WHITE PAPER ON 6G DRIVERS AND THE UN SDGS

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6G

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White Paper on 6G Drivers and the UN SDGs

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Executive summary

The commercial launch of 6G communications systems and the United Nations' Sustainable Development Goals (UN SDGs) are both targeted for 2030. 6G communications are expected to boost global growth and productivity, create new business models and transform many aspects of society. The UN SDGs are a way of framing opportunities and challenges of a desirable future world and cover topics as broad as ending poverty, building gender equality, the fight against climate change and developing smart cities. The relationship between these potentially mutually reinforcing forces is currently under-defined. Building on the vision for 6G, and a review of megatrends, ongoing studies on the relation of mobile communications to the UN SDGs and existing indicators, a novel linkage between 6G and the UN SDGs is proposed. This linkage is via a set of indicators. This white paper also initiates work on a new set of 6G related indicators to guide research on 6G systems. The novel linkage is built on the envisaged three-fold role of 6G as 1) a provider of services to help steer and support communities and countries towards reaching the UN SDGs, 2) a measuring tool for data collection to help the reporting of indicators with hyperlocal granularity, and 3) a reinforcer of new ecosystems based on 6G technology enablers and 6G networks of networks to be developed in line with the UN SDGs which incorporates future mobile communication technologies which will be available in 2030. Related challenges are also identified. An action plan is presented along with prioritized focus areas within the mobile communication sector technology and industry evolution to best support the achievement of the UN SDGs.

Introduction

1

The United Nation's Sustainable Development Goals (UN SDGs) were introduced in 2015. There are 17 goals included in the Agenda 2030. The agenda itself together with the related targets and indicators form an action plan for achieving the goals. The goals are framed to address global challenges including climate change, poverty and inequality [UN 2015]. The UN SDGs also provide a high-level guide as to how governments and companies should plan their future strategies when striving for sustainable ways to live, produce and consume.

This 6G white paper looks at how 6G research and development are connected to the UN SDGs. In the Vision-chapter, the operational environment of 6G is defined. The starting point is that 6G will open a new era of 'Internet of Intelligence' with connected people, things and intelligence. The UN SDGs are a response to global megatrends which will also affect 6G research and development. In the Megatrends-chapter, the trends concerning the sustainable development of 6G are identified and the effects of these trends are examined. The fourth chapter begins with an outline of prior work which has mapped the linkage between the UN SDGs and ICT or more specifically mobile communications industries. The chapter presents a renewed linkage between 6G and the UN SDGs, as well as identifying relevant indicators. Chapter five identifies technical, regulatory and business-related challenges and obstacles. An action plan is presented to guide the development of 6G and support the linkage between 6G and UN SDGs. Finally, concluding remarks present a set of research questions.

In the first 6G white paper from 2019, all the UN SDGs were identified as important targets for future 6G networks [Latva-aho & Leppänen 2019, p. 5]. The white paper also defined societal and business drivers for 6G using a PESTLE analysis framework (examining political, economic, social, technological, legal and environmental factors). In the current white paper, the connection be-

tween 6G and UN SDGs is further elaborated by investigating the existing linkages between the mobile communications and UN SDGs. 6G brings new opportunities help tackle global challenges, but at the same time all stakeholders should take into account the ethical premises of the UN SDGs.

According to the UN Global Sustainable Development Report 2019 [UN 2019b, pp. xxiii-xxxii], a number of cross-cutting factors, which are relevant to all SDGs, are critical to successfully achieving the "Agenda 2030":

· Obstacles to human well-being and capabilities
· Sustainable and just economies
· Food systems and nutrition patterns
· Energy decarbonization with universal access
· Urban and peri-urban development
· Global environmental commons

