key Performance Indicators (KPIs) to enable ICT users to monitor their eco-efficiency and energy management
- Defining networks that connect digital multi-services in cities, producing KPIs to oversee the sustainability of broadband solutions
- Upgrading standards for transmission equipment to aid the European Commission's Eco-design of Energy Related Products Directive
- Supporting the effective management of ICT waste during maintenance periods and end-of-life stages. [48]

Industry Specification Group (ISG) on Operational energy Efficiency for Users (OEU)

ISG OEU is dedicated to minimizing the power consumption and greenhouse gas emissions of infrastructure, utilities, equipment, and software within ICT sites and networks. Its tasks comprise:

- Measuring the energy consumption of IT servers, storage units, broadband fixed access, and mobile access, with the objective of developing global KPIs.
- Managing the end-of-life of ICT equipment.
- Defining global KPI modelling for green smart cities [48].

2.2.3 3rd Generation Partnership Project (3GPP)

The 3rd Generation Partnership Project (3GPP)'s primary focus is developing standards and improving mobile communication technologies, with big effort also being made to address sustainability. Traditionally, within 3GPP's standardization work, specifying network and communication behaviour, there have been numerous reports, studies, and specifications related to devices' electromagnetic compatibility (EMC) and transmission power requirements, and energy efficiency while satisfying the user experience. More recently, the efforts on sustainability and energy efficiency have been more intense and collective, targeted from various groups within the organization. Some of these most notable efforts are described below.

The Technical Specification Group Service and System Aspects (TSG SA) Working Group 5(SA5) group, in Release 17, enhanced its work pursuing energy efficiency and energy saving of mobile networks, by extending its scope from radio access network (RAN) only to the whole 5G system and defined energy efficiency (EE) key performance indicators (KPIs) for the 5G core network and network slices [49].

The TSG Radio Access Network (RAN) groups, in ongoing Release 18, have performed a study on network energy consumption model [50], to identify and study network energy savings techniques and reduce energy consumption in mobile networks. As a result, a number of technical solutions and guidelines have been produced and aim at improving energy efficiency in mobile networks, including the use of energy-saving features in devices and network infrastructure, optimizing network design to reduce power consumption, and developing more efficient transmission protocols.

The TSG SA Working Group 1 (SA1), in emerging Release 19, aims to introduce energy efficiency as a service [51]. The objectives of this work include 1) defining and supporting energy efficiency criteria as part of communication service to user and as part of application services; 2) supporting information exposure on systematic energy consumption or level of energy efficiency to vertical customers, and 3) performing a gap analysis between the identified potential requirements and existing 5G system requirements or functionalities.

Moreover, noteworthy effort is currently made to study a new 3GPP technology that will allow the introduction of IoT devices with the capability to harvest energy (from, e.g., radio waves, heat, motion, etc.) and perform communications without the need of a battery source or with just some limited energy storage capability using a capacitor. This so called Ambient IoT technology is targeted to deliver energy consumption orders of magnitude lower than the existing 3GPP low-power-wide-area (LPWA) technologies at the device side, addressing, among others, the serious environmental issues arising from the potential upcoming deployment of billion IoT devices. The study on Ambient IoT, started by SA1, investigates relevant use cases, traffic scenarios, service requirements and KPIs, with output being captured within technical report TR 22.840 [52]. From RAN side, a relevant study is also ongoing to identify suitable deployment scenarios, Ambient IoT device characteristics and design targets, including power consumption, and to assess the feasibility of meeting these design targets [53].

Overall, 3GPP has also joined the other telecoms organizations, has recognized the importance of sustainability in the development of mobile communications technologies and has been making significant effort to reduce the environmental impact of mobile networks and devices.

2.3 Industry Associations

2.3.1 GSMA

The Global System for Mobile Communications Association's (GSMA) "Mobile for Development" team drives innovation in digital technologies to reduce inequalities in our world [54]. Considering the singular position of GSMA between the mobile ecosystem and the development sector, that team wants to foster innovation that results in sustainable business and relevant socio-economic impact for populations in need. The team/program aims at contributing to the 17 UN SDGs.

The following lists some of GSMA's Mobile for Development actions regarding sustainability. The GSMA Sustainability Assessment Framework [55] is intended to examine sustainability efforts across the mobile industry in a comparable and leading-edge way. The framework has the goal of helping to better understand the landscape of operator efforts in social and environmental sustainability.

The Climate Hub [56] has helped advancing the use of mobile technologies and digital solutions to deliver socio-economic and climate impact. One objective is to create a more resilient future where communities not only survive climate shocks but thrive despite them.

The Platforms for Tomorrow acceleration program (Tunisia) [57] is oriented to provide targeted and customized technical assistance to the selected innovators to optimize their solutions, increase their ability to scale and improve their socio-economic impact (e.g., creating decent employment, improvement of job quality and livelihoods).

Other sustainability initiatives supported by GSMA include the GSMA Innovation Fund [54]. It supports innovative digital solutions with positive socio-economic impact in low- and middle-income countries, based on the premise that digital solutions have the power to sustainably reduce inequalities within the world by connecting everyone and everything.

AgriTech [58] proposed to launch, improve and scale impactful and commercially viable digital solutions for smallholder farmers in the developing world.

The ClimateTech [56] programme wants to unlock the power of digital technology in low- and middle-income countries (LMICs), to enable their transition towards a low-carbon and climate-resilient future.

Connected Society [59] supports the mobile industry to increase access to and adoption of mobile internet, focusing on underserved population groups in developing markets.

Connected Women [60] works with mobile operators and their partners to address the barriers to women accessing and using mobile internet and mobile money services

The mission of Digital Utilities [61] is to enable access to affordable, reliable, safe, and sustainable urban utility services through digital solutions and innovative partnerships.

Mobile Money [62] aims at supporting GSMA members and industry stakeholders to increase the utility and sustainability of mobile money services and increase financial inclusion.

Ecosystem Accelerator [63] looks for building synergies between start-ups and mobile operators, with the aim to scale innovative and sustainable mobile services in emerging markets.

Mobile for Humanitarian Innovation [64] is a programme which catalyses partnerships by bringing together mobile operators and humanitarian partners; invests in innovation through a humanitarian innovation fund; unlocks policy barriers with advocacy efforts; and builds a learning and research agenda to inform the future of digital humanitarian response.

Mobile big data analytics and artificial intelligence (AI) are emerging as powerful forces transforming business and society, and the potential of these technologies to unlock life-changing benefits is only beginning to be seen. The AI for Impact [65] task force defines the technical, commercial and ecosystem requirements to deliver viable data-driven products and services that adhere to principles of privacy and ethics.

At this point GSMA is working jointly with ITU and Global Enabling Sustainability Initiative (GESI) [66] to provide guidance on reporting scope 3 (value chain) emissions of operators.

2.3.2 Next Generation Mobile Networks Alliance (NGMN)

The Next Generation Mobile Networks Alliance (NGMN Alliance) [11] is an open forum founded by world-leading mobile network operators. Its goal is to ensure that next generation network infrastructure, service platforms and devices will meet the requirements of operators and, ultimately, will satisfy end user demand and expectations. NGMN has a large work on sustainability. They provide numerous white papers on the topic [67], especially a series on "Green Future Networks". NGMN's vision is to provide impactful guidance to the industry with Green Future Networks being a core strategic priority.

NGMN started in April 2021 to provide their "6G Drivers and Vision" in a white paper [68]. NGNM outlines their vision for 6G representing a future evolution of networks enabling differentiated services with expanded market opportunities and novel experience to guide the future technologies to respond to the needs of the end users, societies, and MNOs. The key considerations for 6G to meet its goals include enabling a seamless and affordable experience, focusing on sustainability and energy efficiency, taking a holistic approach to development, and considering user terminal and service design to optimize resource usage and reduce waste.

Three months later they released a white paper on sustainability challenges and initiatives in mobile networks [69]. In this white paper NGMN highlighted the challenges and initiatives associated with promoting sustainability in mobile networks. It introduces the subject of sustainability in mobile networks and provides context of this broad and complex topic. The background, measurement and sector targets for greenhouse gas emissions impacting climate change are described, along with the exploration of renewable energy as a key strategy for service providers to tackle emissions, high level KPIs to measure the environmental performance, standardization work, energy efficiency in networks, as well as operator and vendor net-zero initiatives. The paper also outlines some initiatives to address these challenges. These include improving energy efficiency, adopting renewable energy and compensation through investment in carbon sinks, among others. It distinguishes between emission generated by networks and emission avoided by networks by reducing emissions of other sectors.

In February 2023, NGMN completed their vision with a white paper on 6G requirements and a design consideration [70]. NGMN built on the earlier work on "6G Use Cases and Analysis" [71] and identified important aspects for network evolution, considering the opportunities, challenges and design objectives that are intended to guide the broader industry towards delivering services valued by end users. The objectives of this work were to explore design requirements and provide timely guidance to the industry, play a key role in avoiding fragmentation of 6G standards and ecosystem to achieve affordable deployments, and engage with different stakeholders, monitor external 6G activities and facilitate timely exchange with external organizations. NGMN recommends that future ecosystem's research and development prioritize the key challenges to address societal and environmental needs, including well-being, prosperity, sustainability, security, resilience, and inclusion.

Finally, also in February 2023, NGMN published a white paper on thoughts for green future networks, mentioning KPIs and target values for green network assessment [72]. With the publication of KPIs and Target Values for assessing Green Networks, NGMN supports and enables operators and their wider ecosystem partners to measure and manage their progress towards their sustainability goals. A set of KPIs and target values is developed along-side a framework for consolidating these KPIs into an overall measure. The framework proposed encompasses two major pillars – Environmental KPIs and Energy & Quality of Experience KPIs. The latter is presented in a single pillar as NGMN believes that greater energy efficiency should not negatively impact end-user Quality of Experience. Possible future solutions for developing a combined KPI are suggested, although the present set of proposed Energy and Quality of Experience KPIs treat each Energy and Quality of Experience as separate KPIs.

2.3.3 Next G Alliance (NGA) – Green G working group

The Next G Alliance is an initiative aimed at fostering the development of next-generation mobile technology, with the objective of ensuring North American leadership in this field. As a working group within the NGA, Green G focuses on promoting environmental sustainability in the development of future wireless technology. The mission of the NGA Green G working group is therefore to position North America as the global leader in environmental sustainability by creating a sustainable 6G ecosystem and enabling other industries to reduce greenhouse gases and energy consumption, limit land and water use, and move towards circular economy. This encompasses driving sustainability in 6G systems, aggregate information to educate stakeholders and enabling the sustainability of other industries by using wireless technology. The Green G working group has released two whitepapers so far. The Green G Alliance's roadmap includes whitepapers on various 6G ecosystem components.

The first whitepaper, "Green G: The Path Toward Sustainable 6G" [73] was published in January 2022 and examines the current status of environmental sustainability initiatives in the ICT sector. It identifies potential solutions that could be incorporated into next-generation networks to enhance sustainability by reducing energy consumption.

The second whitepaper, "6G Sustainability KPI Assessment: Introduction and Gap Analysis" [74] was published in March 2023. It provides an overview of available sustainability KPIs for the ICT sector for various components of the 6G ecosystem and discusses the development of a harmonized set of sustainability KPIs to benchmark ecosystem components.

Following the release of the KPI white paper [74], the group will release 6G ecosystem component papers around Radio Access Network (RAN), Core Network (CN), cloud and edge data centres, end user communications devices, as well as supply chain and manufacturing.

2.4 Initiatives and Frameworks

In addition to governmental and intergovernmental efforts, work carried out by standardization organizations and industry associations, there are various other undertakings and specific regional initiatives. This chapter references some of these diverse endeavours.

2.4.1 The Nine Planetary Boundaries

From an environmental sustainability perspective, the planetary boundaries framework presents a set of nine planetary boundaries within which humanity can continue to develop and thrive for generations to come, see Figure 2-2 [14]. Crossing these boundaries increases the risk of generating large-scale abrupt or irreversible environmental changes.

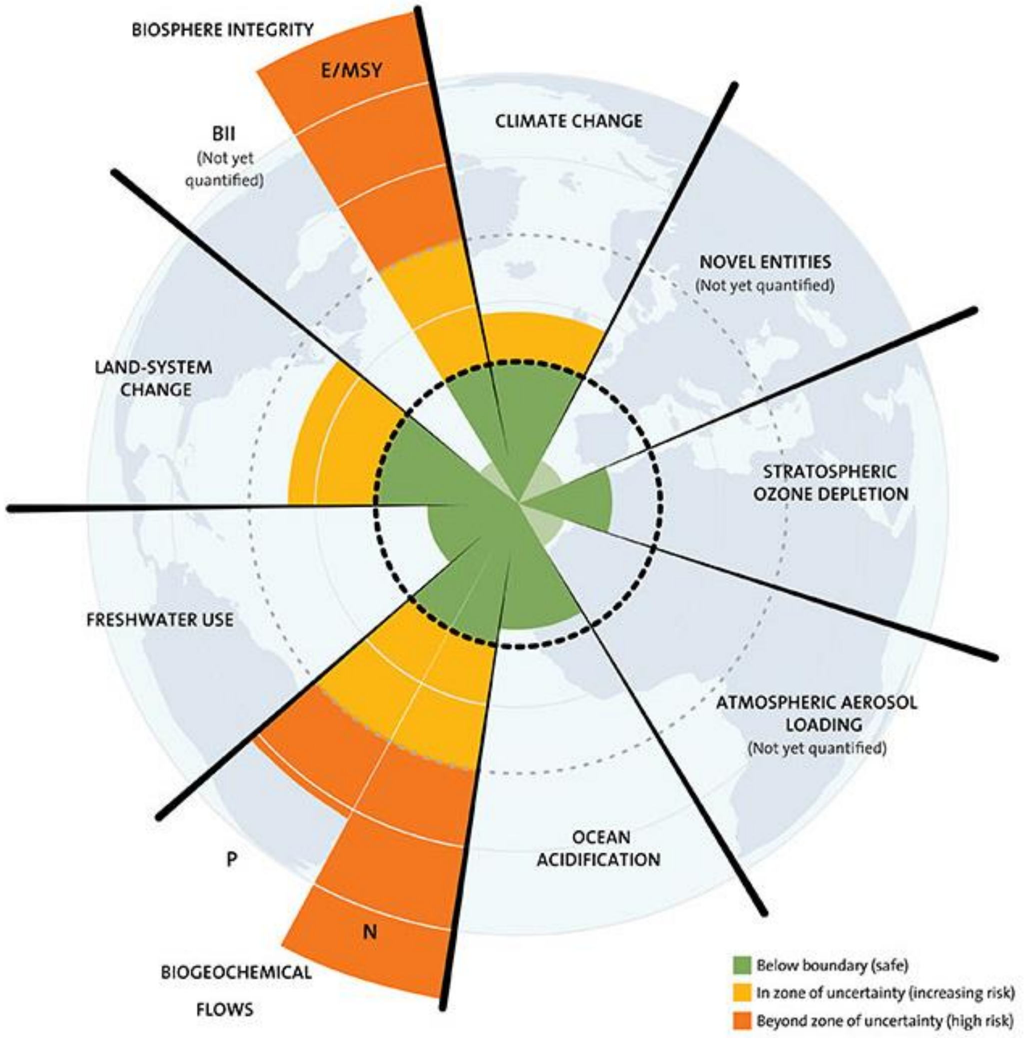

Figure 2-2: The Planetary Boundaries Framework. (Credit: J. Lokrantz/Azote based on Steffen et al. 2015.)

The Planetary Boundaries framework is defined at a global scale Depending on the earth system process the safe operating spaces can have global, regional, and local implications.

It is worth noting that it is not possible to directly apply the planetary boundaries at a company scale without a complex and inevitably value based allocation. The most advanced work in this direction exists for climate change where frameworks such as Race to Zero and SBTi try to provide ambition levels per sector (cf. chapter 2.1.2) Due to this, and as climate impacts are global in the sense that the location of an emission does not decide its effect, from an application perspective climate change could be considered the simplest boundary to apply.

Currently several initiatives are working to translate the Planetary Boundaries to actionable boundaries that could be applied by companies. The Earth Commission of Future Earth[4] develops the scientific foundation for this while the Global Commons Alliance and Science Based Targets Networks (SBTN)[5] work to operationalise other boundaries. For biodiversity, IPBES, synthesizes existing research as described in chapter 2.14

[4] The Earth Commission of Future Earth is a group of leading scientists contributing to re-stabilize Earth's natural systems and work toward ensuring a planet where human can thrive

[5] SBTN is a collaboration of over 50 leading global non-profit and mission-driven organizations which translate the latest interdisciplinary science into targets for the companies and cities.

Overall, the body of literature from the ICT perspective is still quite limited. Two recent papers [75] [76] address the planetary boundaries and how to move forward from the perspective of understanding the impacts of ICT goods, networks and services, and from the perspective of assessing ICT companies proposing indicators that would be relevant. However, at this point there is no framework that can help to conclude whether impacts on planetary boundaries stay within a fair share of the safe operating spaces or not – but companies could still work to minimize impacts associated to the planetary boundaries.

Recently the earth commission has been working towards expanding the planetary boundary framework to include social sciences [77].

2.4.2 The Doughnut Economics

A way of linking the idea of planetary boundaries with society and economy is the concept of Doughnut economics, see Figure 2-3**.** Humanity's 21st century challenge is to meet the needs of all within the means of the planet. In other words, the goal is to ensure that no one falls short on life's essentials (from food and housing to healthcare and political voice), while ensuring that collectively we do not overshoot our pressure on Earth's life-supporting systems, on which we fundamentally depend – such as a stable climate, fertile soils, and a protective ozone layer [15].

Through The Theory of the Doughnut, the issues of environmental integrity and social justice are combined. It calls for enhanced joint work between actors working on these different issues.

At the heart of the doughnut, are the people whose essential needs are not assured. Twelve basic needs are defined that should be met (including food, health, education, drinking water, housing, access to decent work, gender equality, a political voice, etc.). This first green circle is the "social floor": it constitutes the goal to be achieved to ensure the fulfilment of each and everyone.

But this flourishing cannot happen beyond an outer circle, called the "ecological ceiling". Collectively, we cannot use resources too intensively, at the risk of subjecting the balance of the planet to excessive pressure. The Doughnut Theory thus defines 9 planetary limits including climate change, loss of biodiversity, ocean acidification and chemical pollution.

The Doughnut Theory defines the safe space to reach. It also demonstrates the areas for which current economy is beyond the boundary (marked in red colour), whether they are inside the doughnut (i.e., the essential needs that are not yet assured for all of humanity) or outside the doughnut (i.e., the planetary balances are already put under pressure). Getting inside the Doughnut needs economies that are both regenerative and distributive by design. An important perspective of the Doughnut Theory is that under current industrial processes, the planet's resources are captured, transformed, used, and then released. This process, which fuels on the one hand deforestation, the combustion of fossil fuels, the massive use of fertilizers, and on the other end generates CO_2, pollutants, is the reason behind the current overrun of planetary limits.

Apart from the currently applied linear system, there are also other options. It is also possible to act to move towards a circular regenerative system. Waste can be recycled and fuel a circular economy. Also, even before recycling, it is possible to reuse, repair and share. This regenerative economy also relies on renewable energy instead of fossil fuels.

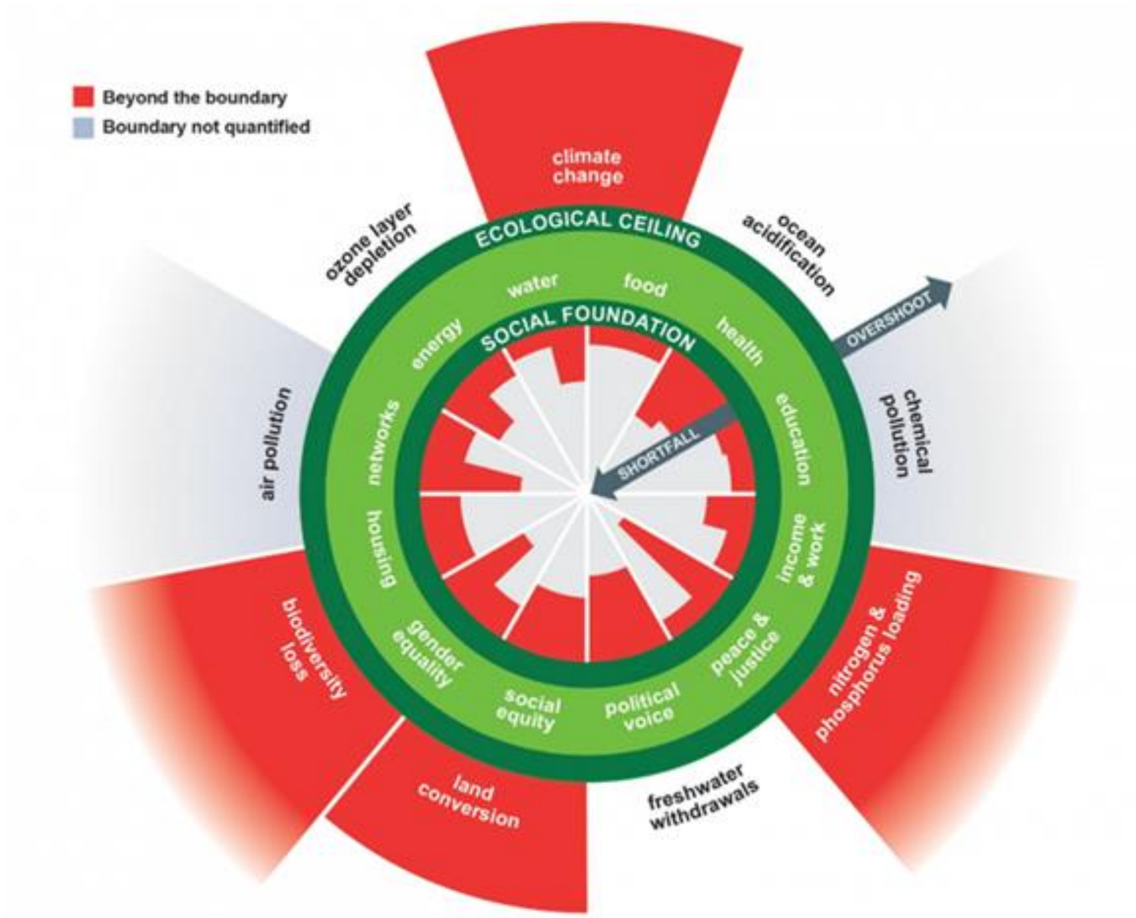

Figure 2-3: The Doughnut of Social and Planetary Boundaries (Credit: Kate Raworth and Christian Guthier. CC-BY-SA 4.0, Citation: Raworth, K. (2017), Doughnut Economics: seven ways to think like a 21st century economist. London: Penguin Random House.)

2.4.3 Ellen MacArthur Foundation's butterfly diagram for circular economy

When it comes to the principles of circular economy, Ellen MacArthur was one of the pioneers within the field when she set up in 2010 a foundation in her name with the purpose to accelerate the transition to a circular economy, with a focus on the use of materials [78].

The circular economy is based on three principles, driven by design:

1) Eliminate waste and pollution
2) Circulate products and materials (at their highest value)
3) Regenerate nature

A useful guideline to better understand the principles of circularity is the Foundation's circular economy systems diagram, known as the butterfly diagram, cf. Figure 2-4. This diagram illustrates the continuous flow of materials in a circular economy. There are two main cycles: (i) the biological cycle and (ii) the technical cycle, and when visualized side-by-side the cycles resemble the shape of a butterfly, which explains the name [16].

For the ICT industry in general and Hexa-X-II specifically, the most useful part is the technical cycle (the right-hand side of the diagram in Figure 2-4), since material used in most cases is not biological. For this reason, the focus in this chapter is on the technical cycle.