The rationale for highlighting these critical success factors (or "entry points") is that progress on all the UN SDGs "will only be achieved if important trade-offs are addressed and transformed" [UN 2019b, p. 27]. The six critical cross-cutting factors should be considered when addressing any of the goals, because it is argued that the goals can only be achieved by adopting a comprehensive approach (See Fig. 1-1). It is important to keep in mind that the advancement of one goal may advance other goals but may also have adverse effects on others. When considering 6G and mobile communications technology and its development, it is important to keep in mind that the developed technology itself should be sustainable and used in a sustainable way. The mobile communications community must pay attention to matters such as overall energy consumption, use of non-toxic materials, environmentally friendly network equipment such as base stations (including locating them where they do not adversely impact the environment), and sustainable supply chains. While not all adverse interactions be-
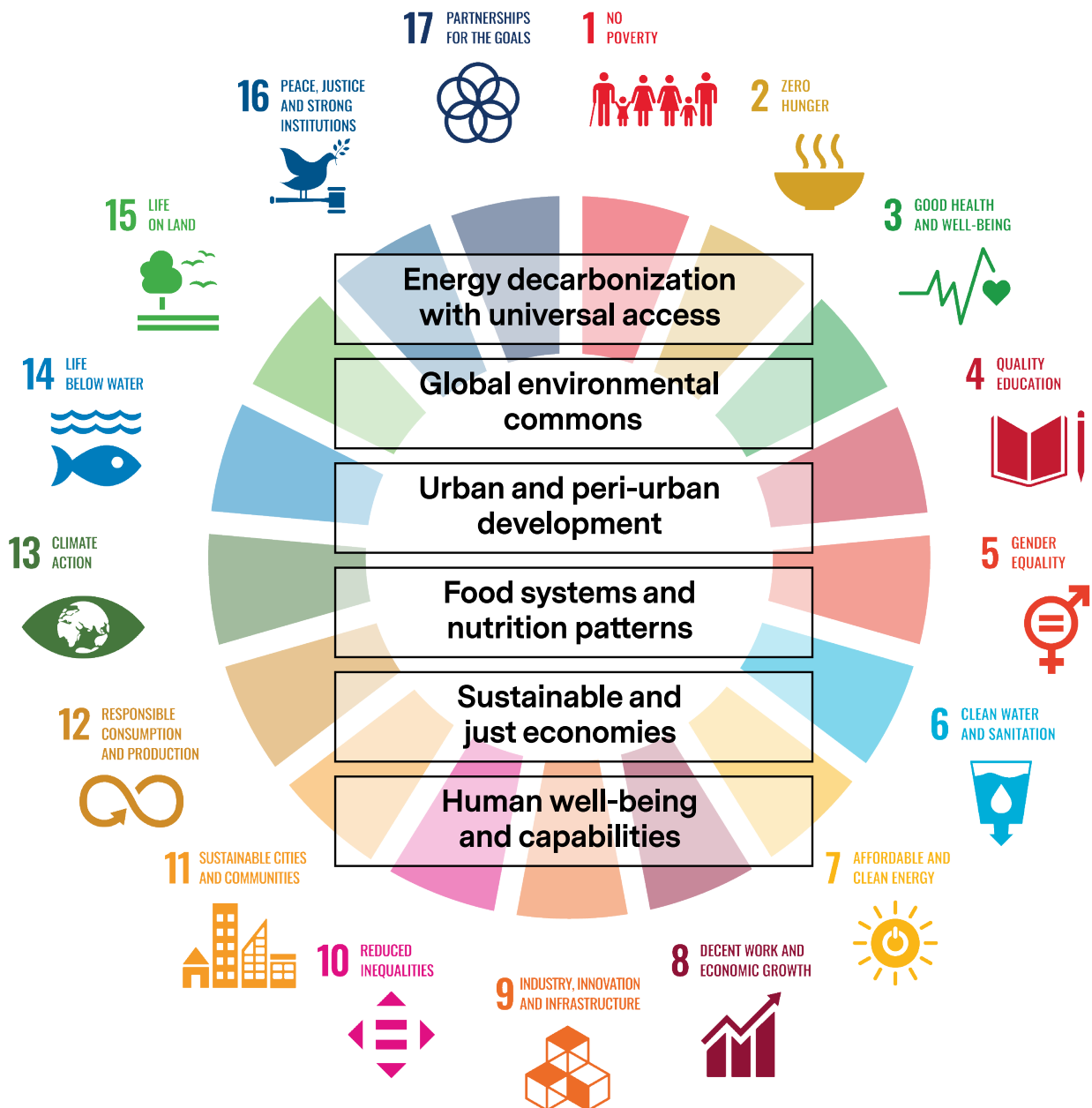
Figure 1-1. The UN SDGs and six cross-cutting factors ("entry-points") mentioned in the UN Global Sustainable Development Report 2019 [UN 2019b]. The entry points are thus factors which concern all the SDGs.