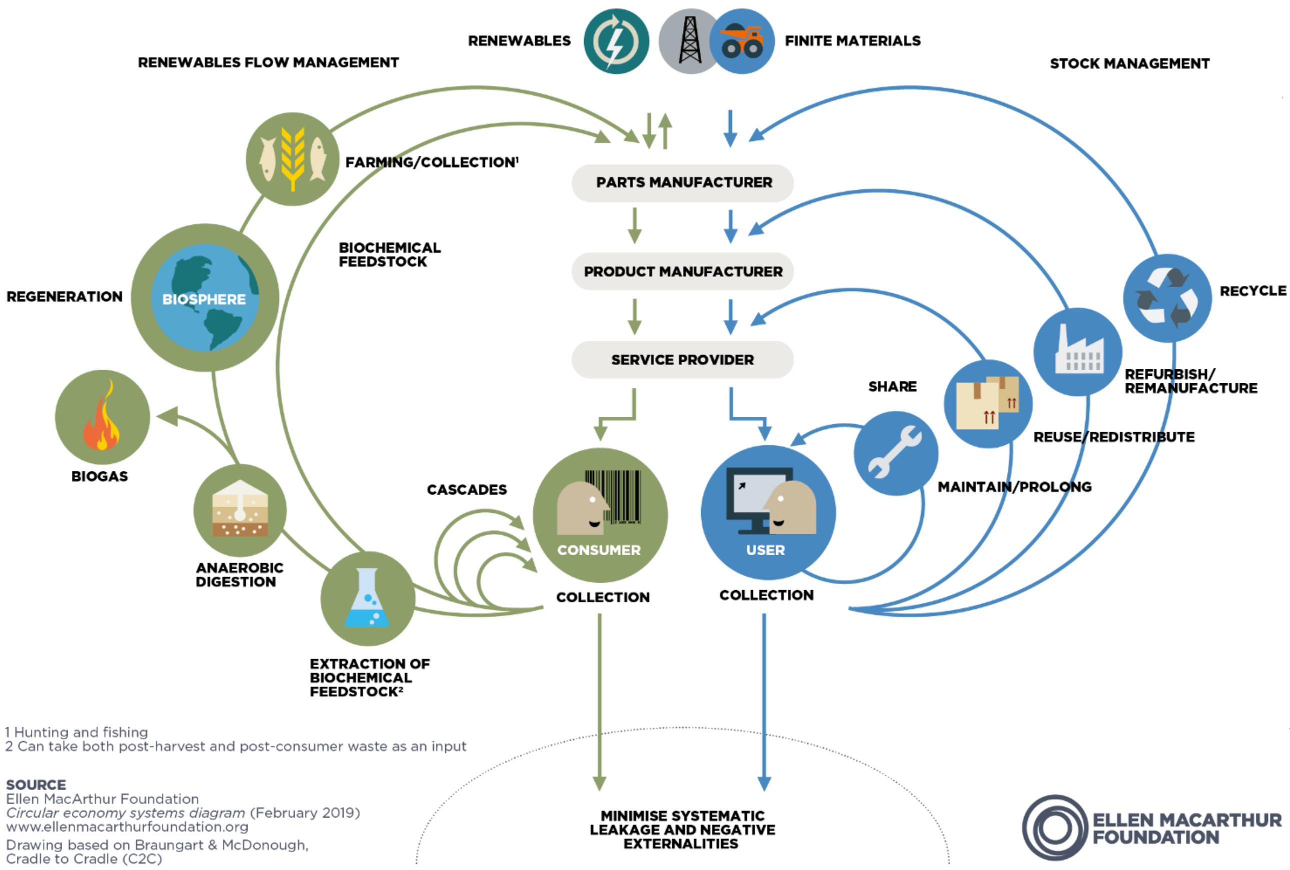

Figure 2-4: The Butterfly Diagram showing the biological cycle on the left and technical cycle on the right (Credit: based on Ellen MacArthur Foundation, Circular economy systems diagram [February 2019], (Credit: based on Ellen MacArthur Foundation, Circular economy systems diagram [February 2019], www.ellenmacarthurfoundation.org)

In the technical cycle, products and materials are kept in circulation through processes and behaviour such as, maintain (repair), share, reuse, remanufacture and recycle. The idea is to decide already from the start that any product should be designed to guarantee that it can be kept in circulation for as long as possible, moving towards the outer circles as slowly as possible.

For example, a user who owns a car can ensure that it is maintained properly, taking it to service to ensure a long lifetime of the car. A user can also share the car with others, by commuting to work. Car sharing could also be offered as a service, from a service provider, for example through a car-pooling service. A company could also collect old cars from users and rent them out to a completely new customer segment, such as the “rent a wreck” concept. This would be an example of the ‘Redistribute’ stage. As an example of what the ‘Refurbish/Remanufacture’ stage could mean for a car that it is collected by the car manufacturer, where it is refurbished and sold again. Today this activity is mostly performed by car dealers, but in general the point is that products could often be refurbished and used again, instead of directly being sent for recycling.

In the end, but only as a last resort, the product goes to recycling, and in this phase as much of the product’s material as possible should go back into the system, to minimize the use of raw materials for the creation of new products, but also to minimize waste, described as ‘systematic leakage’ [79].

3 Existing Sustainability Definitions

When working within the sustainability domain, a lot of notions are used. This chapter provides a summary of main different notions or terms that are used in the context of environmental, social, and economic sustainability.

3.1 Environmental Sustainability

Biocapacity: The capacity of ecosystems to produce biological materials used by people and to absorb waste material generated by humans, under current management schemes and extraction technologies. Biocapacity can change from year to year due to climate, management, and also depending on what portions are considered useful inputs to the human economy. In the National Footprint and Biocapacity Accounts, the biocapacity of an area is calculated by multiplying the actual physical area by the yield factor and the appropriate equivalence factor. Biocapacity is usually expressed in global hectares [80].

Biodiversity refers to all the different kinds of lives existing in one area, i.e., the variety of animals, plants, fungi, and even microorganisms such as bacteria that make up our natural world. Each of these species and organisms work together in ecosystems, like an intricate web, to maintain balance and support life. Biodiversity supports everything in nature that humans need to survive – food, clean water, medicine, and shelter [81].

Carbon footprint is the total greenhouse gas (GHG) emissions caused directly and indirectly by an individual, organization, event, or product. It is calculated by summing the emissions resulting from every stage of a product or service's lifetime (material production, manufacturing, use, and end-of-life). Throughout a product's lifetime, or lifecycle, different GHGs may be emitted, such as carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), each with a greater or lesser ability to trap heat in the atmosphere. These differences are accounted for by the global warming potential (GWP) of each gas, resulting in a carbon footprint in units of mass of carbon dioxide equivalents (CO_2e) [82] [83].

Carbon neutrality refers to the idea of achieving neutrality by balancing GHG emissions, so they are equal (or less than) the emissions that are offset outside the organizations value chain, usually by purchase of carbon credits. However, unlike Net Zero, carbon neutrality is a weaker concept than Net Zero as it does not say anything about the level of emission reduction undertaken within the organizations value chain [84] [85].

Decarbonization refers to finding alternative ways of living and working that reduce emissions and capture and store carbon in our soil and vegetation. It requires drastic reduction in consumption, particularly energy consumption, or switch to low emission technologies and renewable alternatives [86].

Ecological Footprint is a methodology developed by the Global Footprint Network [87], to assess the reliance of human activities on natural resources, so-called "natural capital," by quantifying the amount of nature needed to support human populations and economies. It measures the ecological assets that a given population or product requires to produce the natural resources it consumes (including plant-based food and fibre products, livestock and fish products, timber and other forest products, space for urban infrastructure) and to absorb its waste, especially carbon emissions.

Energy efficiency is the relation between the useful output (telecom service, etc.) and energy consumption.

Environmental impact refers to changes in the natural or built environment, resulting directly from an activity, which has adverse effects on the air, land, water, and/or the inhabitants of an ecosystem [88].

Environmental sustainability refers to the responsible use and management of natural resources (circular instead of linear), ecosystems, and biodiversity in a way that preserves and protects them for present and future generations. It involves balancing economic, social, and environmental factors to ensure that natural resources are used in a way that meets the needs of the present without compromising the ability of future generations to meet their own needs [89] [90]. In other words, ensuring that human society operates within ecological borders. This definition is known as the planetary boundary concept where a set of nine planetary boundaries are presented within which humanity can continue to develop and thrive for generations to come, cf. chapter 2.4.1. for details. Another perspective is looking at how much of the planet's resources are used and track the time for when the 'resource budget' has been used. This is done by the Global Footprint Network, who yearly report the ‘Earth Overshoot Day’, i.e., the date each year when humanity has exhausted nature’s budget for the year [91].

Holistic design in this context refers to an approach to sustainable design considering the entire system or value chain in which 6G will exist. This approach may involve collaboration across different disciplines to ensure that all aspects of the design are aligned and considers the interrelationships between all elements of the system, seeking to integrate them into a cohesive and harmonious whole.

Land cover change refers to the loss of natural and semi-natural vegetated land which is presented as a proxy for pressures on biodiversity and ecosystems. This includes tree cover, grassland, wetland, shrubland and sparse vegetation converted to any other land cover type. Gains of natural and semi-natural vegetated land are conversions in the opposite direction. The denominator used is the ‘stock' of natural and semi-natural land at the start of the period [92].

Land use change indicates the change over time of the distribution of land uses (defined as a series of activities undertaken to produce one or more goods or services within a country. Land use defined in this way establishes a direct link between land cover and the actions of people in their environment. A given land use may take place on one, or more than one, piece of land and several land uses may occur on the same piece of land. By this definition, land use provides a basis for analysis of societal, economic, and environmental characteristics and allows distinctions between land uses, where required [93].

Net zero refers to cutting greenhouse gas emissions to as close as zero as possible, with any remaining emissions re-absorbed by the atmosphere, by oceans and forests for instance [94] **.** It is not until net zero is reached for the whole planet that the amount of GHG in the atmosphere can start declining. In other words, if the planet has not reached net zero, the amount of GHGs in the atmosphere will continue to accumulate and the global temperature continue to rise. The Paris Agreement underlines the need for net zero. It requires states to ‘achieve a balance between anthropogenic emissions by sources and removals by sinks of GHG in the second half of this century [95]. At an organizational level the ISO Net Zero Guidelines [96] and other initiatives positions Net Zero at an organizational level as a future state achieved only when all emissions that are technically possible to reduce have been reduced and the remaining residual of emissions are counterbalanced by removals with a permanence that mimic the timescale of the emissions.

Renewable energy refers to energy derived from natural sources that are replenished at a higher rate than they are consumed. Sunlight and wind, for example, are such sources that are constantly being replenished. [97].

Science-based target, as described in chapter 2, refers to a company’s environmental targets which have been aligned with a science-based trajectory verified by the Science Based Targets initiative (SBTi) [20] Targets. Specifically for climate, science-based targets are usually understood as targets in line with what the latest climate science deems necessary to support the Paris Agreement – limiting global warming to well-below 2°C above pre-industrial levels and, i.e., pursuing efforts to limit warming to 1.5°C above pre-industrial levels. All the 3 scopes (defined by the Greenhouse Gas Protocol [22]) need to be included.

Note: As described in Chapter 2, science-based targets for climate are defined by SBTi and the ICT sector should specifically align with the ICT sector trajectory developed by SBTi in collaboration with ITU, GSMA and GESI.

Sustainable development goals, or UN SDGs are, as described in chapter 2.1.1, 17 goals agreed by all UN member states in 2015 in Paris, under Agenda 2030. Under the motto "leave no one behind" the aim is to meet the needs of the present without compromising the ability of future generations to meet their own needs.

Sustainable as defined by United Nations [98] refers to meeting the needs of the present without compromising the ability of future generations to meet their own needs.

Use of material resources includes material consumption mixes and intensities, material productivity and material footprint intensities [99].

Waste management is the total supervision of waste production, handling, processing, storage, and transport from its point of generation to its final acceptable disposal [100].

3.2 Social Sustainability

There are multiple articles related to the definition and the analysis of societal sustainability. The most basic definition would be the "Ability to maintain and guarantee human survival". However, multiple more aspects (well-being, justice, power, rights, and the needs of the individual), as well as the UN SDGs, need to be considered to define metrics that can guide throughout the work of Hexa-X-II. 8 of the 17 UN SDGs (cf. chapter 2.1.1) address the dimension of the society and contribution to social sustainability. UN Global Compact [101] also lists human rights' metrics such as labour, women's empowerment and gender equality, children, indigenous peoples, people with disabilities, as well as people-centred approaches to business impacts on poverty and issues affecting people like education, health, and security. Other sources [102] [103] also relate social sustainability with how individuals, communities and societies live alongside one another and set out to achieve the objectives of the development models they have chosen for themselves, while taking into account the physical boundaries of their homes and Earth as a whole; a fair degree of social homogeneity; the harmonious evolution of civil society; a balance between respect of tradition and innovation, and self-reliance, endogeneity and self-confidence; and social integration, with improvements in the quality of life for all segments of the population.

According to [104] social sustainability is given, if work within a society and the related institutional arrangements – satisfy an extended set of human needs – are shaped in a way that nature and its reproductive capabilities are preserved over a long period of time and the normative claims of social justice, human dignity and participation are fulfilled".

In [105], social sustainability is referred to as "a process for creating sustainable successful places that promote wellbeing, by understanding what people need from the places they live and work" while in the same article social sustainability is expanded to the ability of supporting not only current but future generations as well to create and maintain health and liveable communities.

In summary, when it comes to companies and organizations, social sustainability is about identifying and managing business impacts, both positive and negative, on people [106].

When focusing on socially sustainable 6G networks the factors are reduced to mainly two large categories: a) trustworthiness, i.e., moving forward with a network design that can address security and data privacy concerns and b) digital inclusion, i.e., making 6G networks and the services offered over them available to and accessible for all. In the following sub-chapters, these terms are further analysed.

3.2.1 Trustworthiness

Trust is the firm belief in the reliability, truth, or ability of an entity to perform actions. In [107] trust is defined as a relational phenomenon that signifies the willingness to rely on another agent to perform actions that benefit oneself in a given context and therefore, the willingness of one party to become vulnerable to another presuming competent reliable and honest party in the hope of an optimistic outcome as a result of relationship [108]. Trustworthiness refers to attributes that compel an individual to consider another individual or entity worthy of their trust [109]. NGMN 5G white paper 2 [110] supports the above definitions.

With pervasive technology becoming more and more used in business, companies can only be successful if people have confidence in the technology systems they use. Trustworthiness in the context of ICT comprises many aspects including user privacy, security, integrity, resilience, reliability, availability, accountability, authenticity, and device independence [109]. In [111], trustworthiness refers to ICT "that is secure, reliable and resilient to attacks and operational failures; guarantees quality of service; protects user data; ensures privacy and provides usable and trusted tools to support the user in his security management.

Authors in [112] follow a similar approach focusing on IoT and software and using the definition of the software trustworthiness as "a key enabler of IoT trustworthiness, which is the degree of confidence that a system will perform as expected. Trustworthiness is based on five characteristics—safety, security, privacy, reliability, and resilience, which directly and in combination provide protection against hazards and threats related to environmental disturbances, human errors, system faults and attacks." [113].

According to ISO/IEC TS 5723:2022 [114] "Trustworthiness is the ability to meet stakeholders' expectations in a verifiable way. Depending on the context or sector, and also on the specific product or service, data, technology and process used, different characteristics apply and need verification to ensure stakeholders' expectations are met. Characteristics of trustworthiness include, for instance, accountability, accuracy, authenticity, availability, controllability, integrity, privacy, quality, reliability, resilience, robustness, safety, security, transparency, and usability. Trustworthiness is an attribute that can be applied to services, products, technology, data, and information as well as to organizations. Verifiability includes measurability and demonstrability by means of objective evidence."

The 6G Smart Networks and Services Industry Association (6G-IA) [115] defines trust as a societal key value: "Feeling of confidence, faith and explainability in the way that advanced systems (e.g., AI-driven decision making) may impact humans". This definition of trust complements the above ISO definition of trustworthiness: the trustworthiness of services and products as a verifiable property can contribute to trust as a feeling of confidence. Distinguishing between trust and trustworthiness is useful as it brings out the limitations that technical measures have in creating trust among the wider public.

Other terms closely related to trustworthiness and commonly used in the ICT domain include:

- **Cybersecurity** refers to measures taken to protect Internet-connected devices, networks, and data from unauthorized access, criminal use, sabotage, and Denial of Service (DoS). It applies to both software and hardware, as well as information on the Internet. It can protect everything from personal information to complex government systems [116].
- **Digital security** refers to the economic and social aspects of cybersecurity, as opposed to purely technical aspects and those related to criminal law enforcement or national and international security. Digital security is essential for trust in the digital age [117].
- A **robust network** is a network that delivers the required levels of network availability, reliability, and resilience, where:
    - **Network availability** refers to a network's ability to accept new traffic.
    - **Network reliability** refers to a network's ability to support its traffic according to the established use-case-specific requirements – for example, its ability to provide the required use-case-specific Quality of Service (QoS) for the duration of communication.
    - **Network resilience** is the ability to provide and maintain an acceptable service level in case of faults, disruptions and other events affecting normal system operation [118].
- **Trustworthy AI** has three components: (1) it should be lawful, ensuring compliance with all applicable laws and regulations (2) it should be ethical, demonstrating respect for, and ensure adherence to, ethical principles and values and (3) it should be robust, both from a technical and social perspective, since, even with good intentions, systems can cause unintentional harm. Trustworthy AI concerns not only the trustworthiness of the system itself but also comprises the trustworthiness of all processes and actors that are part of the system's life cycle [119].

3.2.2 Digital Inclusion

Digital inclusion is a process that brings together a set of offers, services and actions to make digital technology, mainly telephony and the Internet, accessible to individuals and provide them with the digital skills that will enable them to use these tools for their social and economic integration. Digital inclusion is also about securing everyone with access to reliable connectivity and the right digital skills so as to ensure that no one is left behind. This will contribute to equality and inclusion of all individuals and societies to exploit the full potential of digitalization in social and economic life including education, social services, health, as well as social and community participation.

According to [120] digital inclusion is an EU-wide effort to ensure that everybody can contribute to and benefit from the digital world. It includes activities such as:

- accessible ICT: making ICT more accessible for all and fostering the development of accessible technologies.
- assistive technologies: supporting the development of ICT that assists people with disabilities in the digital world.
- skills and digital skills: empowering citizens to fight marginalization and social exclusion, including in careers, through ICT in education.

- social inclusion: increasing the participation rate of disadvantaged people in public, social and economic activities through social inclusion projects.

Accessibility means that all users should be able to access an equivalent user experience, however they encounter a product or service (e.g., using assistive devices) [121].

Digital accessibility enables digital inclusion and ensures inclusive communication for all people – regardless of their gender, age, ability, or location [122].

In UN [123], Digital inclusion is defined as "equitable, meaningful, and safe access to use, lead, and design of digital technologies, services, and associated opportunities for everyone, everywhere". In other words, providing equitable and affordable access to the information and communication technologies in a non-harmful way, independent of e.g., the geographical area, gender, culture, health, educational level, and governing officials.

3.3 Economic Sustainability

From the perspective of being one of the three pillars of sustainable development**,** economic sustainability refers to practices that support long-term economic growth without negatively impacting social, environmental, and cultural aspects of the community [124]. Economic sustainability needs a context supporting sustainable growth, making business in a sustainable way, but also supporting other businesses being sustainable.

Economic sustainability is also sometimes used as a concept that can be applied at both organizational and national level, in principle referring to the ability for that organization or nation to survive over time, which from an economic perspective means having more income than expenses. It does not necessarily require economic growth, although it is often the goal, and at least for private companies and nations, economic growth does increase the chances of survival.

A **business model** describes how an organization creates, delivers, and captures value, in economic, social, cultural, or other contexts. The process of business model construction and modification is also called business model innovation and forms a part of business strategy.

A **business ecosystem** is a system where "companies coevolve capabilities around a new innovation: they work cooperatively and competitively to support new products, satisfy customer needs, and eventually incorporate the next round of innovations" [125]. Ecosystem captures markets which have grown organically, where one stakeholder does not control the other, but where stakeholders are dependent on each other to create value.

The **Butterfly diagram** (also known as the circular economy system diagram) illustrates the continuous flow of materials in a circular economy. There are two main cycles – the technical cycle and the biological cycle. In the technical cycle, products and materials are kept in circulation through processes such as reuse, repair, remanufacture and recycling [16]. Biodegradation is the goal of the biological cycle for the nutrients to regenerate nature.

Circular economy is a systematic approach to the design of processes, products (including services) and business models, and is seen as an alternative to a linear economy, in which products and services are created by finite, raw materials, consumed and then become waste. The circular economy approach manages resources effectively making the flow of materials more circular and reducing and ultimately eliminating waste, enabling sustainable business. It requires a systemic approach that includes all levels involved - from the collection of raw material to the full circle of use and re-use and re-cycling of products. Life cycle analysis provides tools for assessing circular economy principles [126].

Corporate social responsibility (CSR) is the responsibility of enterprises for their impacts on society. The view of CSR has evolved over time to being seen as good for business. CSR is not only good for the environment, social justice and equity and employees, but also for shareholders, since investments in CSR nowadays can be seen as an investment in the company brand and thus increasing the possibilities to increased revenues [127].

Dematerialization refers to the absolute or relative reduction in the quantity of materials required to serve economic functions in society and thus implies doing more with less [128]. Using less material reduces cost thus resulting in increased economic sustainability.

Economic growth in the context of a nation is usually defined as the change in gross domestic product (GDP) in one period of time compared to the previous period [129]. GDP is the monetary value of final goods and services - i.e., those that are bought by a final user - produced within a country's borders in a given period of time. GDP however comes with caveats as it does not consider the cost of environmental impact and does not properly measure the public sector, services produced within the household or inequality [130].

Open value configuration refers to value co-creation and co-capture to maximize the overall ecosystem value, which in turn may increase the value shared and acquired not only by one actor but by many actors within the ecosystem [131].

Productivity is the ratio of outputs to inputs and thus measures how efficiently resources are used to produce goods and services. Higher productivity makes it possible to either produce more with the same level of resources or maintain the same level of production with fewer resources. Productivity can be measured as labour productivity or total factor productivity [132]. Productivity growth is crucial for a country’s welfare and standard of living. If an economic system (or a nation) can create high productivity growth rates, resources will/may be released making it possible to improve other important issues such as health, pollution, security, and education.

Servitization is “the shift from traditional business models to an outcome-based, product as a service (PaaS) model.” [133]. “With a servitization model, the customer pays a fixed fee per unit of service consumed, while the ownership of the system remains with the technology provider, who remains responsible for all operation costs” [134].

Stakeholders are “any group or individual who can affect or is affected by the achievement of the organization’s objectives” [135]. In a corporate context stakeholder is a group, corporate, organization, member, or system that affects or can be affected by an organization's actions. Lately there has been a trend to also include the environment in the stakeholder term including the planet Earth as an important stakeholder.

Sustainable business model innovation is about combining environmental, societal, and financial priorities to re-imagine the core business models and even shift the boundaries of competition [136].

4 Observed Trends in Sustainability

Environmental, social, and economic sustainability issues are inseparable. Significant changes in any one dimension (e.g., environmental) will affect the others (e.g., socio-economic). As an example, a too rapid move from producing energy with fossil fuels, can leave whole regions which were dependent on coal mining prey to unemployment and poverty — if the socio-economic dimensions are not factored in (by retraining the workforce, investing in new workplaces and so on). Although the three perspectives are often treated separately in this report, it should be noted that they directly or indirectly impact each other, which will be highlighted with examples.

4.1 Observed Trends in Environmental Sustainability

To achieve the goal of environmental sustainability it is essential to limit the negative environmental impact. Environmental impacts and environmental sustainability are multidimensional. Some environmental metrics include global warming potential, pollution, acidification, and eutrophication. When studying ICT and future 6G systems' environmental impact/sustainability, it is, however, common to study proxies of environmental impacts, such as energy, material, or resources. It is then important to keep in mind that such proxies do represent some aspects of environmental sustainability, but they do not tell the full story, for instance about the protection of the vitality of the natural ecosystems.

Therefore, it is important to investigate environmental sustainability with a broad perspective. However, not only are there trade-offs between the three sustainability perspectives, as described earlier, but also within environmental sustainability. For instance, renewable energy is preferred from the climate perspective. This, however, could have negative effects on other environmental aspects, such as biodiversity e.g., dams built for hydropower often block fish from moving along their natural pathways between feeding and spawning grounds, causing interruptions in their life cycles that limit their abilities to reproduce [137].

Another example of trade-offs within environmental sustainability is the goal to increase electrification as a measure to reduce the usage of fossil fuels. A clear trend is observed in the Automotive industry, where electric vehicles have increased dramatically in the past decade and within the EU there is even a ban to sell petrol or diesel cars starting from 2035 [138]. The ban is steering the production towards electrical vehicles, which in turn is driving an increased need for batteries, which in turn has caused an increased demand for minerals. The extraction of some of these minerals could cause harm to the environment, as stated by the newly established car battery factory Northvolt. They are addressing this challenge with high ambitions to create car batteries with recycled materials and their aim is to have their new batteries produced from 50% recycled batteries by 2030 [139]. They are not the only company addressing this. Another example is Apple, who have committed to only use recycled cobalt in their batteries by 2025 [140].

4.1.1 Assessing environmental impacts: footprints, indicators, and proxies

The assessment of environmental impacts associated with an emerging technology has gained significant interest among various stakeholders from researchers to industry experts, policymakers, and end users. A range of different measures and metrics including footprints, indicators, and proxies need to be carefully considered in evaluating immediate and long-term risks and consequences on climate, ecosystems, biodiversity, and human health. Understanding and mitigating these impacts is critical for promoting sustainable and responsible development that balances the needs of humans and the environment. The environmental footprint assessment of a technology refers to various impacts associated with its full lifecycle from development and manufacturing to deployment and usage, until end-of-life treatment. This includes its carbon footprint, resource and water footprints, land footprint, waste footprint, and biodiversity footprint among others. The Drivers, Pressures, States, Impacts, and Responses (DPSIR) framework, developed by the Organization for Economic Co-operation and Development (OECD) in 2003 [141] provides a theoretical foundation for understanding the causal relationships between environmental footprints associated with human activities, and impact indicators that influence policymaking. A linear representation of the DPSIR framework is given in Figure 4-1a [142]. Impact indicators including climate change, biodiversity loss, habitat destruction, ocean acidification, water quality degradation, air pollution, soil degradation, land change, ozone depletion, etc. should be comprehensively interpreted and analysed from a full life cycle approach [143]. Trade-offs between different environmental footprints may arise and require the adoption of integrated approaches to achieve sustainable outcomes. This means that the assessment should provide a comprehensive, holistic view that considers interdependencies between various footprint indicators. A visualization of the respective overlaps between different footprints and the correspondence of current footprint indicators to planetary boundaries is given in Figure 4-1b [142].

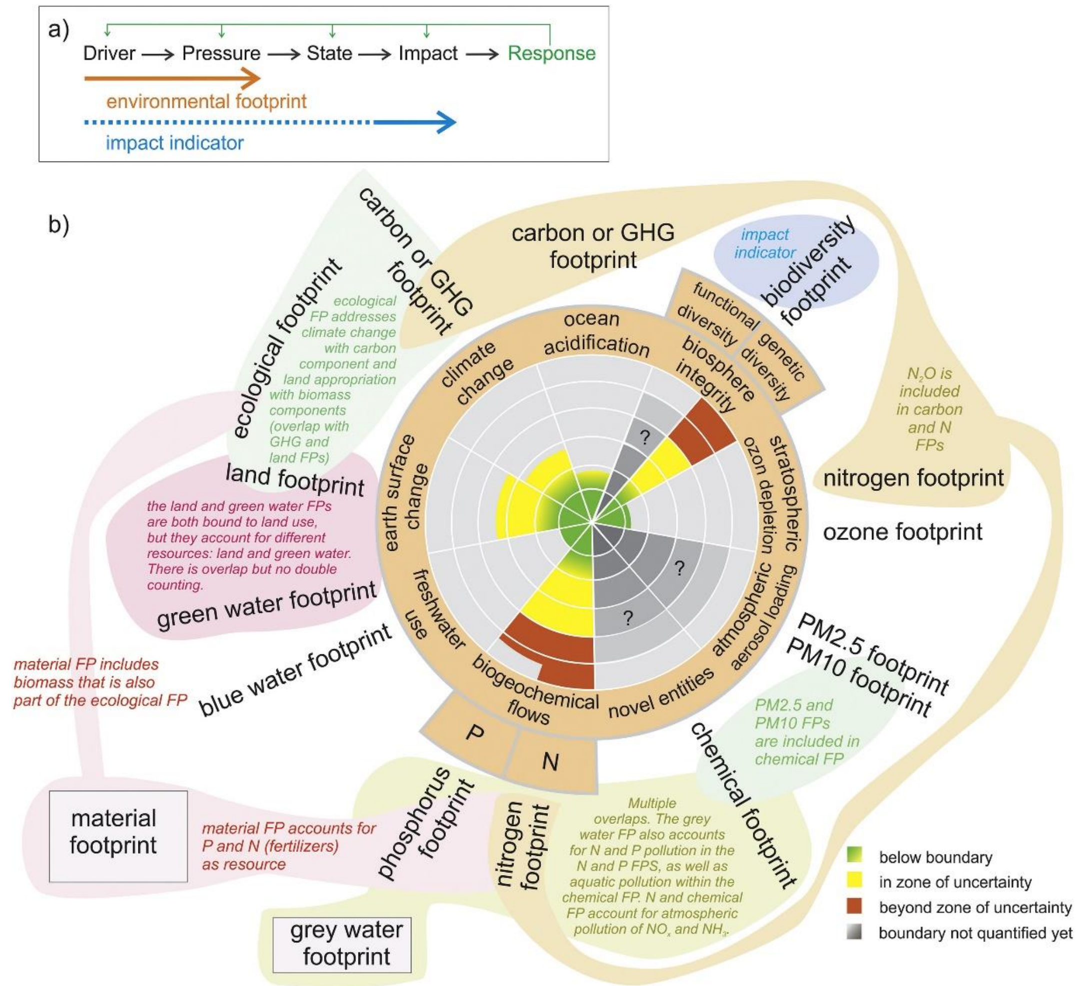

Figure 4-1: Overlap Between Different Footprints, and their Correspondence to Planetary Boundaries [142].

In the following, a brief analysis of different footprint impacts is presented along with their respective impact indicators and proxies. Potential trade-offs between different footprints are also highlighted. It may be useful, to highlight some general principles, criteria, and concepts relevant to environmental targets and indicators. Environmental targets and indicators should be specific, measurable, time-bound, policy-relevant, scientifically sound, accepted by the public, affordable for monitoring, and sensitive to detect changes in decision-making relevant timeframes and scales. These criteria have been developed by the OECD [143] and the Convention on Biological Diversity (CBD) [144] and are known as SMART (Specific, Measurable, Ambitious, Realistic, Time-bound) targets.

- **Carbon footprint:** According to the Global Footprint Network [145], the carbon footprint has increased elevenfold since 1961 and now accounts for 60% of man's total impact on the environment. When it comes to ICT, the energy consumed to power infrastructure, including base stations, data centres, among other components, and operations like data transmission, can be used as a proxy for carbon footprint, since greater consumption levels result in greater GHG emissions. The usage of renewable energy sources, such as wind or solar, is another proxy for carbon footprint as it implies a reduced reliance on fossil fuels which is a primary source of CO_2 emissions [146]. Reducing the GHG emissions is an important environmental KPI to mitigate climate change impacts. Other emissions footprint indicators measure air pollutants such as nitrogen oxides (NOx), sulfur oxides (SOx), volatile organic compounds (VOCs), and particulate matter (PM) associated with manufacturing and operation of a new technology.

- **Resource footprint:** The resource footprint can be measured by considering the natural resources, including both renewable and non-renewable resources such as metals, water, minerals, and other materials, used in the production, operation, and disposal of a new technology. The resource usage indicates the environmental impact related to resource extraction and depletion. Lower usage of resources indicates reduced environmental impact related to resources scarcity and conservation. A meaningful environmental impact analysis should go beyond accounting for pressures from resource use such as resource extraction, energy consumption, and waste generation, and focus on assessing the consequences or impacts of resource demand on ecosystems. This can provide a more comprehensive understanding of the environmental challenges and guide effective environmental policymaking for promoting sustainability and responsible resource management [147].
- **Land footprint:** The land footprint provides insights into the physical land area that is required, impacted, or altered due to the deployment of infrastructure and facilities that support infrastructure and require land such as installations, road accesses, power supply, mobile towers, etc. The land footprint indicators include land cover change, potential loss of natural habitats, soil damage, biodiversity loss, deforestation, conversion of land for installations, resource extraction, and waste generation. According to the [148] monitoring the various elements of biodiversity at global scales is difficult. However, it is increasingly possible to measure changes in the extent and spatial structure of natural habitats. Land cover change is the best measure currently available to monitor pressures on ecosystems and biodiversity globally.
- **Waste footprint:** The waste footprint is associated with the total amount of waste generated from the production to the disposal of infrastructure including electronic waste, battery waste, packaging waste, etc. Material usage can be used as a proxy for waste footprint as excessive use of material with complex compositions, nanomaterials, or non-recyclable materials can be challenging to recycle. The end-of-life management of infrastructure equipment and devices is also an indicator that measures recycling, reuse, and proper disposal practices. The circular economy aims at increasing the amount of material recycled and fed back into the economy, therefore reducing the generation of waste, and limiting the extraction of primary raw materials [149]. The adoption of circular economy practices, such as refurbishing, repairing, and reusing can potentially reduce waste generation, contributing to environmental sustainability.
- **Biodiversity footprint:** The biodiversity footprint measures the impacts on plant and animal species, ecosystems, and natural habitats. Biodiversity impact indicators include potential habitat destruction, fragmentation, and disturbance of natural ecosystems and wildlife due to infrastructure deployment and operation of the technology. According to the OECD’s expert workshop on the Post-2020 biodiversity framework [150] existing indicators for measuring biodiversity at national scale across many countries include ecosystem extent/condition (tree cover loss, natural habitat extent, mangrove forest, land degradation, biodiversity habitat index, etc.), species abundance (species habitat index, wild bird index, fish biomass, etc.), extinction risk/species status (proportion of fish stock within safe biological limits, etc.) community position (mean species abundance, marine trophic index, change in local species richness, etc.). The biodiversity variables that are most important to measure include extinction risk/rate (e.g., Red List Index for species), population trends (e.g., Living planet index, Species Habitat index etc.), biotic integrity (e.g., Biodiversity intactness index, Mean species abundance). The report also highlights the lack of indicators for some biodiversity variables including trends in genetic diversity, risk of ecosystem collapse, ecosystem function, and marine biodiversity, especially in deep waters. Important biodiversity variables to measure include extinction risk/rate, population trends, biotic integrity, genetic diversity, and ecosystem extent/condition.

Another common trade-off between carbon and water footprints occurs in the production of biofuels, where the carbon footprint may be reduced by using renewable biomass as a source of energy, but the water footprint may increase due to the water-intensive nature of biomass production, irrigation, and processing. Land-intensive energy generation processes from renewable energy sources such as solar farms, or wind farms, may have positive impact on carbon and other emissions footprints, but also may result in negative impact on land and resource footprints.

4.1.2 Energy and associated GHG emissions

As described in Chapter 2, to tackle climate change, the 2015 Paris agreement states that GHG emissions need to be drastically reduced by 2030 and reach net zero by 2050. Moreover, latest climate science indicates that the global average temperature increase must be limited to a temperature increase of 1.5°C. According to the latest IPCC report [146], the GHG emissions have not yet decreased – on the contrary, they have continued to *increase*, already today resulting in a global temperature increase of 1.1°C above pre-industrial levels.

According to [151], GHG emissions mainly come from Energy (73.2%) whereas Agriculture, Forestry, and Other Land Uses (AFOLU) contribute to 18.4% of the GHG emissions. Because the ICT sector is not a heavy consumer of land, it can be assumed that it is responsible for extremely limited emissions in the AFOLU only and it will not be addressed in the following chapter. Hence, a connection can be made between the energy consumption of the ICT sector, at all stages of its life cycle, and the GHG emissions of the ICT sector.

4.1.3 Materials

Prior sustainability efforts in the ICT sector have mainly focused on energy consumption and its emissions and from a climate perspective, the energy use is an important topic as stated above. However, with increasing digitalisation, the raw materials requirements for ICT have also become an important sustainability issue [152] [153] [154].

Almost the entire periodic system of elements can be found in digital technologies, with a particularly high share in the consumption of elements such as copper, gallium, germanium, gold, indium, platinum-group metals (PGMs), rare earth elements (REE) and tantalum. For certain raw materials (e.g., indium, gallium, and germanium), the digital economy and its ICT infrastructure has 80–90% of the total consumption of these materials. This can become a problem of competition for resources since the same minerals are of interest for the green energy transition (e.g., for solar panels, wind turbines, and batteries).

A critical raw material (CRM) is a raw material of high importance to the economy and whose supply is associated with high risk [155]. The EU has listed these and updates the list periodically – in 2020, 30 critical raw materials were listed (European Commission 2020). Mineral raw materials are produced by mining and refining processes and to a smaller extent by recycling. To distinguish between these, one speaks of primary and secondary raw materials, respectively. The environmental impact associated with primary raw materials production tend to be greater than that of secondary material production via recycling (cf. [154]) which is a reason why circularity has been presented as a framework for environmental sustainability. Moreover, mining may compete with other forms of land use and is sometimes associated with conflicts – these materials are often referred to as conflict materials.

Globally, as much as 82.6% of all e-waste is not properly documented, collected, or recycled, and e-waste is the fastest growing waste stream in Europe [156]. E-waste also contains over 1000 different chemicals, many of which are hazardous. In addition, for many metals included in ICT devices, the technical limitations to metallurgical processes mean that specialty metals used in small quantities are lost in recycling process to side streams or dusts.

The sustainability challenges related to material resources are thus complex and manifold. Altogether, this means that attention to material resources during technology development is of great importance. As described in chapter 2.4.3, circular economy approaches can be applied to reduce reliance on mining of primary materials and generation of e-waste. The sustainability and circularity of raw materials can be addressed both through eco-design and new business models.

4.1.3.1 Material Resources: Material Efficiency and Circularity

A circular economy approach encourages companies to look at their operations and their supply chains, and think about how resources are sourced, how they can be used more efficiently, where they can be more effectively recovered, and where the need for raw materials can be designed out of the business model altogether.

However, its related challenges also lie in the entanglement of factors and enablers, such as raw materials tracking, waste electrical and electronical equipment (WEEE) treatment capabilities, chemical and physical recycling process. It also lies in the entanglement of approaches, e.g., eco-design, partnerships with second-hand suppliers, new business models, etc. Indicators are important as well: e.g., Material Circularity Indicator (MCI), scarcity related to economic resilience, human toxicity, biodiversity, water depletion etc. Finally, regulations such as the EU critical raw materials regulation [157] must be considered.

Each individual factor already raises a set of questions, for instance about materials criticality, economic importance for the industry, individual companies, and countries, potential of substitutability, price volatility, recyclability, geographical origin and geopolitics, and current ore grade. Sustainable materials management (SMM) is a systematic approach to using and reusing materials more productively over their entire life cycles. It represents a change in how our society thinks about the use of natural resources and environmental protection. By examining how materials are used throughout their life cycle, an SMM approach seeks to use materials in the most productive way with an emphasis on using less, reduce toxic chemicals and environmental impacts throughout the material life cycle and assure that we have sufficient resources to meet today's needs and those of the future.

These stakes apart, initiatives are already being taken. First, standards like ISO/TC 323 [158] and ISO 59010 [159] - under development - or more specific standards like ITU-T L.1023 [160] or L.1100 [161] can offer general guidance. In addition, relevant topics to investigate for ICT sector include the eco-design of equipment / devices / Customer Premises Equipment (CPE) focusing on higher degrees of modularity, allowing quick and easy disassembly of equipment, replacement of aged or defective parts with the finest granularity and compatibility with software upgrade for extended lifetime. Priority for modularity could be given to components that are either subject to obsolescence or prone to defects.

For network equipment, this priority could also be given to components mandatory to change for capacity upgrades or functionality upgrades. Higher capacity and new functionalities being major reasons for equipment replacement decisions. Eco-design of equipment also has implications for the supply chain. This could include open programs of 'take back and refurbishment' supply, along with spare parts availability, marketplaces to facilitate second-hand equipment flows and licensing and contractual conditions adaptations. Studies about lifetime extension relevance are also important, requiring case by case to analyse energy efficiency improvement between 2 generations of equipment and evolution of electricity emission factors according to the country of use. Finally, the research on critical materials management, especially critical materials and hazardous substances substitutability and organizations / companies / country resilience with regards to materials are of high interest.

Resource scarcity occurs when demand for a natural resource is greater than the available supply – leading to a decline in the stock of available resources. It can limit the choices available to the consumers who ultimately make up the economy which potentially lead to unsustainable growth and a rise in inequality as prices rise, making the resource less affordable for those who are least well-off. Thus, critical material management is vital for any sustainable technological eco system.

Supply chain transparency

Supply chain transparency refers to the traceability and visibility of the material, components, production, and distribution processes in a production and consumption system. By fostering transparency, industry can ensure the mitigation of risks associated with environmental degradation, labour exploitation and illegal trade.

Responsible raw material sourcing

Responsible material sourcing is defined by the selection and procurement of raw material and basic components that meet the environmental, societal, and good governance criteria. These practices include the use of conflict-free minerals, renewable resources, and eco-friendly manufacturing, wherever possible. Minimization of hazardous material in possible places in the design process, e.g., some parts with Lead replaced with lead free equivalents, Brominated Flame Retardants (BRFs) in printed circuit boards (PCBs) replaced with non-halogenated flame retardants. Such responsible practices help to reduce the environmental footprint, promote sustainability and ethical business standards.

4.1.3.2 Biodiversity

As noted above, biodiversity is an essential resource for humanity. However, life on land and in water (cf. UN SDGs in chapter 2.1.1) is seriously threatened and has been for a long time. Thus, two of the focus areas for the Agenda 2030 are SDG 15 and 14, i.e., the goals to protect and restore life on land and below water. Currently the trend for biodiversity is going in the wrong direction. Not only is there a decline in biodiversity, but we are also currently seeing that the species extinction rates are accelerating [162]. Biodiversity losses are typically due to land use changes, climate change, invasive species, overexploitation, and pollution. At the United Nations Biodiversity Conference (COP15) in 2022, it was reported that the planet is experiencing its largest loss of life since the dinosaurs. One million plant and animal species are now threatened with extinction, many within decades. At the COP15 the nations did however agree on the historical landmark agreement, the Global Biodiversity Framework, to guide global action on nature through to 2030 [163] [164].

Also from a corporate perspective, there is some progress in terms of an increased awareness of the value of biodiversity and eco system services. For example, there is a joint effort called “Make it mandatory” – a campaign with the aim to make it a mandatory requirement for all large businesses and financial institutions to assess and disclose their impacts and dependencies on biodiversity, as a measure to halt and reverse biodiversity loss by 2030 [165]. From a pure economical perspective, it has also been noted by the World Economic Forum that there is great potential for the economy to grow and become more resilient by ensuring biodiversity. Every dollar spent on nature restoration leads to at least $9 of economic benefits [166].

4.2 Observed Trends in Social Sustainability

According to the World Economic Forum [167], a growing and ageing global population looks to exacerbate existing issues with social mobility and human capital development. Meanwhile, geopolitical tensions are amplifying the need to find alternate energy sources amid the already urgent need to transform into a more sustainable economy. More Social Jobs, those in the education, healthcare, and care sectors, are envisioned to help address social mobility and human capital issues while more Green Jobs are essential for enabling an environmental transition.

This chapter presents the aspects that comprise social sustainability considerations and reviews the current initiatives and trends related to social sustainability as a whole, as well as to these aspects.

4.2.1 Factors that may influence social sustainability and respective challenges

As already implied by the UN SDGs associated with social sustainability (see chapter 2.1.1) and the EU work on social sustainability, the latter is influenced by many different factors and the actions taken for ensuring they are properly addressed. These factors are the availability of enough resources for living; having enough food of good quality (nutrition facts); good health and wellbeing at all ages; quality and lifelong education; gender equality; affordable, reliable, sustainable, and modern energy for all; inclusive, safe, resilient and sustainable cities and human settlements; peace, justice and strong institutions.

Kate Raworth’s 12 basic needs (see chapter 2.4.1), i.e., food, health, education, income and work, peace and justice, political voice, social equity, gender equality, housing, networks, energy, and water, in the Doughnut theory are also in compliance with the abovementioned factors.

The Happy Planet Index (HPI) [168] is the first index that takes into account sustainability aspects and sustainable wellbeing for all, comparing to well-established indexes such as the gross domestic product (GDP) and the Human Development Index (HDI). It measures what matters to people and tells us how well nations are doing when it comes to achieving long, happy, sustainable lives. It is an index of human well-being and environmental impact that was introduced by the New Economics Foundation in 2006 [168]. Each country's HPI value is a function of its average subjective life satisfaction, life expectancy at birth, and ecological footprint per capita. The latest update, reporting 2021 results, reveals improving Happy Planet Index scores in Western Europe and in Africa, but declining scores in South Asia.

Looking from the ICT perspective and next generation networks point of view, the above aspects can be supported, promoting social sustainability, through domain-specific solutions that enhance these verticals, e.g., through agriculture and food safety and security solutions; e-health services for monitoring health status and well-being in young and elder people; VR/XR-based education services or museum visiting; smart cities services in terms of e.g., multi-modal transportation/commute, smart-parking facilities, waste management, smart-homes, etc.; digital voting services and informative services for legislations as well as public affairs digital solutions; etc.

Focusing on socially sustainable networks the factors are reduced to mainly 2 large categories: a) digital inclusion, i.e., making networks and the services offered over them available to and accessible for all in terms of e.g., network coverage, capacity, equally exploitable from all - independent of their gender, IT education, etc.; and b) trustworthiness, i.e., moving forward with a network design that can address security and data privacy concerns. Indicative examples of how digital inclusion may impact social sustainability are:

- Economic inequality is a factor that influences social sustainability and may result in social and economic exclusion, limit opportunities, and exacerbate poverty.
- Education is an important factor although many people face barriers to accessing education, including lack of resources, cultural barriers, digital exclusion, and discrimination.
- Access to healthcare and basic health services is essential. However, many people face barriers to accessing healthcare, including geographical barriers and digital exclusion.
- Respect for human rights and good governance is a corner stone for social sustainability. Around the world today however, societies face challenges related to corruption, lack of transparency, and weak institutions.
- Community engagement and participation are also important factors although many communities face barriers to engagement, such as lack of resources, language barriers, and power imbalances.
- Environmental sustainability is closely linked to social sustainability. Climate change and environmental degradation can disproportionately affect marginalized communities and exacerbate social inequality.

Environmental (mostly related to SDG 7 and 11) and economic (related to SDG 1) aspects, in this deliverable, are still related to social sustainability but handled in chapters 4.1and 4.3

The clear focus in UN SDGs as well as in EU Green deal, i.e., “leave no one behind” independent of location, race, gender, abilities, economic status comes with emerging challenges Some of these challenges are elaborated below.

On a global geopolitical level there is a decreasing trust both between and within nations [169], it can also be noted that democracy is declining in terms of electoral process and pluralism, the functioning of government, political participation, democratic political culture and civil liberties [170].

We see an urbanization especially in the developing world where megacities with more than 10M inhabitants will be more common. Here the density of devices and the data traffic is a challenge for digital inclusion.

In wealthier countries the establishment of “smart cities” is seen, where there is an increasing collection and usage of data. Overall, there is a trend in many countries wanting to monitor people’s behaviour and limiting access to certain content, to protect people from harm i.e., France blocking porn sites, some states in the USA putting requirements on social media companies etc. or to prevent crime.

The usage of ICT in most areas of people’s life is creating a lot of data, which needs to be stored and handled safely. Here digital identities including biometrics will rise in importance as for example to secure correct treatments in e-health which is on the rise boosted by the pandemic. The emergence of different AI models could, depending on the supplier market position and competence, risk to create market segmentation and put digital inclusion at risk for certain sections of the society, depending on their economic activity, race, gender, and location.

In the background, the devastating effects of the climate change are looming, causing extreme weather harming people, nature, and economies.

4.2.2 Exploitation of Doughnut Economics in Cities

A trend observed in society on a city level is to attempt to adopt circularity using the principle of Doughnut economics. Some examples follow. The Dutch capital of Amsterdam became the first city worldwide to formally implement doughnut economics in early April 2020 [171], aiming to train and to apply a systemic approach/regenerative economy during the city's exit from the COVID-19 pandemic. The city aimed at exploiting the Doughnut theory as a tool to guide their social and economic recovery from the pandemic. To this end, the city hall worked closely with the Doughnut Economics Action Lab (DEAL) [172] in order to adapt the general concept of the theory to the city scale with actionable policies (Amsterdam's strategy to be 100% circular by 2050) [173]. Amsterdam's strategy includes a 50% reduction in food waste by 2030, implemented measures to make it easier for residents to consume fewer natural sources (by establishing easily accessible and well-functioning second-hand shops and repair services over the next three years) and a push for construction companies to build with sustainable materials.

Belgium's capital city of Brussels followed their example [174] and went on to adopt the Doughnut in late September 2020, while the Canadian city of Nanaimo voted to follow suit in December 2020.

The Brussels initiative aims to generate and discuss innovative solutions to current challenges faced by residents in the Capital Region, including "the knowledge and experience of groups involved in leading the region's transition, but also city residents who are driven by their own experience of living in the Capital Region. Government offices will also be part of the process, as the initiative aims at creating a "guiding tool" which will help them screen their future decision-making through the prism of the Doughnut and ensure that the Brussels Capital Region solidly anchors the transition of its economy towards prosperity for all and for the planet."

According to the author of "Doughnut Economics" Kate Raworth, ever since, many more towns and cities worldwide are in contact with DEAL every week and work continued with partners in Costa Rica, India, Bangladesh, Zambia, and Barbados, among others.

4.2.3 Consultations on Social Sustainability

Considering digital technologies, working on social sustainability aspects can also consist in understanding and taking into account the needs and specificities of the various stakeholders who may use future technologies.

Recently, public consultations have increased in Europe in the political and business spheres (e.g., 5G deployment, environmental footprint of digital technology). Through these approaches, there is a desire (and a need) to encourage an active position, to give power to future users but also to accept to listen to and understand visions that are different or even dissonant from those generally produced by designers and engineers. Listening to and co-constructing with the stakeholders makes it possible to take diversity into account and to come up with proposals that are consistent and relevant with the needs and constraints of future users. In France recent various consultations have been held. See e.g.:

The **Public consultation on 5G deployment in Rennes (October 2020 to February 2021)** [175]

In the context of the deployment of 5G, Rennes City Council undertook a consultation with its population. This approach aimed to initiate the public debate, and a dialogue around the societal challenge represented by the deployment of 5G, and to propose to the municipality a global reflection around this technology, with a view to informing the decisions taken by the community.

20 elected officials and 20 citizens worked together during 11 working sessions on the challenges of 5G deployment and the associated recommendations.

This initiative shows how a local authority can encourage its citizens to inform, reflect and engage with a complex technological issue; a sort of empowerment and a way of looking after its relationship with its citizens.