tween goals can be avoided, the trade-offs that are made should be openly addressed and mitigated. This is where the entry points offer useful tools so that adverse interactions between the goals are minimized. Besides technology, 6G has a clear potential to directly contribute to the UN SDGs by addressing digital inclusion and societal empowerment. For example, placing the network equipment in a remote area may advance the quality of life and work opportunities in peri-urban or remote locations, but have negative effects on the surrounding wildlife. The entry points offer a more a holistic approach to avoid such adverse interactions between the goals and have proved

to be useful when examining how 6G can help achieve the UN SDGs (see Chapter 4).

The so called "levers" of: governance; economy and finance; individual and collective action; and science and technology; are highlighted in the Global Sustainable Development Report [UN 2019b, p. 29-36]. These levers impact the UN SDGs through these recognized entry points. The Science and Technology lever, which is a pivotal lever from the perspective of 6G development, can bring about transformations in the entry points. Disruptive technologies can help overcome critical gaps in the

delivery of cross-cutting initiatives that stem from the synergies of the UN SDGs.

The mobile communication sector plays an important role in societies around the world, and its linkage to the UN SDGs is many-fold. Mobile communications can significantly contribute to the achievement of the SDGs by offering infrastructure and access to digital services that will result in growth, efficiency and sustainability [ITU; GSMA 2018]. This is particularly true for economies where existing services are limited or the existing service infrastructure is poor. Digitalization of services delivered through mobile communications networks has shown real benefits in developing economies, in particular driving the uptake of micro-banking and micro-finance, micro energy grids and market creation [McKinsey, 2016]. The advancement of technologies for 6G may contribute further to the aim of reducing environmental impacts through the 6G vision of reducing the energy consumption of operating the networks including the use of zero energy devices with impacts across many industries and sectors.

The core principle of the Agenda 2030 is to "leave no one behind", and mobile technologies form the core of connectivity and Internet access [UN 2019a, p. 23]. The approach to achieving the goals will be different around the globe because societies themselves are very different, although 6G has the potential to be a global enabler. Universal access to information is now recognized as a crucial factor when addressing ways to achieve the UN SDGs. The role of mobile communications in digital empowerment was very powerfully articulated by the UN General Secretary António Guterres when he inaugurated the High-Level Panel on Digital Cooperation . The Panel's report, presented in June 2019, addressed a set of recommendations regarding aspects such as affordable access to digital networks , as well as digital and financial inclusion.

The UN SDGs also require consideration of external costs and bringing together a wide range of stakeholders to work towards common goals. As of today, there are still major technological bottlenecks and constraints to achieving the UN SDGs' targets including: opening up, democratizing and improving data; breaking down information silos; shifting the existing paradigm of policy making (which is largely based on intuition) towards an evidence driven approach enabled by big data; leveraging the advanced tooling and prediction capability

of machine learning and artificial intelligence (AI) while assuring privacy, trust and security of users [European Commission, COM 2020, 65; EBA report 2020].

This white paper aims to establish a linkage between 6G and the UN SDGs. In doing so, the scope of considered is not restricted to cellular mobile communication networks but the impact of communications networks more widely. The vision for 6G holds special promise as it includes the powerful concept of the network acting as a service platform with sensing, creating a new paradigm of information collection and sharing. Access to affordable, high-quality, broadband Internet is a fundamental, common factor for achieving the Agenda 2030 goals.

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[1] High-Level Panel on Digital Cooperation, *https://www.un.org/en/digital-cooperation-panel/*.

[2] Notably, recommendation 1A: "We recommend that by 2030, every adult should have affordable access to digital networks, as well as digitally-enabled financial and health services, as a means to make a substantial contribution to achieving the SDGs…" and recommendation 1B: "We recommend that a broad, multi-stakeholder alliance, involving the UN, create a platform for sharing digital public goods…".