The consultation concluded with 54 concrete propositions to Rennes City Council, specifying the partners and the timeframe for implementation. Indicative examples of those are:

- Prioritize the deployment of 5G according to real need, in areas where the 4G network is already present,

- Create a monitoring group to maintain a critical and benevolent dialogue with the operators,
- Make available the information received at the town hall from operators on the installation of antenna sites.

The status of the implementation of the propositions is provided to the public through the "Mission d'étude 5G" website, which already reports 7 of the propositions as achieved.

4.2.4 Observed Trends in Trustworthiness

4.2.4.1 Factors that may influence trust in the solutions and respective challenges

As described in chapter 3.2.1, in the ICT context, trustworthiness refers to ICT which is "secure, reliable and resilient to attacks and operational failures; guarantees quality of service; protects user data; ensures privacy and provides usable and trusted tools to support the user in his security management" [111]. As such, trustworthiness comprises privacy, security, integrity, resilience, reliability, availability, accountability, authenticity, and device independence [109].

Access to data and data ownership are increasingly major factors in value creation, and limiting such access is a means of control. Creating a system that transforms how data is collected, shared and analysed in real time can create strong drivers for future value, and introduce novel stakeholder roles. However, this may also lead to serious privacy and ethical concerns over the location and use of data. Privacy regulation is strongly linked to the rising trends of the data economy, peer-to-peer sharing economy, intelligent assistants, connected living in smart cities, transhumanism, and digital twins' reality at length. "I own my data" is expected to grow particularly in Europe based on General Data Protection Regulation (GDPR) evolution, though severe differences in the global data privacy laws are expected to be living on borrowed time. Data aspects are mostly related to privacy, (cyber-)security, availability, and authenticity.

In parallel, trends in artificial intelligence technology have contrary interpretations. Assuming the availability of appropriate data sets for training purposes, AI has the ability to propose solutions to increasingly complex problems. AI could be a source of great economic growth, shared prosperity, and even lead to the fulfilment of all human rights. However, concerns related to AI misuse, driving inequality, inadvertently dividing communities, and even being actively used to deny human rights in the future are parallel rising concerns [176].

AI trustworthiness is not only about data privacy, how these data are used and what discrimination they can impose, it is also about decision-making based on this data and therefore, it is also about integrity, resilience, reliability, availability, and accountability of the decision. These are the reasons why guidelines and research trends towards "human in the loop" and "trustworthy AI" continuously increase the last years.

To apply Trustworthiness to the AI system, a European high level expert group has proposed guidance [119] that became a trend for companies that want to implement trustworthiness. This proposition could be translated in the context of the next generations telecommunication with its risks:

- Ensure that the system's entire life cycle meets the seven key requirements for Trustworthy AI: (1) human agency and oversight, (2) technical robustness and safety, (3) privacy and data governance, (4) transparency, (5) diversity, non-discrimination and fairness, (6) environmental and societal well-being and (7) accountability.
- Consider technical and non-technical methods to ensure the implementation of those requirements.
- Foster research and innovation to help assessing systems and the fulfilment of the requirements; disseminate results and open questions to the wider public, and systematically train a new generation of experts in AI ethics.
- Communicate, in a clear and proactive manner, information to stakeholders about the system's capabilities and limitations, enabling realistic expectation setting, and about the manner in which the requirements are implemented. Be transparent about the fact that they are dealing with an AI system.
- Facilitate the traceability and auditability of systems, particularly in critical contexts and situations.
- Involve stakeholders throughout the system's life cycle. Foster training and education so that all stakeholders are aware of and trained in Trustworthy AI.
- Be mindful that there might be fundamental tensions between different principles and requirements. Continuously identify, evaluate, document, and communicate these trade-offs and their solutions.

4.2.4.2 Safe zone - trusted spaces in gaming platform

Immersive technologies such as gaming platforms and virtual reality offer an exciting new user experience, but they still lack certain controls. At Orange, several innovative projects are underway to integrate trusted services into these new worlds. One such case is Safe Zone, which provides a safe space against cyberbullying on some of the major online gaming platforms, where children around the world now spend a lot of their time.

This initiative [177] shows how to establish concrete signs of reassurance in the context of digital uses where harassment is unfortunately frequent.

4.2.4.3 The Mobile Health App Trustworthiness Checklist: Usability Assessment

World Health Organization (WHO) adopted in 2020 a Global Strategy on Digital Health also known as eHealth. WHO states that digital technologies are globally integral to daily life but the application to improve health remains largely untapped [178]. European Union did already communicate in 2018 the digital transformation of health and care as part of EU digital strategy [179]. Three main priorities linked to trustworthiness are: 1) citizens' secure access to their health data; 2) personalised medicine through shared European data infrastructure; and 3) citizen empowerment with digital tools for user feedback and person-centred care.

The need for eHealth is not only in the developing countries, also the developed countries face the challenge of remote areas and ageing population driving towards delivering care at home. The recent pandemic showed the urgency of implementation. In addition, futuristic use cases like for example facial imaging may be used to detect diseases like early signs of stroke, rare genetic conditions, and progressive neurodegenerative disease. eHealth is not limited to a smartphone app (mHealth) but could also be for example an IoT device inside our body or controlling the medicine released by an asthma inhaler depending on the need.

Next generation networks may help facilitate improvements in the provision of digital health services, so it must be accepted by the end user with trustworthiness as a core factor. An example of what is needed to achieve this is mHealth (i.e., a mobile health application). In order to achieve trust from the users, important factors for the use of the application are a) Recommendations from friends; b) Recommendation from a doctor; c) Good reviews on different platforms; and d) Idea of “everyone using it”. Cost of the application, privacy handling, user autonomy and empowerment in the application are other factors affecting peoples’ trust in the service.

Trustworthiness can be lost if there is a high hacking probability of the application, application tracking user activity, use of lengthy terms and conditions, requiring excessive personal details in order to register or operate an application, and finally limited digital literacy and indifference [180] [181] [108].

Some of these aspects like cost/TCO, user privacy or data handling, user autonomy, secure delivery of contents, handling user activity or location tracking, and addressing digital inclusion should be part of next generations network system design for trustworthiness of an mHealth application.

4.2.4.4 Ethics for trustworthy AI respecting fundamental rights

Already today AI is involved in many different aspects of our life, and more is to come. In the past year, the European Commission’s vision for trustworthy development and deployment of new technologies has been taking shape with the release of number pieces of legislation to regulate the digital economy, including the Digital Services Act [182], the Digital Markets Act [183], and Data Act [184], and the upcoming AI Act, which is expected in 2024. While 2023 has been a defining year for European legislation, ensuring a fair and resilient digital economy, work on projecting a European vision for responsible technological development has been taking shape for the last decade. This includes, of course, the General Regulation on Data Protection (GDPR) and also the important work of the High-Level Group on Artificial Intelligence. The High-Level Group, formed in 2018, developed a set of ethics guidelines for the development and deployment of artificial intelligence, focusing on a human-centric approach to the subject. This group—made up of 52 leading experts in industry and academia—also developed 33 recommendations to guide a European path to AI development that would be sustainable, inclusive, and economically competitive [185].
In the light of the GDPR and the EU ethics guidelines for trustworthy AI [119] as well as the work conducted from the High Level Group on AI [185]and materials released from the Fundamental Rights Agency, more

and more companies create an internal board that has the competence to monitor and guide the company's procedures in such aspects. Stricter regulations can be expected in the future. Today as mentioned in chapter 3, we already have European guidelines for trustworthy AI. The EU Agency for Fundamental Rights states: "From tracking the spread of COVID-19 to deciding who will receive social benefits, artificial intelligence (AI) affects the lives of millions of Europeans. Automation can improve decision-making. But AI can lead to mistakes, discrimination and be hard to challenge. A new EU Agency for Fundamental Rights (FRA) report reveals confusion about the impact of AI on people's rights. This even among organizations already using it. FRA calls on policymakers to provide more guidance on how existing rules apply to AI and ensure any future AI laws protect fundamental rights." "Its aim is to ensure that AI systems placed on the EU market and used in the Union are safe and respect existing law on fundamental rights and Union values." [186]. Many companies have already realized the need for AI ethics and acted proactively, we give two examples from the ICT industry.

Example 1 Sony - Responsible AI

Through the utilization of AI, Sony aims to contribute to the development of a peaceful and sustainable society while delivering its kando experience - a sense of excitement, wonder or emotion - to the world.

In September 2018, Sony established the Sony Group AI Ethics Guidelines which were amended in 2021.

The Sony Group AI Ethics Committee, established in 2019, examines AI use cases to ensure compliance with these abovementioned guidelines. In 2021, the AI Ethics Office was established to provide subject matter expertise on AI ethics to all Sony business units. In addition, Sony has established a notification system for AI utilization in products, services, and internal operations in Sony Group's business units, to share information on AI ethics risks.

In March 2021, in accordance with the Sony Group AI Ethics Guidelines, Sony established an internal document stipulating requirements to be complied with in the commercialization process of electronic products and services, and in July 2021 started conducting AI ethics assessments in the product development life cycle. Sony uses e-learning tools to promote an understanding of AI ethics among its employees and invites speakers from outside the company to discuss this issue at lectures and symposia [187].

Example 2 Orange - Data and AI Ethics Council and Data and AI Ethical Charter

Orange created an AI Ethics Council in 2021 made up of 11 members, selected for their independence and neutrality, their expertise on these topics, and the diversity of their backgrounds. The council's mission is to define an ethical framework for AI and Data, excluding regulatory obligations. It oversees and advises the Executive Committee on governance and the concrete use cases that are referred to it. Finally, it monitors the company's implementation of the ethical principles validated by the Executive Committee, as defined in the Orange Data and AI charter [188] published in November 2022. The council delivered in October 2022 a Data and Artificial Intelligence Ethical Charter, which sets out the company's ethical values in terms of data and artificial intelligence. This is based on European and international recommendations for ethical data and artificial intelligence. It takes into account the ecosystems and environments of the countries where Orange and its subsidiaries are present and includes the six following principles [189] [190]:

- Contribute to environmental and social wellbeing challenges,
- Respect the autonomy and needs of humans, and operate under their supervision,
- Respect equality, diversity, and non-discrimination,
- Respect privacy through attentive protection and governance of data,
- Respect the specific challenges of each AI-based system in terms of resilience and security,
- Communicate transparently and clearly about the end use of AI-based solutions and establish a clear chain of responsibility.

Orange is also contributing to best practice sharing groups: e.g., AI governance implementation guide [191] and participation in the construction of certification standards [192].

4.2.5 Observed Trends in Digital Inclusion

Digital inclusion refers to the efforts to ensure that everyone has access to and can effectively use digital technologies, such as the internet, computers, and mobile devices. It aims to address the digital divide, which is the gap between those who have access to digital technologies and those who do not.

Moving from digital divide to digital inclusion involves ensuring that everyone has access to digital technologies and the skills necessary to use them effectively. There are some strategies that can be used to promote digital inclusion, as such:

- Infrastructure deployment: One of the first steps to promoting digital inclusion is to ensure that the necessary infrastructure is in place to support digital technologies. This includes building out broadband networks and providing access to affordable devices.
- Digital literacy training: Providing digital literacy training can help individuals develop the skills necessary to use digital technologies effectively. This can include training on how to use computers, access the internet, and use digital applications.
- Community access points: Creating community access points, such as libraries, community centres, and schools, can help to ensure that individuals have access to digital technologies even if they do not have them at home.
- Affordable pricing: Making digital technologies affordable can help to ensure that everyone has access to them. This can include providing subsidies or discounts for low-income individuals or families.
- Language and cultural sensitivity: Ensuring that digital technologies are accessible to individuals with different language backgrounds and cultural experiences is also important for promoting digital inclusion.
- Partnerships and collaborations: Collaborating with community-based organizations, government agencies, and private companies can help to leverage resources and promote digital inclusion initiatives.
- Addressing digital inequalities: Recognizing and addressing digital inequalities, such as unequal access to high-speed internet or digital skills, is also important for promoting digital inclusion.

By taking these steps, we can work towards a more inclusive digital society where everyone has the opportunity to participate and benefit from the digital age [193].

This can help to ensure that people of all backgrounds and abilities can benefit from the advantages of the digital age, such as increased communication, access to information, and economic opportunities. It's particularly important in today's society, where so many aspects of life, including education, healthcare, and employment, are increasingly reliant on digital technologies. Without access to these technologies and the skills to use them effectively, individuals and communities' risk being left behind and experiencing greater inequality [120].

4.2.5.1 Factors that may influence digital inclusion and respective challenges

The need for digital connectivity has never been clearer, nor more urgent [194]. ICT has become the primary medium for communications, information, transactions, education, and entertainment worldwide. Its implementation by the ICT industry, legislators and policy makers in all countries is essential to ensure that everyone's right to communicate in the digital world is respected [122]. Securing everyone with access to reliable connectivity and the right digital skills is key to ensuring that no one is left behind. The work within this area focuses on contributing to equality and inclusion to ensure that individuals and societies capture the full potential of digitalization.

More specifically, urbanization will bring 5 billion people together to live in cities, many of them megacities with more than 10M inhabitants, by 2030 occupying 3% of the Earth's land but accounting for 80% of the energy consumption and 75% of carbon emissions. 95% of urban expansion in the next decades will take place in the developing world where 883 million people live in slums today [176].

While there is a trend that indicates the next billion Internet users will be mobile only, not everyone will have equal access to the latest educational technology. This refers to how ubiquitous cheap phones and increasingly affordable network connections in mega cities and rural areas will help the next billion users to join the Internet and access applications and digital content increasingly in non-English speaking markets. For many, mobile technology is the primary or only channel for accessing the Internet and services [176]. On the other hand, almost half of the global population still has no internet, and this exclusion takes many forms. In sub-Saharan Africa, 25% of the population lack network coverage, while 49% cannot use the internet because they cannot afford smartphones or mobile services, they lack the skills to use them, or the services don't actually meet their needs [195]. In Europe, this figure is 17.5% [196]. In France, recent figures mention 13 million people who struggle with technology.

The above observations, i.e., the increased density of the users in urban areas, but also the remaining low density of the users in rural areas, create 2 main challenges for the next generation networks:

a) The need for increased network capacity in rural areas at affordable costs for all (especially when used for social digital services, e.g., education, health, democracy facilities); and
b) The need for increased coverage in areas where the users are scattered in large geographical areas, e.g., rural areas. In such areas, the need for access to digital social services at affordable costs may be even more needed given their distance from the cities where there may be more access points to such services.

The last observation related to digital inclusion is the fact that not all people have the same IT literacy or even understanding of the interfaces in the digital services due to e.g., culture-related perception. This poses one more challenge for digital inclusion and it is related not to the communication network per se but to how the digital social services are designed and developed or how seamlessly one can connect to the network.

In a nutshell, digital inclusion is about accessible ICT (in terms of coverage, capacity, cost), assistive technologies, skills and digital skills and social inclusion.

4.2.5.2 Digital inclusion in eHealth/mHealth services

Ensuring healthy lives and well-being for all at all ages is one of the UN SDG goals. Improving access to healthcare and reducing death and illness, therefore, is an important target in social sustainability, this particularly in the areas with limited access to healthcare systems. The use of technology in healthcare, often referred to as eHealth [108], while digital technology is becoming more embedded in US healthcare delivery models, tens of millions of people in the United States face a significant barrier to eHealth since they either lack access to affordable broadband or face other hurdles to getting online.

For instance, as highlighted in [197], while digital technology is becoming more embedded in US healthcare delivery models, tens of millions of people in the United States face a significant barrier to eHealth since they either lack access to affordable broadband or face other hurdles to getting online.

"In the European Union, 70% of homes in 2021 had high-speed internet connections, up from 16% in 2013, according to Eurostat. But in rural areas, which can struggle to get internet coverage, only 37% of homes had high-speed internet in 2021. For example, no homes in rural areas of Greece have high-speed internet connections, according to the Eurostat data. In the Czech Republic, only 7% of rural homes have it. And in Finland, that figure is just 12%." [198].

Moving over to India "a recent report by the Internet and Mobile Association of India (IAMAI) found that only 29% of rural India has access to the internet, compared to 64% of urban India. This digital divide is not only a social issue but also an economic one […] Digital inclusion can improve healthcare in rural India. Telemedicine, for example, can provide remote access to healthcare services, reducing the need for travel and improving healthcare outcomes. Additionally, digital technologies can help track disease outbreaks and improve public health outcomes" [199].

These examples show that there are challenges that still need to be addressed in terms of coverage, geographical areas, acceptance by the stakeholders, and government approach.

4.3 Observed Trends in Economic Sustainability

Economic sustainability can be considered in the following three levels:

- **Corporate level -** Commercial enterprises need to cater for and balance social and environmental sustainability, while being profitable and meet the customer demands to be productive. Companies are bound to follow sustainability requirements defined by various regulations ranging from financial reporting to sector specific requirements. Business decisions aim to maximize benefits and minimize risks and make use of different business and economic KPIs, such as cost, revenues, total cost of ownership, customer orders, customer inquiries, etc. Enhancing business decisions means learning from past mistakes and mitigating challenges faced by the telecoms sector. To address poor returns on capital invested and an overall lack of investment, cutting complexity in a hyper-competitive market as well as encouraging technology companies to contribute fairly to network deployment where they utilize a disproportionate share of network resources to traffic data are seen as important.
- **Ecosystem level -** Economic sustainability needs to consider the full business ecosystem view and not just one stakeholder. An economy must be sustainable for all contributors and every organization needs to do their part – roles/actors/firms must be able to envision profit opportunities. As there are increasing dependencies between stakeholders to realize benefits, the measuring of the health of the ecosystem is important to reach a balance between conflicting stakeholder claims. For example, the current MNOs' revenue stagnation impacts the entire ecosystem, which calls for self-assessment of the mobile sector. It also calls into question whether earlier models of revenue growth pertaining to previous generations of mobile communications are still sustainable within a maturing industry, prompting consideration of new commercial viability frameworks. A sustainable economy may be characterized by being open to new firms (value creators), new innovations, serving new customers, e.g., higher degree of newcomers, turnover, new services etc. is a good indicator for sustainability.
- **Societal level -** Economic prosperity and economic growth measured at the societal level are fundamental pillars in economic sustainability. However, traditional economic indicators, such as the GDP, do not properly characterize the situation as they generally do not take environmental aspects into account. Economic growth in a sustainable economy must be less dependent on fossil fuels and other environmentally harmful approaches. Changes in consumption models that impact the mobile communication market can appear rapidly, such as COVID stopping global travel and increasing the use of communications tools and the resulting data transfer.

The following trends in economic sustainability have been observed:

- **Sustainable realization of productivity growth.** Doing more with less is a business opportunity for both the mobile communication sector itself and other sectors. Data driven approaches to productivity growth are particularly promising. Productivity implies that resources will be released making it possible to improve other important issues such as health, pollution, security, and education. However, higher productivity also has rebound effects leading to higher demand and consumption if prices go down. These rebound effects can be both good and bad for the environment.
- **Co-creating the Fourth Industrial Revolution** [200]**.** The Fourth Industrial Revolution potentially represents a fundamental change in the way we live, work, and relate to one another. It is a new chapter in human development, enabled by extraordinary technological advances commensurate with those of the first, second and third industrial revolutions. These advances are merging the physical, digital, and biological worlds in ways that create both huge promise and potential peril. The speed, breadth and depth of this revolution is forcing us to rethink how countries develop, how organizations create value and even what it means to be human. The Fourth Industrial Revolution is about more than just technology-driven change; it is an opportunity to help everyone, including leaders, policymakers and people from all income groups and nations, to harness converging technologies to create an inclusive, human-centred future. The real opportunity is to look beyond technology and find ways to give the greatest number of people the ability to positively impact their families, organizations, and communities.
- **Endeavour to net zero.** Net zero state where emitted GHGs into the atmosphere are balanced by their removal from the atmosphere could transform economies and societies. While more investment in renewable energy resources is necessary to attain net-zero GHG emissions, ICT is key to achieving that target, as it can help overcome climate change in many ways. These include increasing efficiency as data processing and communications grow while carbon emissions level off or decline, and dematerialization due to substitution effects, for example, remote working instead of commuting to

and from the office or business travel reduction, and the digitalization of services. On average over the last decade, ICT investment has accounted for approximately 15% of total GDP growth worldwide. Achieving net zero is challenging in many countries as there are insufficient incentives for households and businesses to invest in net zero technologies and few penalties for failing to do so. Circular economy and related life cycle assessment methods building on data driven approaches provide tools for this transition. Realizing dematerialization i.e., the absolute or relative reduction in the quantity of materials required to serve economic functions in society and thus implies doing more with less. Dematerialization is crucial to obtain a sustainable economy.

- **Identifying new business opportunities from enablement effect.** There is potential of new businesses to emerge from solving environmental sustainability challenges including optimizing the operations in different sectors of society towards sustainability requirements/cost savings/new business opportunities. With the use of real-time data, effective data monetization, digital automation of different processes and the use of visualization methods, businesses can shift their focus towards generating higher revenues from the servitization of products.
- **Preparing for environmental sustainability regulations.** New legislation related to sustainability has appeared in different sectors very recently to control industries' activities. Regarding mobile communications, this development is still at its infancy and regulators in Europe are collecting possible indicators to be measured. There is controversy in levelling the playing field in terms of how much sustainability related actions should be enforced by laws vs. actions arising from firms' own operations that are not forced by regulations.
- **Preparing for Taxes**. The European Green Deal acknowledges the crucial role of taxation in the transition to a greener and more sustainable economy, and this may drive the implementation of environmental taxes in coming years [201].
- **Adapting to uncertain operational environment**. There is uncertainty for the future business from changing user behaviour, unknown sustainability requirements, geopolitics, and climate change among others. Resilience as the capacity of a system (e.g., individual, a forest, a city or an economy) to deal with change and continue to develop and evolve is an increasingly important driver for 6G. According to the World Economic Forum Risk Survey, environmental risks are perceived to be the five most critical long-term threats to the world as well as the most potentially damaging to people and planet, with "climate action failure", "extreme weather", and "biodiversity loss" ranking as the top three most severe risks. Respondents to the survey also signalled "debt crises" and "geoeconomic confrontations", "digital inequality" and "cybersecurity failure"—as critical short- and medium-term threats. For risk mitigation efforts related to "Artificial intelligence", "space exploitation", "cross-border cyberattacks and misinformation" and "migration and refugees" respondents believe the current state of risk mitigation efforts fall short. Resilience is about how humans and nature can use shocks and disturbances like a financial crisis or climate change to spur renewal and innovative thinking.
- **Connecting with social sustainability**. A sustainable economy should adhere to social sustainability principles such as obtaining full employment with decent work conditions, creating systems for lifelong learning, and promoting well-being. A socially just transition needs to protect from economic and societal disruption and make the consequences bearable to those affected. Many developing countries are at levels of consumption that are lower than those in more advanced economies and are working hard to reduce poverty and improve living conditions. As productivity gains reduce costs, it is reasonable to expect significant increases in consumption due to rebound effects. Meanwhile, in the more advanced economies, dematerialization is increasingly evident.
- **Automation and AI will drive change in the labour market.** Automation will continue to change the demand for skills among workers. For example, when repetitive tasks are automated in a factory setting, the demand for low-skilled workers decreases. However, automation may drive demand of high-skilled workers specialized in ICT who are responsible for the connected machines [197].

5 Drivers and Goals for 6G

5.1 Environmental Sustainability

5.1.1 External Recommendations and Guidelines for Environmentally Sustainable 6G

Looking at the coming decade, many of the trends mentioned in this report can be expected to continue to evolve and will in different ways affect the entire ICT industry.

Naturally, global warming will continue for many years to come, since the GHG emissions continue to increase, as described in IPCC's recently released AR6 Synthesis Report [202]. This will in turn continue to have a negative impact on the environment. The report mentions for example that we can expect an increase in heat-related human mortality and morbidity, food-borne, water-borne, and vector-borne diseases, and mental health challenges, flooding in coastal and other low-lying cities and regions, biodiversity loss in land, freshwater and ocean ecosystems, and a decrease in food production in some regions. The report does, however, give guidance to policy makers with a simple message: "Some future changes are unavoidable and/or irreversible but can be limited by deep, rapid and sustained global greenhouse gas emissions reduction. […] Limiting human-caused global warming requires net zero CO_2 emissions" [202]. Thus, it can be expected that there will be a great focus among policy makers on ensuring that activity performed by nations or organizations reaches net zero emissions.

However, regulations around environment protection will not only evolve around global warming. The Agenda 2030 encompasses many more dimensions and keeps pushing regions and nations forward, especially in the EU. As mentioned, we have seen broad environmental sustainability guidelines coming, such as 'The European Green Deal', which has clear climate focus but still a wider perspective, with goals extending to many different sectors, including construction, biodiversity, energy, transport, and food [203].

Another example is product sustainability legislation covering ease of repair, availability of spare parts, or repair by independent providers, which is on the way in both Europe and the U.S. [204] [205]. As the consequences of climate change will be increasingly noticeable across the world, it could be assumed that there will be increasing global regulations demanding businesses and nations to act in an environmentally sustainable way.

To adapt to these regulations, it is expected that ICT products and services in the 2030's will need to have a minimal environmental footprint, thus be designed for a circular economy, especially since the number of devices including IoT devices with cellular connectivity will increase rapidly in the coming decade. We can expect an increased focus both on the materials used in the design of hardware, but also the design of software. In the 2030's it will most likely not be accepted by neither legislation nor consumers to offer products with software without offering several software upgrades to prolong the product's lifespan. As software become more prevalent in network architectures, and devices, its own carbon footprint and contribution to GHG emissions should come under scrutiny, especially considering that the manner in which code is written can have a sizeable impact on the processing power required to perform tasks.

This is already recognized in the ITU, which is a key driver for the global development of ICT. As described in chapter 2.2.1, already now there is a clear focus on dealing with both climate change and e-waste and since work is currently ongoing to create standards and guidelines for circular economy, we can expect this to be in place in time for launch of the 6G platform in 2030.

It should also be mentioned that in some cases we can expect companies to be ahead of the legislation. Some examples are 'Make it mandatory', 'Science-based targets' and the new ISO standard of net zero, which all rely on companies voluntarily complying with regulations [165] [206] [207][[208].

A concept which can provide tangible environmental guidelines for the future of the ICT industry is the technical cycle of the Butterfly diagram mentioned in chapter 2.4.3. In terms of product design for ICT, here are some examples of what the five principles could mean, to ensure that whatever is produced, it is making as little environmental impact as possible:

- **Share**: To ensure effective use of resources, the ICT products and services could be shared, both devices and the infrastructure. An example is the pilot performed in the UK, where masts and frequencies were shared by mobile network operators in rural areas [209].
- **Maintain/prolong**: To ensure that used resources are delivering maximum value, both products and services need to be designed to last. For hardware this would, e.g., mean to consider robustness, and for software it could mean to ensure that the product will get several software upgrades over its lifetime.
- **Reuse/redistribute**: A simple question to ask when designing the 6G platform would be: What can be reused from the previous generations?
- **Refurbish/Remanufacture**: For ICT this could mean to trade in used products and refurbish them to 'as new' quality with performance guarantee to reduce the demand for raw materials. This could be done by the manufacturer themselves, e.g., the Philips Circular Edition system [210] or by a third party, e.g., the vendor Inrego offering refurbished consumer electronics.
- **Recycle**: Only when other options for resources are no longer available should products be recycled. Already in the product design phase, it needs to be considered how to easily separate product material so that they could be reused (such as the cobalt in batteries and plastic).

5.1.2 Environmental Sustainability Trends as Drivers of 6G

The increased awareness and concerns about the impact of human activities on the environment, and the need for sustainable solutions to address environmental challenges, have resulted in growing efforts to adopt sustainable solutions and practices that minimize harm to the environment. Despite the growing efforts of the ICT sector, including the mobile infrastructure, radio access technology, data centres, and devices, decades in reducing energy consumption per compute and network traffic, high demands of the digital economy require larger computational resources, increased connectivity, and higher bandwidth, leading to higher network traffic loads. Consequently, the overall energy consumption in the ICT sector continues to rise.

The development of 6G technology is therefore likely to be influenced and driven by different environmental sustainability trends including decarbonization of energy sources and processes, circular economy practices, product design, usage of sustainable materials, recycling of equipment, etc. In the following, we discuss some of these trends and how could they drive the development of 6G.

According to the International Environmental Agency [211], in 2022, the total greenhouse gas emissions from energy-related sources reached an all-time new record high of 41.3 Gt CO_2e. Most of these emissions, accounting for 89%, were attributed to CO_2 emissions resulting from fossil fuel combustion and industrial processes. This requires transitioning to renewable energy sources, reducing carbon emissions, and implementing climate-friendly policies.

5.1.2.1 Power Consumption and Decarbonization of Energy Sources

Previous studies show that ICT and network represents about 1.4% of global GHG emissions [212], however, it is foreseen that the number of connected devices and the amount of data transmitted per user will increase drastically. For this reason, it is of paramount importance to ensure that future 6G developments are aiming for a high energy efficiency on one hand, and to incorporate renewable sources for energy provision as much as possible on the other hand.

For communication service providers (CSPs), most of the power consumption comes from the RAN, as shown in Figure 5-1 from a survey of CSPs from over 30 networks [213]. It can be seen that RAN represents 73% of the total energy consumption of the telecom network. Of this 73% there is a further breakdown of the energy consumption in terms of various equipment at the base station.

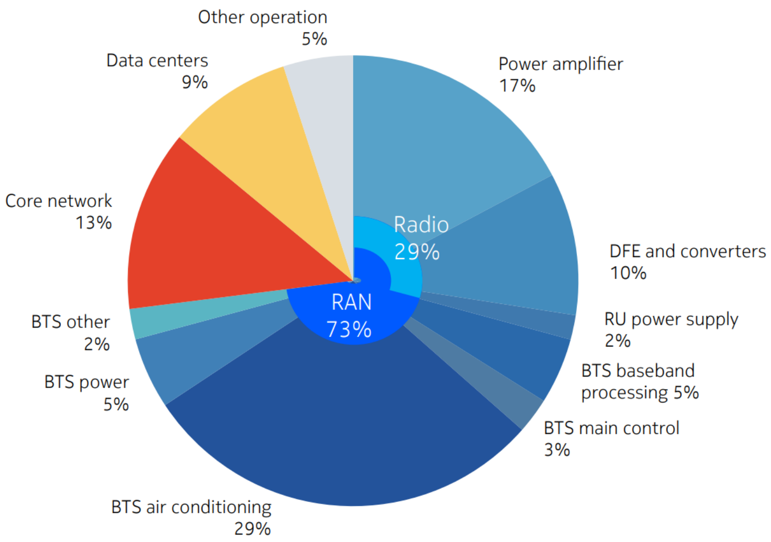

Figure 5-1: Energy Consumption Breakdown for a CSP (from: [213])

As can be seen in Figure 5-1, Radio equipment amounts to 40% of the 73% (i.e., 29% of the total energy consumption) which is a significant amount of energy. A detailed breakdown of the power consumption of a massive multiple input multiple output (mMIMO) radio unit at full load is given in Figure 5-2 [213]. Here, PA PSU refers to the power supply unit of the PA, and the power consumption for this unit becomes relevant since the PA consumes the most power.

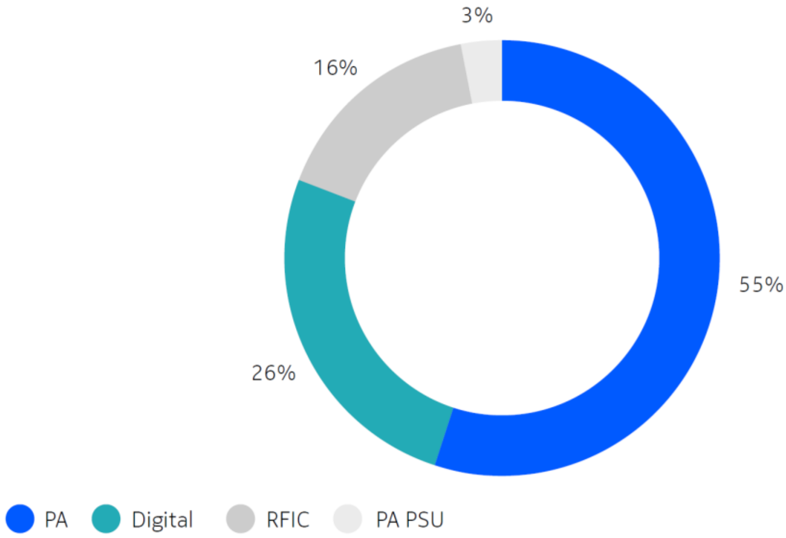

Figure 5-2: Power Consumption Breakdown for a mMIMO RU at Full Load (from: [213])

According to [213], 6G energy efficiency goals with respect to 4G and 5G are shown in Figure 5-3. At full load, a 5G NR 64 TRX 100 MHz massive MIMO (mMIMO) cell has 20 times the peak capacity and is 90% more energy efficient (bits/s per Watt) than a 20 MHz 4G LTE (Long Term Evolution) cell. This trend is expected to continue with 6G, where the peak capacity could be 10 to 20 times that of 5G but the target power consumption at peak capacity should only be twice that of 5G.

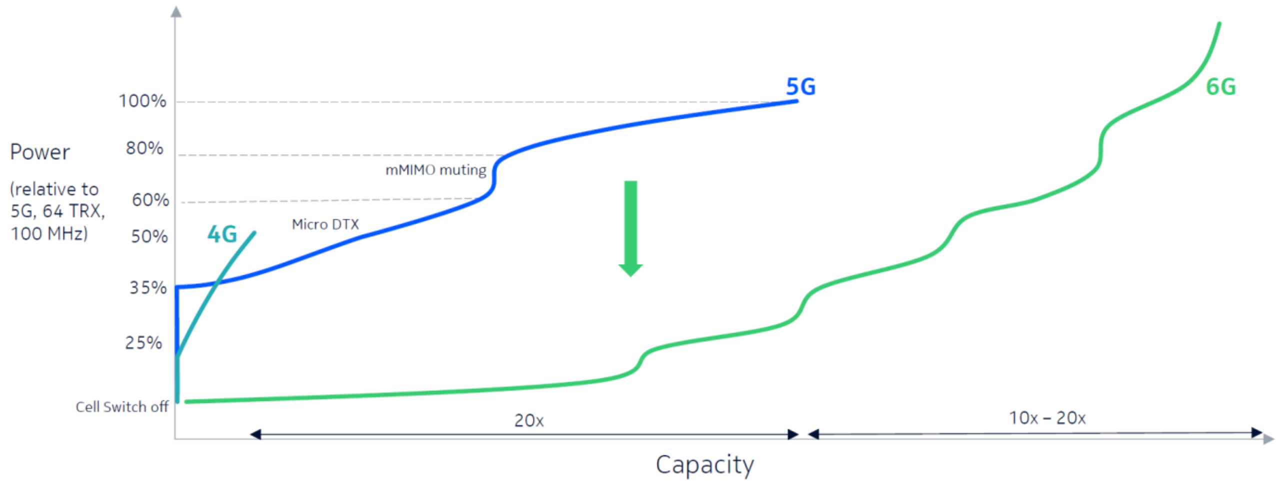

Figure 5-3: 6G Power Consumption Goal Versus 4G and 5G (from [213])

Methods such as MIMO muting, and micro discontinuous transmission (DTX) reduce the power consumption of 5G at medium loads. But at low loads, 5G consumes more power to provide the same capacity as LTE at low loads, due to insufficient scalability and flexibility. Note that the load here refers to the number of physical resource blocks (PRBs) allocated with the highest permitted power spectral density.

Considering the growing significance of data centres in modern and next-generation mobile networks, the environmental sustainability of 6G networks should be examined through networks and data centres operations, as well as devices and hardware manufacturing.

- Network Structure: According to Next G Alliance report [214], across the components of 4G and 5G mobile networks, the RAN consumes the most power. The advances in technology allow the communication of more data using less power, which presents an increase in efficiency, but also significant increases in the expected future traffic and hence higher power consumption. Hence, energy efficiency and sustainability should be key considerations in the planning, architecture, and operation of 6G networks.
- Data Centres: Another observed trend in network power consumption is the increased data centre power consumption of 5G compared to previous technologies. As of 2019, data centres consume approximately 200 TWh of electricity, or nearly 1% of global electricity demand, contributing to 0.3% of all global CO_2 emissions according to the International Energy Agency [211]. Shifting towards renewable energy sources is a crucial measure in the process of decarbonizing data centres. Several market-based solutions are currently available for procuring renewable energy, including physical power purchase agreements, green tariffs, virtual power purchase agreement contracts and self-generation either on-site or off-site, as well as Renewable Energy Credits [214]. Data centres have backup generators to keep systems running when primary power supplies fail. Moving workloads to data centres fuelled by more sustainable backup solutions like hydrogen fuel cells will lower energy emissions. If transitioning to hydrogen fuel cells is not an option soon, natural gas offers 28.6% lower CO_2 emissions [215]. Energy-Aware or Grid-interactive Battery Energy Storage Systems and Uninterruptable Power Supply batteries can also reduce emissions while also giving back to the grid. Renewable energy sources can be used to charge these batteries and energy surplus can be automatically exported to the utility grid for use in time of low generation using AI based energy prediction systems [216]. Data centres require significant amounts of water consumed to either generate electricity (traditional thermoelectric power) or through cooling (air conditioning and evaporative cooling of buildings). There currently are a few developing techniques to try to reduce the electricity and water load needed to cool data centres including using the cold seawater for cooling like the Hamina data centre in Finland or immersive cooling as implemented by Project Natick [217].
- Cloud computing and automation: The estimated data globally produced by IoT devices in 2020 is about 2.8 Zettabyte (ZB). Almost 90% of generated data is transferred to the cloud. Transferring 1 GB of data to the cloud costs between 5 kWh on average. IoT-generated data transferred to the cloud would be responsible for 8 billion metric tons of CO_2 in 2025. Edge computing can reduce the total amount

of data traversing the network as it moves the processing power from the cloud to a point closer to the end user or device, reducing by that the overall energy consumption in networks according to Medium [218]. Automated and intelligent systems could also help reduce the energy consumption in networks and devices by managing their on/off states to match demand. For instance, inactive devices can be automatically transitioned to reduced or turn off power consumption. This can help reduce energy usage without impacts on the performance.

- Devices: The production of mobile devices, as highlighted in a report by Greenpeace [219], is heavily dependent on fossil fuels and leads to the production of greenhouse gas emissions. ITU L.1410 [39] mentions that most emissions associated with smartphones arise from the production chain. It is worth noting that although phones consume relatively little energy during their usage, 85% of their overall emissions impact comes from production-related activities such as material extraction, manufacturing, and distribution. Strategies such as increased usage of renewable electricity, abatement of fluorinated gases, process and equipment optimization and energy and water conservation help reduce production emissions.

5.1.2.1.1 Energy Efficiency Key Enablers

6G is envisioned to overcome some of the limitations of 5G and could achieve higher energy efficiency at all loads through the following key enablers:

- Radiofrequency (RF) Power Amplifier: Significantly decreases RAN Power Consumption. Solutions are targeting areas such as new adaptive load-dependent waveform design and amplifier pre-distortion/post-distortion techniques.
- Passive Devices and Network: Energy harvesting from RF signals and ambient energy sources and using those to power communication devices. Use of passive Reconfigurable Intelligent Surfaces (RIS) to replace active communication relay/repeaters which would enable improved network coverage in an energy efficient manner [220] [221].
- Dynamically scalable arrays to minimize the number of active elements at low loads
- Adaptive in-band guard subcarriers where the guard bandwidth increases with decreasing load. The tones in the guard band are used to minimize the peak-to-average power ratio (PAPR) of the transmitted waveform.
- Network densification and cell free mMIMO to lower transmit power.
- Powering ON/OFF: Increased granularity of powering OFF/ON 6G components in the networks, data centres and devices. Leveraging AI/ML techniques for optimizing power turned OFF/ON operations.
- AI/ML:
  - AI/ML based receiver processing that is robust to transmit hardware imperfections
  - Use of AI/ML network / devices can be optimized for specific scenarios and operational modes e.g., wireless environment, traffic patterns and user distributions.
- Analog compute-in-memory to improve power efficiency of neural network implementations.
- Cloudification of RAN CU and DU functions to enable scalability.
- Centralization of network functions to benefit from statistical pooling gains and lower climate control energy consumption with centralized baseband liquid cooling solutions.
- Sensors:
  - Tighter coordination and cooperation between sensing and communication in cellular networks.
  - Deploy network of sensors across network entities and mobile devices to be used in monitoring activities and conditions.

5.1.2.2 Modular and Durable Equipment

Given that the 6G era may coincide with greater data rates and potentially different network architectures, the need for efficient and sustainable equipment will only become more pressing. One of the biggest challenges of the electronic industry is the high amount of e-waste generated by the disposal of old and outdated electronic devices. To address this issue, it's important to make electronic devices easier to refurbish and repair so that they can be reused instead of discarded. Re-evaluating the materials used in electronics is a crucial step towards creating a more sustainable and circular economy. To achieve this, it's important to assess the entire lifecycle of devices, from the extraction of raw materials to the end-of-life disposal. By understanding the environmental impact of each stage, we can identify opportunities to improve the sustainability of 6G infrastructure. Achieving a sufficient level of supply chain transparency and responsible sourcing in 6G design faces several unique and traditional challenges. These include complex global supply chains, and supply chain disruptions, lack of standardized guidelines, and inadequacy in regulatory framework. On the other hand, a more transparent and responsible 6G ecosystem will also create inclusive opportunities for innovation and value creation. The cutting-edge technologies such as internet of things (IoT) and blockchain can be helpful to raise the traceability and accountability in the supply chain. 6G technology itself can benefit its supply chain transparency. These considerations must be balanced with the need to upgrade equipment to more energy-efficient forms so that we avoid extending the lifecycle of existing equipment already known to have higher emissions intensity.

- Modular equipment: Allows for easier customization and scalability of network infrastructure, while also reducing maintenance costs and facilitating more rapid upgrades. This would allow for the repair and refurbishment of devices, extending their lifespan and reducing the need for new devices. Additionally, by making it easier to disassemble and recover component parts, we can extract valuable materials and re-use them to manufacture new devices.
- Durable equipment: Helps extend the lifespan of network equipment and reduce waste generation, while improving reliability and reducing downtime. Durable equipment can also better resist the effects of a changing climate and high temperatures, thus offering economic benefits, as it can reduce the need for frequent replacements and repairs.

As these trends become more established in 5G networks, they are likely to become drivers for the development of modular and durable equipment for 6G networks.

5.1.2.3 Circular Economy Practices

Circular economy practices are gaining momentum. While circular economy policies are varied, several initiatives are being implemented by the OECD member countries and are aimed at reducing waste and increasing material efficiency. This includes measures to reduce resource consumption, increase recycling and reuse, and minimize waste generation. Adopting circularity practices in the production and operation of 6G requires a fundamental shift in the way equipment and devices are designed, produced, consumed, and disposed of, and that this requires action from all stakeholders, including governments, the telecoms industry, and consumers.

- Renewable Resources: Rapidly renewable resources like bioplastics and green energy can help reduce our reliance on non-renewable resources like petroleum plastics and diesel [214]. Bioplastics can be used in a variety of applications including packaging materials and disposable utensils. Renewable energy sources can also replace fossil fuels to power 6G infrastructure.
- Reuse/Refurbish/Recycle/Repair: A product's circularity may be predetermined up to 80% of the way through its design process [214] . Make it simpler to refurbish and repair equipment and recover component parts allows them to be used in the production of new equipment. Short-term expenditures can be balanced by gains in material reclamation.
- Take-back programs: In addition to producing modular and durable equipment, another way to reduce e-waste is to implement take-back programs and encourage consumers to recycle their old electronics instead of throwing them away. These programs can help recover valuable materials from old devices and reduce the environmental impact of electronic waste.

5.1.3 Impact, Challenges, and Uncertainties of new ICTs on Environmental Sustainability

We consider multiple driving technologies in the 6G era and discuss the benefits and challenges of these technologies from the standpoint of environmental sustainability. However, some of these technologies pose a unique set of challenges and uncertainties that must be addressed. We also discuss potential mitigations to these challenges.

One key driver for 6G is Artificial Intelligence / Machine Learning (AI/ML). AI/ML could help build a sustainable 6G system that can deliver data at faster rates than 5G networks, while still meeting stringent energy-efficiency goals. 6G may have an AI-native air interface where functions ranging from the RAN to the core network are optimized by AI [222]. Through pilotless transmission, such an AI-driven 6G air interface is shown to offer up 20% higher throughput for the same transmit power [223]. AI-driven networks can also improve resource allocation, thereby increasing spectral efficiency for the same transmit power or analyse and forecast cell traffic to optimize energy saving functions at low loads [224]. Lastly, an AI-driven 6G air interface can also be rendered robust to transmitter and receiver impairments [225] which would enable components such as the PA to operate in the more efficient non-linear region. Since the power consumption in a network is dominated by the consumption in the PA, this would lead to considerable power savings. With all these innovations, a 6G AI-driven air interface could be approximately 50% more energy efficient [226].

However, two of the main challenges with AI/ML is storage and energy consumption associated with computation. The former can be mitigated by only saving the model parameters instead of the whole data set. However, for the latter, computation needs are growing with increasing AI adoption, raising sustainability concerns that are not just limited to 6G networks. For example, in the last decade, the computing needs of AI systems have grown dramatically, while data centre power consumption has remained flat at around 1% of the global power consumption, owing to hardware efficiency gains. However, with further adoption of AI, this trend is not expected to continue in the future with demand for computation outpacing the gains in hardware efficiency [227].

The fact that demand is being outpaced by the rapid growth of AI technology is a serious concern for sustainability. Training a single neural network can have a significant CO_2 impact, more than the amount required to manufacture, and fuel a car over its entire lifetime [228]. Since a large chunk of the compute complexity with AI/ML systems is in the training phase, part of this complexity can be reduced by utilizing pre-trained models. In addition, AI/ML developers could reduce the energy associated with model tuning by offering easy-to-use APIs for implementing more efficient alternatives to brute-force grid search for hyperparameter tuning, e.g., random or Bayesian hyperparameter search techniques [228]. The compute complexity and power consumption during inference can be reduced with technologies such as analogue in-compute memory.

A digital twin, which is an up-to-date digital representation of a physical object/process, is another key ICT driver that promises significant efficiency gains. Digital twins and AI/ML are companion technologies that enable comprehensive monitoring and prediction of parameters/events. They improve efficiency by learning the relationship between the monitored, environmental, and adjustable parameters.

[229] considers the case where a digital twin is used along with AI/ML technologies to improve data centre energy efficiency by monitoring, predicting, and optimizing parameters in systems like air conditioning and chilled water. AI algorithms learn the relationship between refrigeration capacity, environmental parameters, and controllable parameters such as frequency of cooling and freezing pumps to enhance energy savings and utilization ratios.

As is the case with AI, computational complexity is a challenge with digital twins, with the computational complexity depending on the complexity of the model of the underlying process. For example, real-time implementations of ray tracing or computational fluid dynamics solvers may be energy intensive. Further, the digital twin may itself be built using a ML-based data-driven model, which again could be computationally intensive. In such cases, methods that improve the energy efficiency of AI/ML technologies could help with digital twins.

An important ICT driver for 6G is the reality spectrum (also known as the reality-virtuality continuum) which describes the range of experiences that exist between the real world and virtual reality [230]. The reality spectrum, through new generations of ICT networks, has the potential to contribute to environmental sustainability through for instance remote work, remote education, and energy management. Facilitating better management of environmental resources, such as energy and water, as well as new and more sustainable transportation systems.

While different points on the reality spectrum, such as extended reality (XR), might have a strong enablement effect over a variety of use-cases, they also have an environmental footprint owing to stringent requirements on connectivity and computation. With regards to the former, the increase in power consumption is a result of the higher data throughput that needs to be transmitted with latency constraints for this technology to render objects in real-time. As with power consumption for video streaming, the power consumption for augmented reality (AR)/ virtual reality (VR)/XR would be higher if utilized outdoors and assuming reliance on cellular connectivity. Under these conditions, a significant chunk of this power might come from the 6G RAN. Consequently, advances in the 6G network energy efficiency would help mitigate the environmental footprint of the reality spectrum.

Computing needs in the reality spectrum also contribute to increased power consumption when rendering high resolution video. Tackling this challenge would necessitate the development of energy efficient rendering algorithms, AI-based optimization, and hardware improvements.

Lastly, cloud computing is an important enabler for several ICT use-cases, some of which are mentioned above, and is also an important ICT driver in the 6G era. Several use-cases and technologies such as AI/ML, digital twins, and the reality spectrum benefit from offloading computations to the cloud where computational resources are abundant. Moreover, consolidating compute resources can lead to a greater energy efficiency or a smaller carbon footprint compared to a distributed approach through efficient resource utilization, advanced cooling techniques and by sourcing energy through renewable sources. However, these gains may be reduced or eliminated by the need to ferry data to the cloud for processing.

5.1.4 6G for the Environmental Sustainability of other Sectors of Society: Trends in Enablement, Effect Assessment, and Maximization

It is well known from literature [231] that ICT can be a powerful tool to support all sectors of the economy in achieving their sustainability targets, in line with the UN SDGs. With specific reference to 6G, a three-fold role was identified in [176] where 6G is seen as:

- a provider of services to support activities towards UN SDGs,
- an enabler of hyperlocal measuring tool,
- to be developed in support of the UN SDGs.

In fact, 6G will be both an infrastructure that supports a multitude of services to help the achievement of the individual targets in the UN SDG framework, as well as a tool to help authorities and other stakeholders to collect various data, thus enabling the monitoring of relevant indicators.

5.1.4.1 How can 6G Support Different Sectors in Reducing Emissions

While it is hard to predict exactly what 6G may bring to life — just like how the smartphone and the plethora of applications were not envisioned to its fullest potential when 5G was being envisioned and designed, we can already imagine its global impact to create new possibilities for our future society. It is envisioned that 6G will enable energy efficient, low latency ubiquitous communication for mobile devices. 6G is also expected to support existing use cases while delivering an evolutionary path for fixed and mobile broadband (e.g., more capacity, faster throughput, lower latency), providing even more pervasive access (e.g., higher density connections and ubiquitous coverage), and expanding mission-critical services (e.g., higher reliability and availability and lower latency). Enhanced communication capabilities in addition to other capabilities such as sensing (i.e., capability to create comprehensive spatial perception of the environment) as well as AI/ML could be leveraged to enable environmental sustainability in sectors such as manufacturing, transportation, and agriculture. It is however important to acknowledge that, when analysing the enablement effect, the potential rebound effects associated with the adoption of a better performing technology must be considered and not to overestimate the benefits in terms of enablement effects. Examples of advancement in technologies that can be considered for this goal include 'Integrated Communication and Sensing', 'Joint Communication and Compute Powered by AI/ML' and 'Telepresence and Metaverse'.

In addition, the 5G-enabled carbon abatement potential varied across various use cases in the study conducted by Accenture [232], and consequently, across many industry verticals as well. This study suggests that with 5G, reduction in annual carbon abatement could be up to 20% of the US carbon emission target by 2025.

Carbon abatement potential of 6G should be designed to become higher than 5G as it would enable new use cases in untapped verticals. Following is a discussion on how 6G may enable improved environmental sustainability in sectors such as transportation, agriculture, manufacturing, and energy.

- Transportation: 6G use cases could potentially allow us to rethink the ecosystem of sustainable transportation. On the road, 6G may help drivers spend less time idling their cars in traffic because vehicles would be able to communicate and safely manoeuvre through the road infrastructure in a more efficient way thus avoiding congestion, pollution, and heavy dependence on multi lane traffic networks. 6G would be designed to allow energy efficient low latency ubiquitous communication between vehicles which would enable high-definition sensor sharing between vehicles leading to much more efficient driving. Also in cities, integrated sensing and communication would enable more efficient monitoring, forecasting and dynamic and optimized resource allocation. For example, a digital twin of road infrastructures could enable safer and more efficient road traffic flow thus leading to lower emissions.
- Agriculture: 6G should enable wider coverage, denser and more intelligent sensor deployments compared to 5G which would enable potentially ubiquitous monitoring and collection of valuable data about the growth patterns of crops, and the real time control of water flow, pesticides, and picking of the fruits and vegetables to help increase food yields and reduce food wastage. AI/ ML based systems native to 6G networks could help enable precise agriculture such as just in time sowing and picking of yields. 6G could make agriculture smarter, more efficient, and resilient which would foster environmental sustainability.
- Industry: Telepresence / metaverse / XR powered by AI/ ML and connected with the 6G capabilities would potentially enable the next gen immersive experiences for remote work, both field work and in office work. Examples of industries which would benefit are construction, education, codesign with metaverse collaboration, remote medical care, and diagnosis. Leveraging the telepresence and metaverse with 6G could potentially lead to reduction in GHG emissions associated with the travel industry.
- Energy and Building: Building infrastructures with integrated communication and sensing capabilities connected to the edge cloud could regulate the temperatures better by controlling heating, cooling and illumination needs of the occupants based on predicted weather patterns and personal preferences, thus reducing energy waste.
- Manufacturing: Integrated communication and sensing would potentially enable the next generation of smart autonomous manufacturing techniques which could be capable of optimization of end-to-end processes by using data collected by sensing and the actuation of robotics powered by AI/ML technologies.

5.1.4.2 6G as Biodiversity Enabler

6G technology should contribute to promoting and safeguarding biodiversity in the ecosystem which may be witnessed over many use cases, including the below.

- Habitat and fauna restoration

Digital twins in 6G could potentially be applied for ecosystems which allows to model the habitat and fauna restoration projects and predict the future impact on biodiversity. Thus, it could support better decision making and effective planning of such restoration projects.

- Anti-poaching

Advanced deployment of surveillance systems, and sensing capabilities in 6G could be used to trace and tackle illicit activities in real time happening within forests [233].

- AI-assisted biodiversity conservation

The new capabilities of 6G including enhanced sensing, ultra-high data rates and low latency should help deploy advanced AI and machine learning algorithms for biodiversity conservation which could help to identify invasive species, predict potential threats, and provide conservation strategies.

- Climate change adaptation on biodiversity

The real time precise sensing capabilities of 6G driven by joint communication and sensing (JCAS) and its other analytics are likely to help researchers understand the impact of climatic change on biodiversity which would lead to the development of effective methods to minimize the impact. JCAS not only facilitates the collection of large-scale, high-resolution environmental data but also offers advanced sensing to monitor subtle environmental changes with its hyper sensing capabilities. The technique can significantly enhance the traditional means by carrying out improved biodiversity.

- Better connectivity for remote research fields

Enhanced connectivity, and sensing in remote locations can enable researchers to collect and share field data more efficiently and reliably. The enhanced sensing capabilities in 6G have the potential to support precise field data collection and sharing.

5.1.4.3 How to Evaluate Enablement

The evaluation of the enablement impact is a complex problem, in particular for new technologies such as 6G.

Avoided GHG emissions permitted by ICT have been studied for quite a few years. Several studies have been proposed but quite often seem to be fragmented as they rely on selected use cases, arbitrary hypothesis, and do not always take rebound effects into account properly [234].

A common basis for previous research in this area is the definition of a baseline scenario, a definition of a scenario with a solution that reduces GHG emissions applied and a comparison between the two. This is by necessity a hypothetical setup since the two scenarios cannot exist at the same time. As a matter of fact, for 6G it is not possible to rely on measured data and also the definition of the baseline scenario is challenging taking into account that 5G is still under deployment.

ITU [39] refers to three levels of environmental effects associated with ICT products and services:

- First order effects: the impacts associated with the physical existence of ICTs and related processes throughout its lifecycle (often referred to as a solution’s footprint)
- Second order effects: the impacts and opportunities associated with the use and application of ICT (also referred to as enabling effects, if positive)
- Other effects: rebound and other behavioural and societal effects.

While LCAs of ICT´s first order effects are well established albeit complex, and covered by standards, ICT for sustainability is a less mature area, and a well-grounded approach has been proposed by ITU-T only recently with Recommendation ITU-T L.1480 [40].

This ITU-T Recommendation provides a methodology for assessing the impact of ICT solutions on GHG emissions of other sectors. It offers a structured methodological approach, thus aiming at improving the consistency, transparency, and comprehensiveness of assessments of the impacts of the use of ICT solutions on GHG emissions over time. More specifically, the methodology covers the net second order effect (i.e., the resulting second order effect after accounting for emissions due to the first order effects of the ICT solution), and the higher order effects such as rebound. The methodology encompasses different assessment depths (tier 1-3) as well as different scale levels (organization, city, country, worldwide level).

While to some extent this methodology could be applicable also to new technologies, the high level of uncertainty associated to the lack of information is to be acknowledged. This implies that until more data would be available, the quantitative part of the ITU-T methodology cannot be properly applied to 6G.

As a final remark, it is important to note that 6G can be an important enabler, but literature highlights that technology itself is not sufficient to unleash the enablement effect: it is also necessary to implement suitable strategies and policies to drive cultural change and new personal behaviours. Specifically, organizations adopting ICT solutions to reduce CO_2 emissions, should be supported by policy makers through specific campaigns, and should also embrace appropriate policies and labour management with the aim to broaden and drive such adoptions.

5.2 Social Sustainability

A hyper connected globe will continue to feel ever smaller in 2030. Globally, 90% people will be able to read, according to the World Bank, and have access to the Internet. It will be essential to recognize that 6G could transform urban and rural life and this will be affected by geopolitics, rights to information transparency and information citizenry.

Public network funding has traditionally been directed towards unserved and underserved areas in terms of broadband access and coverage. Lately support for deployment programs has extended to policy areas, such as smart city community development, worksites and ecosystems (such as harbours and airports), advanced health services, logistics and transport, smart cities, public safety and critical infrastructure. Smart society builds dependable systems and communications, and standardized data is utilized by walled garden platform monopolies across verticals. The focus on smart cities will be extended to rural inclusion. 6G could enhance urban and rural life and may also be influenced by geopolitics, rights to information transparency and information citizenry.

Different technologies such as AI-based systems over IoT platforms, XR technologies, the Internet of Senses concept are areas of centre research and might incrementally be included in different social aspects in terms of enhanced digital social services for ehealth/mhealth, governmental services, multi-modal transportation, and information of the available services, monitoring of food production and safety, etc. Within the next decade, these services may to enter the market and to be proposed to the public and wider end-user groups stressing even more the need for building networks capable of easily adjusting in terms of coverage and capacity as well as in terms of prioritization based on the criticality of the offered service (e.g., flexible topologies, AI-based monitoring of networks, slicing, etc.). This would also increase the need for security and trustworthy networks in terms of privacy but also reliability that should be offered to all citizens across any country at reasonable costs.

5.2.1 Trustworthiness

5.2.1.1 Trust in what and in whom

Earlier in this report (see chapter 3.2.1), a broad definition of trust was provided, but applying the concept of trust to a piece of infrastructure is not trivial. Trust is generally applied to institutions or individuals rather than inanimate objects. To return to the metaphor of physical infrastructure, people need to trust that infrastructure is going to be properly maintained. There have been recent examples of the failure of bridges and railroads that have led to injuries and death. And while trust can fit into this discussion, people's trust in the infrastructure is about the institutions that maintain those bridges and railroads, and not the infrastructure itself. We inherently understand that a bridge will always serve its function—what people need to believe is that those bridges will not fall down, and this is where trust comes into play.

Trust in organizations

If the question of trust is formulated from an institutional perspective, the question becomes more how much do users trust those institutions that are charged with running and maintaining the infrastructure. And certainly, issues around existing telecommunications technology have been asked. There has been a long-running debate in policy circles and the market around net neutrality, and whether discriminating against particular packets of data represents a proper reimbursement for the burden created by particular activities. At the same time, providers have also used and sold information about the users of their systems to marketing companies and government agencies. Again, the trust question here is with the providers of services and the regulatory framework—such as the General Data Protection Regulation (2016/679) [235] and Open Internet Regulation (2015/2120) [236] have helped to mitigate the potential negative effects. Arguably, in some cases, the regulatory environment is the right place to mitigate these negative effects, given that there are normative and value judgements that need to be made—and these values can change over time and differ by jurisdiction.

Trust in protection (cybersecurity)

There is also a distinction to be made between trust that citizens (and businesses) feel in digital infrastructure versus the technical trustworthiness—namely, whether hardware and software interacting within the system can know the legitimacy of the information that they receive. Is that information secure from external attack and is it represented in a correct way? This is a more limited and technical definition—and an important component of trust—that is easier to measure and conceptualise.

5.2.1.2 Trust and technological complexity

The usefulness of technology in general, and mobile networks in particular, is directly related to its complexity: number of functions, interfaces, radio technologies, AI models, etc. However, complexity is also directly related to distrust. The importance and number of aspects in the definition of trustworthiness has grown alongside the complexity of machines in an effort to overcome this issue, as it is shown in previous chapters. Nonetheless, it is still foreseeable that lack of trust may become the main reason preventing the adoption of otherwise useful technologies [237].

On the one hand, for traditional complex systems, not relying on automatic machine learning, a possible strategy to increase trustworthiness is to make the whole set of source code and used data openly public. This has led to complex yet highly trusted systems (at least from a technological point of view), such as fully-fledged operating systems controlling live-critical machines, open cryptography algorithms protecting the privacy of highly sensitive data, blockchain technologies providing the foundations for wealth exchange, etc.

On the other hand, it is substantially more difficult to provide trustworthiness for machine-learning systems, as those expected in the near future. Their ability to replicate human-like tasks is very attractive, but the lack of understanding about their internal "reasoning", attained after large amounts of training, may even outweigh the potential openness of their algorithms and source data. There have been remarkable efforts in recent years to provide explainable AI systems, that is, systems that can not only provide useful results, but are able to argue the full path from input to outputs.

Considering the above, it is thus foreseeable that mobile operators may increase their use of open technologies and interfaces. At the same time, in order to provide trustworthy AI systems, it will not be enough to provide effective, open algorithms based on open data. Instead, AI systems will need to be able to explain themselves, that is, to justify the decisions they take, on request. Customer needs are the driver for technological innovation. Then new technologies must be developed with trustworthiness embedded within them.

The need for cybersecurity and trust will be ubiquitous in the hyper connected world in 2030. Even a temporary loss of technology may have, not only a productivity impact, but also a psychological impact on our lives. Furthermore, the subversion or corruption of our technology could result in disastrous harm to our lives and businesses if, e.g., medical treatment devices deliver the wrong medication, or educational systems teach propaganda, or home or work automation systems cause us injury or damage our products and businesses. In particular, expectations to protect and safeguard society and critical infrastructures from emergency situations by means of technological advancements are anticipated to grow. Furthermore, with increasing polarization and the ageing and diversification of the population new tribes and communities could emerge around various imaginary groups representing a wide variety of values, places of residence, political opinion, consumption choices or lifestyles [176].

From a user perspective digital security involves preservation of people’s privacy and integrity. European legislation (GDPR) might be followed by similar legislation in other parts of the world. On the other hand, from society's perspective the ability to prevent organized crime and terrorism must be considered [238]. These two aspects, personal user integrity versus social security, may need a delicate balance in the specification of 6G. This is further emphasized by the trend of a tougher geopolitical climate across countries in the world.

Robustness is often discussed in terms of ultra-reliability and low latency. This applies to some, though essential, use cases, for example in the segments manufacturing, ports and automotive [118]. There are, however, many other aspects of robustness to consider in 6G, such as roaming possibilities [239] [240] [238], including reasonable cost, and a good coverage and cell edge performance for communication and distress calls.

Another aspect are over-the-top services that could be globally standardized to a higher extent. One example is digital identities (e.g., electronic ID cards [241], Covid vaccine proof [242]). Another example is global and reliable digital payment arrangements [243]. In this work, the resistance to fraud against individuals and organizations should be considered. The resistance to hacker attacks including other attacks against infrastructure should be considered in terms of robustness and the security of people and society [244].

5.2.1.3 Towards Trust and Trustworthiness of 6G

A clear and obvious requirement for 6G and its underlying design is that it does not undermine the trust that users already have in 4G and 5G systems in use today. Without going into a detailed analysis of the 6G design, several topics that are relevant can already be listed.

The 6G design needs to proactively address concerns and questions in areas that are new compared to earlier mobile network generations. This shows that the scope of trust and trustworthiness could become wider as networks evolve:

- Privacy: Joint Communication and Sensing, computational offloading and edge computing, and the AI-driven network orchestration based on data on traffic flows and end user location can raise questions on how data is collected and used [245].
- Fairness and avoidance of bias: Distribution of (scarce) network resources among applications and their users can raise questions on how fair the decisions are made.
- Digital Autonomy: the origin of 6G hardware and software components and the way they are controlled could raise questions. Moreover, the 6G design needs to address present concerns in areas that are already known, and potential future concerns.
- Resilience
- Trusted interoperability

As known from 4G and 5G mobile networking, the level of technical trustworthiness needed to earn trust from users differs strongly between user groups (consumer vs business) and applications (e.g., entertainment vs health).

For privacy, fairness and avoidance of bias, the analogy with Trustworthy AI [246] is relevant and useful (see also sub-chapter 4.2.4). Although 6G is not the same as AI, 6G is expected to use AI. More importantly, it shares some of the key requirements with AI to qualify as trustworthy, including Technical Robustness and safety; Privacy and data governance; Transparency; and Diversity, non-discrimination, and fairness. For fairness and avoidance of bias, the analogy with earlier discussions on net neutrality [247] should be considered. Although, the distribution of resources may be performed by AI functions in 6G, the ultimate responsibility for a fair distribution lies with the providers of 6G services. An open question is whether detailed stipulations like those put in place for net neutrality [236] would be helpful in 6G given the potentially wider scope of fairness discussions.

5.2.2 Digital Inclusion

Digital accessibility incorporates that users shall manage to convey the intended message with a minimal (reasonable) effort. User equipment and system should put the user in focus. From this point of view, it is essential to understand that different users could have very different background needs. Factors that must be considered are cultural, socio-economic factors, age, and gender [238], and factors of functional variation where characteristics and abilities of people are different throughout the population [238].

To achieve digital accessibility, ICT should not only be available and affordable, but also accessible, which means designed to meet the needs and abilities of as many people as possible – including those with functional variations. Accessibility of ICT is key given that ICT has become the primary medium for communications, information, transactions, education, and entertainment worldwide. Its implementation by ICT industry, legislators and policy makers in all countries is essential to ensure that everyone’s right to communicate in the digital world is respected [122].

Coverage of cellular connectivity in geographical areas where public interests cannot be satisfied by the market alone, is another aspect of digital inclusion [248] [249]. Besides, the quality for occasional visitors and the possibility for emergency communication, it is about digital inclusion of people living in rural and urban areas.

6G is the next generation of wireless communication technology that is still in the research and development stage.

When referring to digital inclusion in 6G, building on the features of 5G technology, it will be crucial to ensure that everyone has equal access to the benefits of this new technology. This includes not only providing access to 6G networks and devices, but also ensuring that individuals and communities have the digital skills and literacy necessary to use these technologies effectively.

To achieve digital inclusion on 6G, it will be important to address the barriers that currently prevent some individuals and communities from accessing and using digital technologies.

Some of the efforts to promote digital inclusion on 6G may involve initiatives such as:

- Building out 6G infrastructure in areas that currently lack access to high-speed internet and other digital technologies.
- Providing affordable access to 6G devices and networks, including through subsidized programs for low-income individuals and families.
- Offering digital skills training and support to individuals and communities, including programs focused on developing the skills necessary to use 6G technologies effectively.
- Creating digital content and services that are accessible and inclusive to diverse populations, including those with disabilities, language barriers, or other special needs.

By prioritizing digital inclusion in 6G, we can ensure that this new technology benefits everyone, and that it helps to reduce rather than exacerbate existing inequalities [250] [120].

5.3 Economic Sustainability

5.3.1 Drivers and Goals for 6G

A key commercial challenge facing the telecommunications industry is related to the low return on capital for European MNOs, especially considering the use cases for consumers so far. It is important to consider whether 6G could provide an opportunity to address low returns on capital invested and a lack of investment in the industry overall. The key to increase the return on investment will be to will be to assure that 6G provides opportunities for individuals and firms to increase productivity. There may be initiatives that could help the European telecoms sector to align with EU policy goals [251]. Cutting complexity in a very competitive market is seen as one potential improvement [252]. It has been recognised that 5G population coverage is 95% in the US vs. 72% in the EU. There has also been recognition within the EU that Europe needs to invest significantly in its telecoms network to achieve its digital goals. One way of achieving this could be to consider a "fair share" model where technology companies who disproportionately utilise the network to traffic data could be charged a higher fee that is proportionate to their data utilisation. One additional possibility could be that firms also pay for priority in the networks [253].

Economic sustainability when 6G will be deployed in the beginning of 2030 will involve a broad set of decision-making principles and business practices aimed at achieving economic growth from services running on 6G network deployments, limiting harmful social and environmental trade-offs. Based on the trends in economic sustainability observed in chapter 4.3 the following drivers and goals for 6G development have been developed are expected.

Value-based 6G design. Value-based design will be important for 6G systems and services presenting an approach to sustainable design that prioritizes the values and needs of the end-users, and thereby incorporates them into the design process to create solutions that are effective and efficient. Based on the observed trends "co-creating the fourth industrial revolution", "automation and AI driving change in the labour market", and "connecting with social sustainability", the new value-based 6G design should aim at supporting socially just transition and providing opportunity for different stakeholders to harness converging technologies to create an inclusive, future oriented around what the customer needs instead of traditional technology-driven development. This calls for stakeholder engagement in the design phases of 6G.

Sustainable 6G business model innovation. During the past 50 years the average business models' life span has reduced from 15 to 5 years [254] and young generations' acceptance of existing business models is not guaranteed in the future. 6G business models need to be sustainable and transparently show the economic and social impact of consumer choices. Based on the observed trends "sustainable realization of productivity growth" "preparing for environmental sustainability regulations" and "identifying new business opportunities from enablement effects" in economic sustainability, new business model innovation should drive 6G development that solves major sustainability challenges and is sustainable itself. A balance would need to be struck between firms maximizing their own profits and establish new sustainable ways of doing business. This would entail sustainable resource combinations including different elements and components of infrastructures and services to meet the tailored needs of specific situations. The quantification of the sustainability impact of different resource combinations as well as the resulting enablement effects will be new drivers for 6G development. This change may herald new economic progress indicators instead of traditional economic growth measured with GDP, while still recognizing the KPIs used to measure business performance and profitability.

Open value configurations via 6G. New open value configurations and open-source paradigms may provide a powerful avenue in 6G to reinvent stakeholder participatory processes. Utilizing the sharing and circular economy principles will lead to co-creation and the utilization of existing resources and processes in new ways. As counterforces to the creation of platform monopolies, decentralized co-operative platforms, the peer-to-peer economy and sharing economy models and the progress of a human-driven fair data economy have already emerged [176]. Towards 2030 platform ecosystems will provide an infrastructure on which innovation and transaction platforms are built. Building on the observed trends in economic sustainability including "co-creating the Fourth Industrial Revolution", "connecting with social sustainability", and "automation and AI driving change in labour market", 6G development will likely be driven by open value configurations and sharing economy models creating new collaborative business models for the whole 6G ecosystem. Crowdsourcing and crowdfunding are expanding the space for new forms of organization and innovation.

Sustainable competitive advantage via correlated/holistic sustainability perspective in 6G. Economic sustainability in 6G cannot be considered in isolation from environmental and social sustainability but they must go hand in hand. Based on the observed trends in economic sustainability including "endeavour to net zero", "identifying new business opportunities from enablement effect", and "connecting with social sustainability", a new correlated sustainability perspective for 6G will need to be developed to identify the complex interdependencies and trade-offs between environmental, social, and economic sustainability to reach long-term competitive advantage in the new 6G ecosystem.

Monetizing with 6G in challenging business environment. The business environment around 6G is challenged by required investment and competition from new stakeholders and alternative data delivery mechanisms. The business environment around mobile communications faces growing amounts of transferred data without mobile network operators being able to charge more based on the increased amounts of transferred data. Competition with alternative delivery mechanisms has challenged the monetizing methods and end users are not incentivized for consuming less data. Based on the observed trends "preparing for environmental sustainability regulations" and "adapting to uncertain operational environment", 6G needs to bring return on investment in different environments including megacities (more than 10M inhabitants) and rural areas supporting varying density of users, data and energy usage, while operating under stricter environmental sustainability requirements.

Preparing for mitigating risks with 6G. By 2030 at the time of launching 6G, environmental risks including climate action failure, extreme weather, and biodiversity loss [255], as well as social risks including debt crises, geoeconomic confrontations, digital inequality and cybersecurity failure will have potentially big impact on the economy of nations, companies, and individuals. Consequently, these risks will impact the uptake of new 6G solutions and services. Responding to the observed trends on "adapting to uncertain operational environment", "connecting with social sustainability", and "endeavour to next zero" and mitigating the risks mentioned above, 6G development and deployment need to prepare for protecting stakeholders from the increasing risks in the changing operational environment.

5.3.2 Initial ecosystem stakeholder description

In this chapter, we will introduce some important stakeholders in the emerging 6G ecosystem, and some early analysis of challenges and opportunities. We will start of from the 5G ecosystem, and add stakeholders of the environmental, societal and economic domain. In particular, Hexa-X-II consider spectrum allocations to be a topic which may create tensions.

Ecosystem is a term used to capture stakeholders and relationships in a market and technology domain characterized by interdependency. However, one stakeholder does not have control over others stakeholders which take part in the co-creation of a solution and deliviering value. The ecosystem term, borrowed from biology, illustrates how co-existing stakeholders have found some sustainable financial and technological balance [256]. It follows that there may be ecosystems that never took off, or stranded because of imbalances or uncertainties in the sharing of risks and revenues [257]. Approaches such as technological innovation systems [258] aim to describe and assess technologies and markets also in early stages of their evolution, and focus on how and why an ecosystem can take off.

The 6G technology, and ecosystem, is in an early phase. Hexa-X-II experts suggest there may be alternative future 6G ecosystems, with different evolutionary paths. These may be more or less preferrable, probable, or plausible [259]. Preferability for a future ecosystem can be suggested based on values and norms coming from 6G sustainability requirements. The probability and plausability of future 6G ecosystems are more uncertain, even though we can expect them to be reinforced by historic paths and stakeholder positions. Figure 5-4 illustrates the time-span of an analysis of the 6G ecosystems and the challenge of bridging current predictions about and assessment of future ecosystems and with potential mitigations to push the ecosystem in a preferred direction.

The ecosystem analysis will identify and describe 6G stakeholders, their motivations and relationships. This is a foundation for discussing if all stakeholders share the same vision and motivation, or if there are differing views and tensions. Differences and tensions create dynamics in an ecosystem which may steer it into alternative paths, or also dead ends.

In Hexa-X-II, the objective of the ecosystem analysis is to identify factors which enables and hinders the 6G ecosystem to evolve, and to evovle in the direction of sustainability goals. The project will use this insight to identify adequate mitigations.

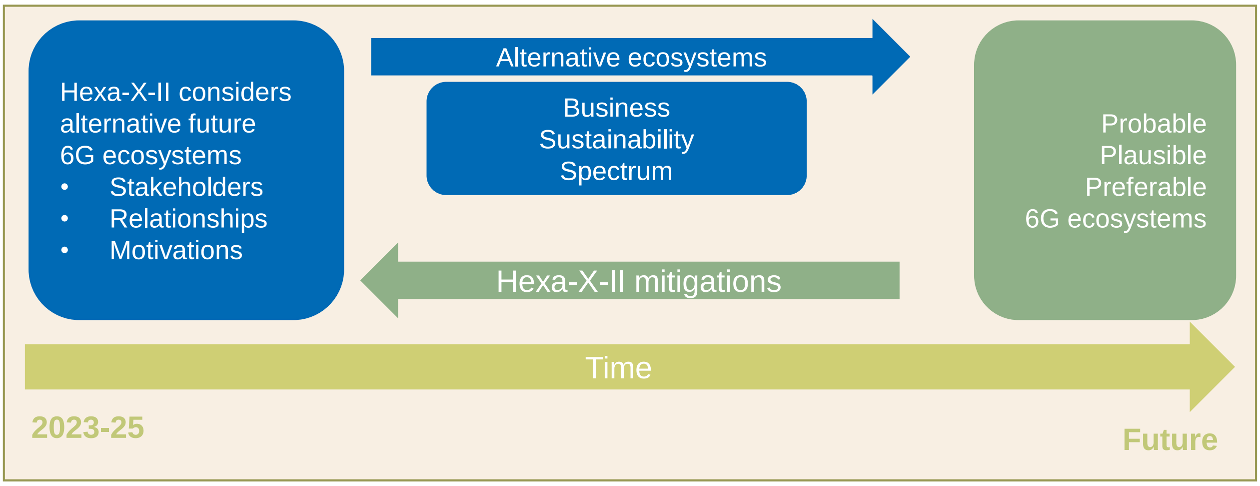

Figure 5-4 Time-span: our Current Perspective as Researchers, Futures we Suggest, and Potential Mitigations from Hexa-X-II to Push the 6G Ecosystem in Preferred Directions

5.3.3 6G general ecosystem - short overview

The 5GPPP Target stakeholder picture [260] [261] embraces 5G industries, vertical industries, their respective associations, standard defining organizations, financing bodies, and policy makers across all these domains. In sum, it concerns the business aspects of the 5G technology and market.

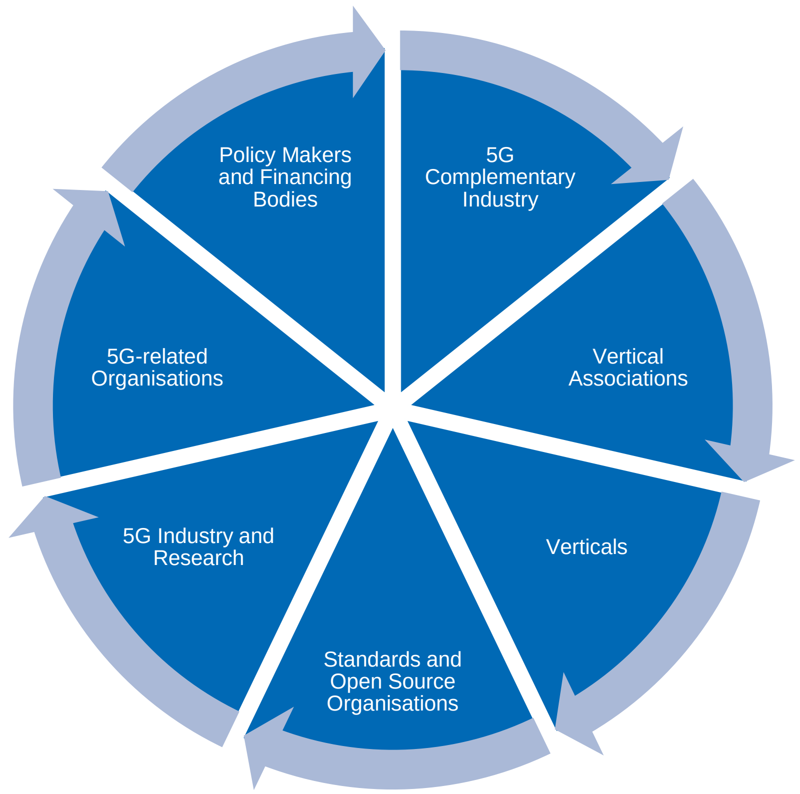

Figure 5-5: 5G main target stakeholders [260]

Along the same line, the 5G provisioning and vertical ecosystems were suggested by [262]. This was to better separate and study the innovation and competitive dynamics created by 5G within the traditional telecommunication supply chains, and within specific vertical industries and the information and operational technology (IT, and OT) sector, and in turn, between them all.

The 5G provisioning ecosystems comprises stakeholders which are creating, delivering, and capturing value directly from 5G – and next 6G – technologies [263]. They are such as Communication Service Provider, Network Operator, Hardware and Software suppliers, and Datacentre Service Providers. The vertical ecosystem providers act as users and customers of 5G technologies and integrate them into solutions which are composed of resources from many domains [262].

Stakeholders in the 5G vertical ecosystem can be regarded as complementors to the 5G provisioning ecosystem, and thus, they are mutually dependent in value creation and capturing. Specific vertical ecosystem stakeholders such as Machine builders or High-definition map providers belong to the OT sector. More generic stakeholders from the IT sector are Computer consultancy activity, System and Software integration, or Data processing and hosting.

6G will continue the disaggregation and programmability with e.g., network functions virtualization that 5G kicked off and allow both technologies and ecosystems to take new paths, enable sustainable and profitable growth as well as innovation. New architectures and operability may also lead to disruptions, failures, or dysfunctions. For instance, we have already seen how global cloud providers such as AWS are entering the 5G domain as potential disrupters [264]. A 6G vision is to enable local communications and compute, including device-to-device communication [265]. This may challenge the current central control and operation of devices in a mobile network, however, will bring benefits from enabling offloading procedures and compute which in turn allows implementation of functionalities in any network node. The combination of edge computing and local device connectivity may create completely new constellations, e.g., at manufacturing or emergency sites, and entertainment events. This may be part of further ecosystem analyses.

Moreover, the abovementioned 5G PPP stakeholder picture does not capture stakeholders who are humans, e.g., consumers or otherwise affected by a technology. Neither does the picture elaborate on those who hold stakes in more specific sustainability objectives for such topics as climate and trustworthiness. Spectrum stakeholders are not detailed. The 6G ecosystem must address such stakeholders, as sustainability, societal value, and fair spectrum allocation are key concerns in a preferred future ecosystem. The next chapters sketch emerging stakeholders in these domains, and their interests.

5.3.4 Emerging ecosystem stakeholders from Environment and Social domain

The indisputable call for sustainability has introduced an expectation that the implementation of 6G technologies shall answer to goals for environmental and social values and sustainability. In parallel over the past years, 5G has created a stir amongst cities or smaller areas. Citizens, local authorities, and non-governmental organizations have shown more and more concerns for new network generation, and subsequently [266], will probably show similar concerns for 6G. The entities calling for sustainability are thus important 6G stakeholders, and moreover, the new goals involve stakeholders on all levels of society.

One difficulty to consider for future dialogue or discussion with this category of stakeholders is their lack of knowledge on this sharp technological topic. One of the challenges and drivers will be to be able to deliver simple and clear information on 6G technologies.

Institutions and authorities may have stakes in 6G deployment, locally, regionally, and internationally, in rural and urban areas. They influence the deployment of technologies and infrastructures in their territory. Their needs may be stretched between developing territories to remain attractive for economic development, and catering to their citizens among whom some are already sceptical to 4G and 5G benefits. Local authorities may be more dependent on citizens' adherence to investments than central government, and thus, must be more receptive to citizens' perceptions and reactions.

Citizens is an important stakeholder group, which also will be stretched between contradictory concerns. They could fear health issues from design and deployment of 6G specifications and infrastructure [267], and issues from operation and use of 6G such as security of data and mass surveillance [268]. On the other side, citizens could acknowledge benefits such as digital inclusion through equality in access.

Following the above logic, democratic institutions are increasingly becoming stakeholders. The 6G deployment is expected to enable use cases impacting on society, thus, expectations to democratically handling of choices could increase among citizens and local authorities. Therefore, the European Union, as one institution, could be proactive in laying down a legal framework for use cases related to such as environmental resources, possible mass surveillance, and social credit.

Just as the public is currently questioning the applications of artificial intelligence and its desirable ethical and legal framework, it is likely to have the same expectations of 6G. Just as there are ethics committees on AI (in EU, countries, and companies), so there could be on 6G.

Moreover, non-governmental organizations (NGO) and local associations should also be considered as stakeholders, as "organized citizens" who may be able to carry out commission impact studies or to push their claims and demands. Their concerns could be both "in favour of" or in "disfavour of" the deployment of 6G or 6G use cases.

Think tanks either from NGO, public institutions or private companies can also be considered as stakeholders insofar as they can analyse and question the political, environmental, and societal issues raised by a new technology. The shift project is one famous example of think tank in France influencing public opinion on energy transition issues [269]. Moreover, research institutions and universities might identify new fields of research embracing societal and environmental issues related to technology.

Eventually, the media can relay and even amplify possible controversies related to the technology and play an influential role in the way they present and explain 6G technology to the citizens. There is clearly a big issue of what to say about the 6G technology and how to present the information.

The call for sustainability is not only a new set of requirements to adhere to, for those developing and putting a 6G technology into operation. It comes with a whole new set of stakeholders in the larger ecosystem, which must be understood and catered to. The potential tensions between different preferences must be addressed, as well as how stakeholders in sustainable-friendly ecosystems must be heard and allowed impact.

5.3.5 Spectrum allocations and ecosystem perspectives

Spectrum is the natural resource applied by all radio technologies to transmit wirelessly, including connecting mobile devices to a network. Thus, it is a valuable and scarce resource from technological, business, and economies' points of views, and the allocation of rights is highly regulated. Thus, spectrum and the 6G ecosystem will be discussed in the light of new goals for social, environmental, and economic sustainability.

Nevertheless, spectrum requirements - and their subsequent allocation – are first and foremost derived from use cases. In this context we focus on four different frequency ranges: spectrum that is already available today for 5G services in FR 1 (starting below 1 GHz up to 7 GHz) and FR 2 (24–71 GHz) as well as further frequency ranges that are currently discussed, 7–15 GHz and 92–300 GHz (sub-THz). The closer to currently used bands, the greater the possibility of reusing the existing base station grids and the lower the number of required new sites, costs, and power consumption for delivery of services. The higher the frequency range, the more bandwidth is usually available and can reach up to multiple contiguous GHz at sub-THz frequencies. However, due to the physical constraints in RF propagation, sub-THz will target localized use cases. As a result, this reduces the need to license spectrum nationwide in the sub-THz range. Figure 5-6: tries to visualize the trade-offs.

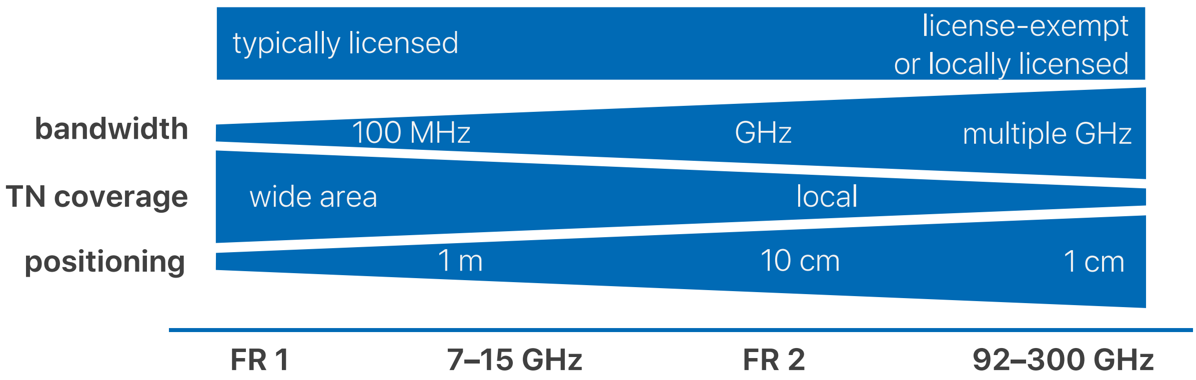

Figure 5-6: Frequency Ranges Currently Under Discussion

An initial set of Hexa-X-II use cases is available and introduced in chapter 6 of this document. It has been collected from the set of use cases of the predecessor project Hexa-X and will be amended and extended during the first year of the Hexa-X-II project. Hexa-X use cases capture a fundamental customer need or a key service opportunity, motivate 6G key capabilities, like fully immersive experience or connected intelligence, and draw upon key values, such as trustworthiness. The full Hexa-X use case specification also foresees deployment aspects as well as functional and performance requirements [231] [234].

Stakeholders like network operators or equipment manufacturers will base their economic opportunity and technical requirement analysis on accurate and instructive deployment scenarios. Those deployment scenarios are often exemplary and not necessarily comprehensive, and spectrum requirements need to be specified in (more) detail. The new Hexa-X-II use case format will be shaped accordingly. As a guideline, we provide in the next chapter 6G goals for spectrum use.

5.3.6 6G goals for spectrum use

When we look at what spectrum (which bands, what bandwidths, which licensing regime, etc.) is needed for 6G, we first need to have a look at the goals that 6G needs to achieve. Goals identified, but not limited to, are as follows:

- **Provide additional capacity:** with ever growing use of mobile communication, 6G needs to provide more capacity along all dimensions. Ideally the spectrum to be made available will be enough to accommodate the required use cases using the existing grid of base stations, reducing the cost of identifying, acquiring, and deploying additional base station sites by operators.

- **Support high data rate services:** new services such as XR and holographic presence require the support of high data rates. For high data rates, large bandwidths are needed. These large bandwidths are typically easier to find in higher frequency ranges.
- **Support mobility:** most applications of mobile communications need mobility. We see that in 6G this mobility requirement may be combined with increasingly high data rates. Spectrum is needed that can combine high data rates and the continuous coverage that is required for mobility.
- **Support wide area coverage:** the goal to make 6G inclusive, implies that 6G should be available everywhere, and with service continuity (when user/device is moving). For wide area coverage, lower frequency ranges are more suitable due to radio wave propagation characteristics. In addition, the deployment of Non-Terrestrial Networks might be a supplement to wide area coverage provided by terrestrial networks
- **Provide indoor coverage:** new high data rate applications like mobile AR/VR communication and gaming are expected to also be used indoors, increasing the volumes of indoor mobile data. Indoor coverage can be delivered in different ways:
  - **Outdoor to indoor coverage:** here, indoor coverage is provided from outdoor base stations, possibly with the use of relays (repeaters) to improve indoor coverage. Lower frequency ranges are preferred, as the higher the frequency range is, the more walls and windows are attenuating the radio signals.
  - **Indoor to Indoor coverage:** here, indoor base stations are used that e.g., are connected to fixed fibre networks. Even though higher frequencies may be used, still the indoor environment can result in coverage blocking from walls/furniture/people. At high frequency ranges, it may be required to have a base station in every room. Reflective surfaces may be useful to circumvent blocking.
- **Service continuity:** mobile data applications increasingly require seamless continuation of connectivity travelling across e.g., outdoor-indoor, urban-rural, private-public situations. Currently, the device is configured to decide the handover between e.g., cellular and Wi-Fi networks [270].
- **Enable positioning and sensing:** 6G will have to support ever more accurate positioning. This positioning can be based on base stations or on dedicated beacons, or on combinations of all available methods, including satellite based, triangulation, observed time difference of arrival etc. Joint sensing and communication may be new technology advancements in 6G. For sensing, both base stations and mobile devices can be transmitters and/or receivers. In general, higher frequency ranges imply more accurate positioning and sensing.

5.3.7 Spectrum ecosystem stakeholders

Having use cases, verticals, providers, and the goals for 6G in mind, we presume that the following players will continue to be significant stakeholders in the 6G spectrum ecosystem.

Telecom operators will continue to play a key role for mobile networks during the 6G timeframe. Existing networks in frequency ranges below 6 GHz are expected to migrate to 6G in the future and thus, similar to previous generations, 6G is expected to be deployed in the same frequency bands as used for earlier generations. Large wide area coverage can be achieved using sub-GHz spectrum and the frequency range 1-6 GHz can be used for coverage and capacity. New advanced 6G radio technology should make it possible to also use spectrum in the 7-15 GHz range on existing base station grids. This will make these frequency bands attractive for use by telecom operators to provide 6G coverage and capacity.

Stakeholders deploying private networks and specific purpose networks, starting with 4G, and continuing with 5G include telecom operators and others. For example, 3.4-3.8 GHz is the core band for 5G public networks in many markets. Public-network-integrated non-public-networks (PNI-NPN) might share RAN and spectrum with the public network. Stand-alone NPN (S-NPN) are often deployed in dedicated spectrum (3.8-4.2 GHz). It can be expected that further spectrum made available for 6G will also be of interest for such use. For spectrum above 100 GHz, the very short communication ranges potentially allow reuse of the same spectrum in the same area, hence could be of interest in this case.

Network vendors, software vendors and/or system integrators: New 6G hardware and software elements need to be added to enable 6G services. Deployment of 6G in new frequency bands does not require backwards compatibility to earlier system generations. For existing frequency bands, migration solutions to ensure soft re-farming to 6G may be required. Network deployments may be "global" or local, and a variety of operator models can emerge.

End User Equipment Manufacturers: 6G will play an integral role in many end user devices. Still, devices are likely to include a multitude of wireless technologies enabling a large variety of applications. Many frequency ranges are already allocated to mobile services in certain geographical regions. Regional or global frequency band harmonization and allocation will benefit the 6G ecosystem as scale will be bigger, bringing down cost.

Incumbent users: There is a variety of incumbent services and applications in the frequency range 7-15 GHz. Parts of this range are envisaged for 6G. These incumbents include both primary and secondary services and will need to be considered accordingly.

Regulators will play a crucial role in enabling 6G by making spectrum available for 6G and assigning spectrum access rights to those requesting them.

Building owners demand indoor coverage in their home, office, factory, or other building even where coverage from outside public mobile networks is a challenge. Because they see indoor coverage as crucial, they are also prepared to invest in Wi-Fi networks, private networks, or indoor cellular solutions. Which of the available solutions these building owners chose determines the deployed frequency range and spectrum access mechanisms. Note that building owners can be both those that carry out a specific activity in the building, e.g., hospitals and manufacturer, and professional building owners renting premises.

Neutral hosts' idea is to build and operate an (indoor) radio networks and rent capacity to network operators. Neutral hosts deployed solutions would determine spectrum use. This is a role that might add on to the other role but is strictly speaking not mandatory.

5.3.8 Spectrum Discussions in the Context of 6G Ecosystem

There are some topics up for discussion, in the current and emerging spectrum allocation landscape with spectrum goals and stakeholders with ambitions on behalf of use cases, businesses, society, and the environment. We presume that some of negotiations will circle around allocation of new frequency bands or re-allocation of existing frequency bands, licensing of spectrum and understanding which positions stakeholders may take. Not the least, we will need to understand if and how spectrum has a climate dimension. Here, we present the contexts of such negotiations, some perspectives of significant stakeholders, and open questions.

Upcoming spectrum discussions at WRC-23 and WRC-27

The next World Radio Conference (WRC) is convened in Dubai from 20 November – 15 December 2023, [271]. While for WRC-23 here is no explicit 6G Agenda Item, two of the Agenda Items (AI 1.2 and 1.3) under discussion at WRC-23 are the possible identification of more frequency bands for International Mobile Telecommunications (IMT) services, namely: 3300-3400 MHz, 3600-3800 MHz, 6425-7025 MHz (ITU region 1 only, i.e., including Europe), 7025-7125 MHz (globally) and 10-10.5 GHz. The other Agenda Item (1.5) of interest at WRC-23 is to review the spectrum use and needs in the band 470-960 MHz and consider possible regulatory actions between 470-694 MHz in Region 1. This is likely to be about the 700 and 800 MHz, so-called Digital Dividend bands (DD, DD2). The next step in refarming may also concern broadcast frequencies to mobile use and 'release' of the 600 MHz band.). We expect a focus on 6G frequencies at the following WRC-27. The agenda will be decided this year. The findings of Hexa-X-II project will play an instrumental role in defining an agenda item for WRC-27 [272, 273, 274].

Spectrum licensing conditions

The access to spectrum affects how radio technology is designed. Two major spectrum access models include: 1) defining spectrum property rights that are awarded through market-based or administrative allocation mechanisms; and 2) the unlicensed commons where the spectrum is given without requiring a license authorization. While at lower frequency ranges ensuring re-use of the same frequency band in the same area is a complex task this becomes less of a hurdle at very high frequency ranges. There, the use of antenna arrays and beamforming facilitates [275] concurrent use of the same frequency in the same area. This makes it a prime enabler for technical sharing mechanisms, local license, or unlicensed usage, depending on the use case requirements, in particular for ranges above 92GHz. Overall, unlicensed use of spectrum presents a lower hurdle for operations by end users and small or private networks. The question to ask, may then be how spectrum affects the 6G radio and network design, which again depends on the foreseen use cases. Historically there has been a close link between identifications of frequency bands for IMT and exclusive licensed spectrum access. In sub-THz frequency ranges a local license or license-exempt regulatory framework may be more appropriate.

An example of how frequencies ended up as licensed and license-exempt are between mobile telecommunication- and Wi-Fi technologies. These industry segments are not only different due to spectrum regimes but evolved to rely on different business models to finance technology and market development. Those different industry segments are expected to position themselves for both keeping and expanding their spectrum use and demands in the 6G timeframe.

Spectrum and climate change

Does spectrum have a climate dimension? That is the question which the EC has asked its Radio Spectrum Policy Group (RSPG) [276] to find out. An opinion published in 2021 discusses this issue, and points to some dependencies. It is not so that any bands, by nature, are more climate friendly than others, but it points to issues like tower/network grid sharing, suitability of certain frequency bands for coverage and capacity and contiguous bandwidths instead of aggregating multiple narrower bandwidths from separate frequency bands as factors to reduce energy consumption (and carbon footprint) through equipment operating more energy efficiently. A consultation was open until 12 April 2023 on the issue [277].

6 What do identified Drivers and Goals mean for the Use Cases?

6.1 Introduction

In the recent years, we have seen a new concept of Corporate Social Responsibility (CSR), where leading companies in this area have started to realize the importance of creating real social impact as a consequence of their core business and not only due to sporadic "charity campaigns". This has led to value-based design thinking, where companies try to ensure that the solutions, they bring to market, contribute in terms of values to both individual customers but also the wider society. An example of this new conception of CSR, is the inclusion of sustainability from environmental, economic, and social values (incorporating inclusiveness and trustworthiness) as an overarching element of the 6G value proposition. Accordingly, in Hexa-X-II, we will analyse the impact of 6G stakeholders' expectations in that 6G values influence their core business; from influencing drivers and use cases, to defining requirements and technology solutions.

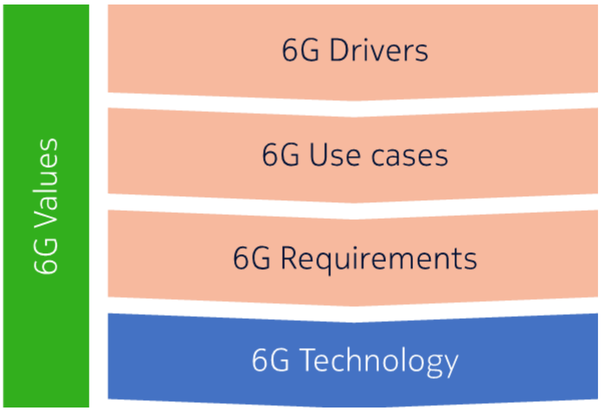

Figure 6-1: Influence of 6G Values on 6G Drivers, 6G Use Cases and 6G Requirements and Technology

6G values should be directly influencing 6G drivers in many cases. One example is to offer improved means for surveillance of national parks to aid biodiversity preservation. There is a clear and direct connection between 6G values and the driver of a use case, as well as between the 6G values and requirements on solutions with the value being improved chances of a successful preservation of certain species.

Use cases may have other main drivers. An example of such a use case can be, e.g., introducing technology support for offering advanced gaming applications in wide areas.

While it is undeniable that not all 6G drivers derive from environmental, social, and economic sustainability, but also come from pure technology requirements, all use cases must be addressed with value-based design in mind. When looking at both use case examples described above, this means that they need to be achieved having all the 6G values in mind. This means for any use case, that the sustainability aspects need to be considered as requirements of the technology in the sense that negative impacts must be minimized regardless of whether there are (from a sustainability perspective) positive impacts as an output value or side effects of executing a use case.

It is the Hexa-X-II project's mission to create a system blueprint of the 6G platform: which provides technical solutions responding to the 6G vision of merged physical, digital, and human worlds, which enables use cases and services to contribute to environmental, social, and economical sustainability.

The following Chapters 6.2 to 6.5 introduce three use case dimensions and an initial set of use cases selected from Hexa-X, spanning the space of possible 6G use case drivers. Chapter 6.6 concludes on the way forward to derive a complete, coherent, and instructive set of use cases that helps to develop the 6G system.

6.2 Initial Set of Use Cases

Previous generations of mobile radio systems focused on use cases which were driven by technology, aiming to make new technology and functionality available for the end user. In 4G, and mainly in 5G, use cases were driven by needs and challenges of a vertical business branch and providing tailored solutions to them. Examples are vehicular communications, smart industry, agriculture, or education. In 6G, the Hexa-X-II project introduces a new dimension of use cases, i.e., use cases driven by sustainability. Going even deeper, the Hexa-X-II project differentiates environmental, social, and economic sustainability.

The initial set of use cases provided in this chapter, aims to represent the following three dimensions: technology, verticals, and sustainability. These three dimensions of use cases are not mutually exclusive; meaning that the same use case may have components of all of them while one dimension might be dominant.

The initial set of use cases is based on Hexa-X use cases [231] [234]. The Hexa-X use cases were selected to represent real-life applications of the physical, human, and digital worlds, to support one or more applications of these three worlds, and to apply to one or more verticals.

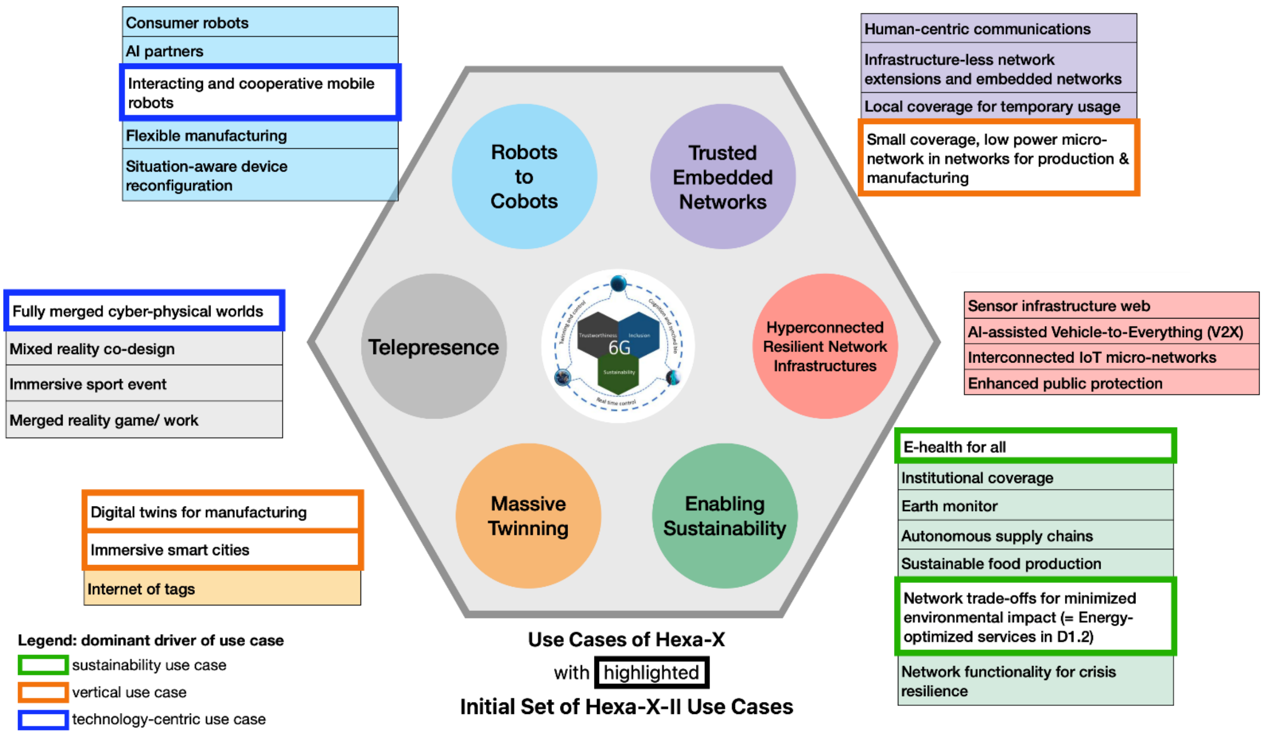

Figure 6-2: Initial set of Hexa-X-II use cases highlighted in the well-known representation of Hexa-X use cases

In Hexa-X sustainability refers only to environmental sustainability. Nevertheless, as shown in this document, Hexa-X-II goes beyond extending environmental sustainability and adding to the study societal and economic sustainability. These changes will also reflect in the future set of use cases of Hexa-X-II, which will aim to be completed in D1.2. In addition, in Hexa-X-II, sustainable values are not isolated to a single type of use case, instead they should be integrated and studied in all use cases with respect to both: positive and negative impact.

One of the objectives of Hexa-X-II is to help to not only achieve 6G for sustainability but as well to define sustainable 6G. Furthermore, the introduction of sustainability and the extension on the other use cases may come with changes on the use cases families. Nonetheless, this is not covering all use case aspects. To have a complete, coherent, and instructive set of use cases that helps to develop the 6G system we need to answer the questions in the following chapters.

For the initial set we have selected two technology-centric use cases (interacting and cooperative mobile robots; and fully merged cyber-physical worlds), three vertical use cases (digital twins for manufacturing;

immersive smart cities; and small coverage, low power micro-network for production & manufacturing), and two sustainability use cases (e-health for all; and network trade-offs for minimized environmental impact). These initial use cases are highlighted with blue, orange, and green boxes in Figure 6 2, respectively.

In the following, we provide a description for each use case and give details on their objectives, research challenges, as well as technologies, and sustainability drivers.

6.3 Sustainability Use Cases in Initial Set

This category contains use cases whose strongest motivation is sustainability driver(s). While E-health for all has aspects of a vertical use case and uses Digital Twin technology for an advanced implementation, the dominating drivers of this use case are the UN SDG health goals as well as inclusion and trustworthiness. Similar: Network trade-offs for minimized environment impact is directly motivated by environmental sustainability. Neither are novel technology enablers pronounced nor do we characterize this use case as vertical.

6.3.1 E-Health for All [234]

Description

- Improving access to healthcare and reducing premature mortality are among the main targets of UN SDG#3. The stakes are specifically high in areas with limited access to healthcare infrastructure. The use case globally encompasses new services offered in these areas, so that access to a minimum set of E-health services should be guaranteed everywhere through trustworthy connections, such as virtual medical consultation or local E-health hubs with remote access to medical experts.

Objective

- Improved access to healthcare infrastructure and (new) healthcare services.

6G Research Challenges & Technologies

- Extending service accessibility with heterogeneous connectivity solutions.
- Digital twins for the provisioning of health services.

Sustainability Drivers

- Social sustainability:
  - Inclusion: United Nations Sustainable Development Goal (SDG#3) of Ensure healthy lives and promote well-being for all at all ages; target 3.8, i.e., achieve universal health coverage.
  - Trustworthiness: supporting the development of effective, accountable, and transparent institutions at all levels.

6.3.2 Network Trade-offs for Minimized Environmental Impact (Energy optimized Services in [231])

Description

- For most usages, different levels of Quality of Service (QoS) can be achieved, depending on the trade-offs between performance and the environmental impact. The user will be able to select their preferences, accepting that for predefined cases, the quality of service will not be maximized in order to minimize the environmental cost.

Objective

- Enable tuning of the 6G network towards a targeted trade-off between Quality of Experience (QoE) and environmental sustainability.

6G Research Challenges & Technologies

- Extending service availability: in an environmentally sustainable way by supporting different QoE service levels.

Sustainability Drivers

- UN SDGs were not explicitly stated in [231] or in [234] for this use case. It is nonetheless concerned with E2E energy consumption and E2E environmental cost or impact.

6.4 Vertical Use Cases in Initial Set

This category refers to use cases whose strongest motivation is a vertical business branch or an industrial segment requiring a tailored solution. Both manufacturing and city infrastructure management are classical vertical segments.

6.4.1 Digital Twins for Manufacturing [234]

Description

- Digital Twins provide a full digital representation of the industrial environment and will be increasingly used in the manufacturing area to improve the efficiency and agility of the production processes (e.g., by enabling dynamic adaptations of the process and reconfigurations of the resources) or adjust to critical situations (by simulating the situation and testing possible solutions) to meet the extreme reliability requirements.

Objective

- Optimize efficiency, dependability, and productivity in Industry 4.0 manufacturing

6G Research Challenges & Technologies

- Digital Twin (DT) as a virtual replica of a physical asset or a process that connects to and receives data from the “real twin” will enable a real-time and accurate digital representation of the manufacturing environment.

Sustainability Drivers

- Environmental sustainability: UN SDG#12: Responsible consumption and production by optimizing the industrial manufacturing process.
- Economic sustainability: UN SDG#9: Industry innovation and infrastructure. For instance, by increasing the resilience of the production infrastructure by the DT-based analysis of the impact of disturbances and related mitigation strategies.
- Economic and social sustainability: UN SDG#8: Decent work and economic growth by exploiting the DT-based data analysis for higher productivity and higher safety on manufacturing sites.

6.4.2 Digital Twins for Immersive Smart City [231]

Description

- Digital Twins can also be applied to different environments such as the management of city infrastructure. It encompasses the management of the different networks and utilities such as gas or heating, traffic handling and management of city services such as garbage, public transports, or parking. Mapping of the different networks and infrastructures will facilitate their management and facilitate the prevention of risks.

Objective

- Management of infrastructure, resources, utilities, and social life of digitally transformed cities.

6G Research Challenges & Technologies

- Massive Digital Twin technology to manage city infrastructure and utilities, environmental resources like air or water, and social aspects incl. healthcare, education, culture, stability, and safety.
- Massive Digital Twin technology to assist planning of future immersive smart cities.

Sustainability Drivers

- Environmental and social sustainability: UN SDG#11: Make cities and human settlements inclusive, safe, resilient, and sustainable.
- Environmental sustainability: UN SDG#6: Clean water and sanitization.

6.4.3 Small Coverage, Low Power Micro-network in Networks for Production and Manufacturing [231]

Description

- Machine manufacturers might want to mutually connect a large population of sensors in their machinery with very low-power devices and very limited coverage as an underlay network, potentially with sensing devices getting authorization from the public or private network. A key aspect of this vertical use case is its relationship to flexible spectrum access concepts.

Objective

- Enable energy- and spectrum-efficient production and manufacturing.

6G Research Challenges & Technologies

- Sensing: a sensor network with a sensor root node.
- Networks-in-network (sub-networks): an underlay model for a small coverage micro-network.

Sustainability Drivers

- Economic sustainability: UN SDG#9: Industry innovation and infrastructure by enabling the embedding of a sensor sub-network into a public or private network.

6.5 Technology-centric Use Cases in Initial Set

This category refers to use cases whose dominant characteristic is an underlying technology which is novel and/or challenging like in the case of the fully merged cyber-physical worlds use case.

6.5.1 Fully Merged Cyber-physical Worlds [234]

Description

- The generalization of mixed reality and holographic telepresence will transform the interactions between people, offering a quality of interaction between distant persons nearly similar as if located in the same place. This improved Quality of Experience (QoE) facilitates the collaboration between workers as well as the social interactions. Improved QoE will benefit various sectors such as education.

Objective

- Transforming interaction and collaboration in various vertical sectors of production, work, education, and social life.

6G Research Challenges & Technologies

- Extreme experiences: enhanced quality of experience using immersive telepresence technology.
- Sensing and connected intelligence: establishing context-awareness for telepresence.

Sustainability Drivers

- Fully merged cyber-physical worlds or immersive telepresence technology are used in many vertical sectors, accordingly key values will vary with the actual application sector.
- Social sustainability - inclusion:

  - improved student-teacher interaction draws upon education quality and availability linked to UN SDG#4 Quality education and the capability of remote interaction draws upon the UN Target#3.8 Access to quality healthcare services.
  - capability of remote interaction may also reduce energy consumption and carbon footprint from commuting and traveling UN SDG#13 Climate action.
- Environmental sustainability: the capability of remote interaction may reduce energy consumption and carbon footprint due to commuting and traveling and refers to UN SDG#13 Climate action

6.5.2 Interacting and Cooperative Mobile Robots [234]

Description

- The presence of robots will increase and extend, beyond the manufacturing and production sectors, in other sectors and even in everyday life at home. These robots will have to interact and collaborate to perform their assigned tasks in an assembly line for instance.

Objective:

- Mobile robots which learn from humans interact mutually and with the environment

6G Research Challenges & Technologies

- Interacting robots, or cooperative and cognizant robots (“cobots”), mutually interact as well as with the (fixed) environment; humans and robots interact directly or indirectly, and robots learn from humans: for productivity increase if in an industrial environment, for every-day life improvement in a private home, to mention two examples.

Sustainability Drivers

- Economic sustainability (industry environment): UN SDG#9: Industry innovation and infrastructure.
- Economic and social sustainability (industry environment): UN SDG#8: Decent work and economic growth.
- Social sustainability (home environment): UN SDG#3: Good health and well-being.

The fact that Hexa-X-II differentiates environmental, social, and economic sustainability will reflect in the future set of Hexa-X-II use cases to be completed in the subsequent deliverable D1.2. In addition, in Hexa-X-II sustainability values are not isolated to a single type of use case, instead they should be integrated and studied in all use cases with respect to both: positive and negative impact.

Furthermore, it is an objective of Hexa-X-II to not only achieve 6G for sustainability but as well to define sustainable 6G. Finally, the introduction of three sustainability categories and the extension to other use case categories may come with changes on the use cases families. Nonetheless, this is not covering all use case aspects. To have a complete, coherent, and instructive set of use cases that helps to develop the 6G system we need to answer the questions following in chapter 6.6.

6.6 Way Forward on Use Cases in Coming Deliverables

As the world becomes increasingly interconnected, the demand for faster and more reliable mobile network connectivity continues to grow. In order to meet these demands, the development of 6G technology is currently underway. However, to truly understand the potential value of 6G, it is important to first answer three fundamental questions.

The first question is "What end user need are we addressing?" It is essential to identify a specific need that 6G can address to determine its potential value. A considerable amount of use cases has already been formulated for 5G. 6G will take over where 5G could not fully deliver and will improve further. As an example, 6G takes environmental impact to the next level. This may make a use case that was technologically viable before also economically viable now. In addition, 6G potentially solves the issue of providing connectivity to underserved areas and populations, where fibre deployments are not commercially viable, at a reasonable cost and with a lower environmental impact. By clearly identifying the need, it becomes easier to determine the potential value of 6G.

The second question is "Why are current technologies not enough to solve the problem?" Understanding the limitations of current technologies is key to understanding the potential value of 6G. For example, while 5G technology has greatly improved key network performance parameters such as throughput, latency, or position accuracy, it still may face issues with more demanding applications like use of collaborative robots in industrial environments or real-time digital twins for manufacturing deployed at large scale. By understanding the shortcomings of current technologies, we can better understand the potential value of 6G in addressing these issues.

The third and final question is "What innovations should 6G bring?" It is important to identify how 6G technology may bring new innovative capabilities beyond improving performance of previous network parameters standards, in order to provide an enhanced solution to the identified problem. For example, 6G technology could potentially leverage sensing capabilities to provide enhanced user experience in a remote virtual education environment.

In addition to solving specific problems, the value of 6G is also driven by stakeholder perception of its ability to address the key values of sustainability. The challenge to meet these key values should influence not only the customer problems being addressed as can be seen from several of the above-described examples, but also the way the problem is being solved. For example, by prioritizing solutions that allow more energy efficient network operations, 6G technology will be perceived as more valuable in addressing the issue of climate change.

In Hexa-X-II we will propose an enhanced methodology to analyse 6G use cases anchored on a deep understanding of the specific problems to be solved, the limitations of current technologies, and use of innovative capabilities, to ensure appetite for new 6G services is clearly present from the early days of 6G deployments. A first attempt to this enhanced methodology will come from the proposed new use case “format” that will be delivered in the subsequent deliverable (D1.2).

Based on identified drivers and goals and following a first analysis of available use case formats within the Hexa-X project [13], 3GPP [9], NGMN [11] and NGA [12], the new use case format will describe: family clusters, value in addressing end user needs and sustainability goals, gaps of 5G, scenarios and examples, deployment characteristics (i.e., network, spectrum, environment, devices and users, content, and application), and functional requirements, and KPIs.

Finally, this methodology will ensure that the key values of environmental, social, and economic sustainability are well reflected, both in the selection of the Hexa-X-II use cases and in the way identified issues are being solved.

7 Sustainability Guidelines for 6G Design

This chapter provides a wrap up of chapter 5 “Drivers and Goals for 6G” and chapter 6 “What do identified Drivers and Goals mean for the Use Cases?”. This synthesis are guidelines on environmental, social and economic sustainability that the 6G design should take into account. It furthermore sums up the initial set of use cases for 6G. All this output is aimed at providing input to the other (technical) Work Packages (WP) of Hexa-X-II, mainly the WP on end-to-end design.

The design of 6G should consider all three pillars of sustainability, namely economic, social, and environmental, in an interdependent manner to promote a sustainable future for everyone. This is to ensure that the development of 6G is environmentally, socially, and economically responsible, equitable, and accessible to everyone, regardless of their location or socioeconomic status.

7.1 Guideline for Environmental Sustainability

As part of the efforts towards creating a sustainable future, it is imperative to create a more sustainable and resilient communication system that supports economic development while minimizing harm to the planet. Instead of relying solely on pre-existing technologies to achieve optimal absolute performance, as previous generations have done, 6G technology design should incorporate environmental sustainability considerations in the planning, architecture, and operation of networks.

- **Holistic footprint approach:** 6G networks will have several different footprints, including carbon, water, resources, and land footprints, which will have different environmental impacts. A holistic and comprehensive approach to the different footprints, as well as the different trade-offs between different sustainability factors need to be considered from an LCA approach in the design of 6G infrastructure and operations.
- **Alternative materials:** Hazardous substances should be avoided in the production of 6G network components. This could involve complying with Restriction of Hazardous Substances (RoHS) Directive 2002/95/EC [278] and Registration, Evaluation, Authorisation, and restriction of chemicals (REACH) Directive 1907/2006 [279] regulations and using alternative materials.
- **Modular and durable equipment:** Design 6G equipment to be modular and durable allowing for extended lifespan, easier customization and scalability while also reducing waste generation, downtime, and improving reliability.
- **Energy Efficiency:** As significant increases in future traffic are expected and could lead to higher power consumption, the design of 6G technology should prioritize energy efficiency and minimize overall energy usage, both in its production and operational phases. This includes the use of low-power components, optimization of network architecture and protocols, and implementation of energy-efficient algorithms and energy-management systems. The implementation of certain strategies in the devices production chain and data centres, such as the use of more renewable electricity, reducing the amount of fluorinated gases, optimizing equipment and processes, and conserving energy and water should also be key considerations in the design of 6G.
- **Cloud Computing and Automation:** The operation design of 6G may reduce energy consumption of networks by edge computing, which involves moving the processing power from the cloud to a location closer to the end user or device. This results in a reduction in the total amount of data that travels through the network. Other automated and intelligent systems allowing to manage the on/off states of networks and devices to match demand should also be implemented.
- **Circularity practices:** Achieving circularity requires a fundamental shift in the way equipment and devices are designed, produced, consumed, and disposed of, and requires action from all stakeholders. 6G network production and operation should adopt circularity practices through renewable resources such as bioplastics and green energy. Reusing, refurbishing, recycling, and repairing components can make it simpler to recover component parts to produce new equipment. Plan for responsible end-of-life disposal of the technology by designing equipment that can be easily disassembled and recycled.

7.2 Guideline for Social Sustainability

Social sustainability is comprised of two main aspects: Trustworthiness and digital inclusion. Based on the analysis is the previous chapters, the following main drivers have been identified:

- 6G solutions and networks need to be cyber-secure and respect end-users' privacy.
- AI-based approaches need to be clear, transparent and keep the human in the loop so that accountability, and thus trust, can be maintained.
- 6G networks need to be flexible and adjustable in terms of capacity and coverage depending on the areas and the end-users' characteristics, as well as the criticality of the offered solutions, e.g., ehealth aspects vs. entertainment.
- 6G solutions need to be non-discriminatory, e.g., consider IT literacy and culture of all types of end-users; and
- 6G network availability in terms of both coverage and capacity need to be ensured at certain levels so as to maintain people's trust in digital capabilities and services.

7.3 Guideline for Economic Sustainability

Economic sustainability perspective identified the following six drivers and goals for 6G:

1) **Value-based 6G design:** 6G should be designed in a manner that it brings economic value beyond users/buyers more widely to community supporting socially just transition and providing opportunity for different stakeholders to harness converging technologies to create an inclusive, human-centred future.
2) **Sustainable 6G business model innovation:** In the 6G era, sustainability is imperative to economic success. 6G should be developed to solve major sustainability challenges while being sustainable. Sustainability will be the source of value, which is an opportunity for the mobile communication sector to rethink its the existing business models and take sustainability to the core of future business models.
3) **Open value configurations via 6G:** 6G needs to be developed encouraging innovation via open value configurations and sharing economy models which allows stakeholders to innovate and create new collaborative business models for the whole 6G ecosystem while considering security concerns.
4) **Sustainable competitive advantage via correlated/holistic sustainability perspective in 6G:** 6G development needs to identify the complex interdependencies and trade-offs between environmental, social and economic sustainability in order to develop a new correlated sustainability perspective to reach long-term competitive advantage in the new 6G ecosystem.
5) **Monetizing with 6G in challenging business environment:** 6G needs to bring return on investment in different environments including supporting the varying density of users, data and energy usage while operating under increasing environmental sustainability requirements, which calls for different business models.
6) **Preparing for mitigating risks with 6G:** 6G development and deployment need to prepare for protecting stakeholders from the increasing risks in the changing operational environment related to environmental, social, and business aspects among others.

These guidelines influence our 6G design in two ways: how to use 6G and how to develop 6G. Details for above are found in chapter 5 and overall conclusion is that new technology and stakeholders will demand new business models for a sustainable 6G in order to be relevant players in the markets of 2030s.

7.4 Guideline on Use Cases

6G values will directly influence 6G drivers in many cases. There is a clear and direct connection between 6G values and the driver of a use case. While it is undeniable that not all 6G drivers may be mapped to sustainability values, Hexa-X-II use cases are defined with value-based design in mind.

Previous mobile communication generations focused on a desired functionality for the end user, mobile voice call or mobile broadband internet access, and its enabling technology. Whereas in 5G, a second use case dimension was introduced to capture the requirements of verticals such as vehicular-2-everything (V2X) or industrial internet-of-things (IIoT) for which tailored 5G solutions were developed. In 6G, the Hexa-X-II project introduces a third dimension, i.e., use cases driven by environmental, social, and economic sustainability.

We chose an initial set of use cases from the existing Hexa-X use cases reflecting the three use case dimensions: technology, verticals, and sustainability. Accordingly, we selected two mainly technology-centric use cases, one of them being fully merged cyber-physical worlds, three vertical use cases, like digital twins for manufacturing, and two sustainability-driven use cases, for which e-health for all is a great representative.

In the coming deliverables, we will amend and extend the set of Hexa-X-II use cases. For a complete, coherent, and instructive set of use cases that helps to develop the 6G system, we will be proposing a new way of thinking use cases centred around following questions:

1. What end user need are we addressing?
2. Why are current technologies not enough to solve the problem?
3. What innovations should 6G bring?

This enhanced methodology to analyse 6G use cases will be anchored in a deep understanding of the specific problems to be solved, the limitations of current technologies, and use of innovative capabilities, to ensure appetite for new 6G services is clearly present from the early days of 6G deployments.

8 Summary & Next Steps

This document provided a summary of existing guidelines and works on sustainability (cf. chapter 2) and a state of the art for the different definitions which are found (cf. chapter 3). The different trends in environmental, social, and economic sustainability were worked out in chapter 4. These are the trends which are observed for the time being of the production of this deliverable. 6G networks will come to the market in the beginning of the 2030s. It is thus important to project ourselves about 10 years in the future to analyse the current trends in this sense. This leads us to the "Drivers and goals for 6G" as provided in chapter 5. On the other hand, we have an initial set of use cases provided in chapter 6 and reflect the question what those identified drivers and goals mean for them. Finally, in chapter 7 we provide our "Sustainability Guidelines for 6G Design", this is the Hexa-X-II WP1 outcome to be used for all other WPs within Hexa-X-II. As we are at the very beginning of Hexa-X-II, this is a first outcome.

Our next step in WP1 is deep diving into the use cases and use cases families in our next deliverable D1.2 entitled "6G use cases and requirements" which is planned for December 2023. This deliverable will present a consolidated view on use cases and requirements for 6G and first insights on the business and revenue model for 6G ecosystem.

WP1 is then going on to its third deliverable D1.3 "Environmental and societal impacts of 6G" planned for March 2024. It will provide a comprehensive view of the business ecosystem including the identification of key stakeholders. It will provide an analysis of the challenges and risks to meet in environmental, economic, and societal sustainability and give a first view on societal acceptance.

Finally, WP1 closes its work in April 2025 with the deliverable D1.4 "6G Value, requirements and ecosystem". In this deliverable WP1provides a final analysis on the value to be created by 6G for society and people. It encompasses environmental and economic sustainability. WP1 provide in this deliverable the final set of use cases and requirements and the outcome of the various exchanges with the ecosystem.

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