Our 6G vision

2

Our vision of 6G accentuates development that will provide much more than just innovative use-case-driven mobile communication solutions but will rather serve higher societal ambitions. Foremost amongst these are the UN SDGs. We foresee that our future society will be increasingly digitized, hyper-connected and globally data-driven as outlined in [Latva-aho & Leppänen 2019]. Utilizing these opportunities, our vision allows for 6G to contribute to accomplishments such as helping people, society and the economy adapt to the digital age—emphasizing connecting the unconnected—strengthening the economy in a way that works for people and enhances people's well-being, and supports our planet through "Green Deals" and extreme energy efficiency. Policy frameworks and regulations have to be aligned, work hand in hand and have to reach up to the task level required to create the 6G future. Our societal ambitions

are huge, including "societal readiness" on all levels for a digital future. This incorporates help for disaster relief for pandemics and similar threats to be minimized through contributions from 6G development.

Fig. 2-1 illustrates the relationship between the UN SDGs and our 6G vision. 6G aims at ubiquitously providing several capabilities or services, as shown on the left side of Fig. 2-1. The 6G vision elements here include *connectivity, processing, actuating, sensing, data* and *intelligence* everywhere. Regarding deployments, 6G will cover a wide range of setups from global to hyperlocal. Global and regional deployments are expected like in traditional cellular systems allowing roaming and economies of scale for equipment. While wide area coverage continues using mainly lower carrier frequencies, 6G will bring local specialization through local network deployments
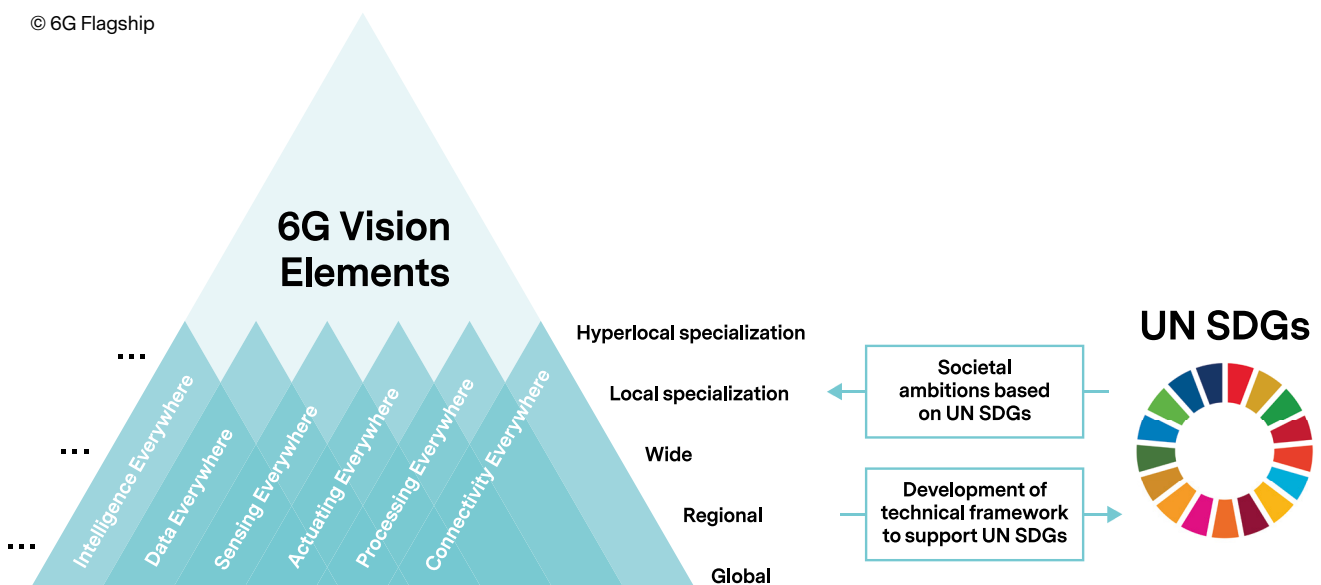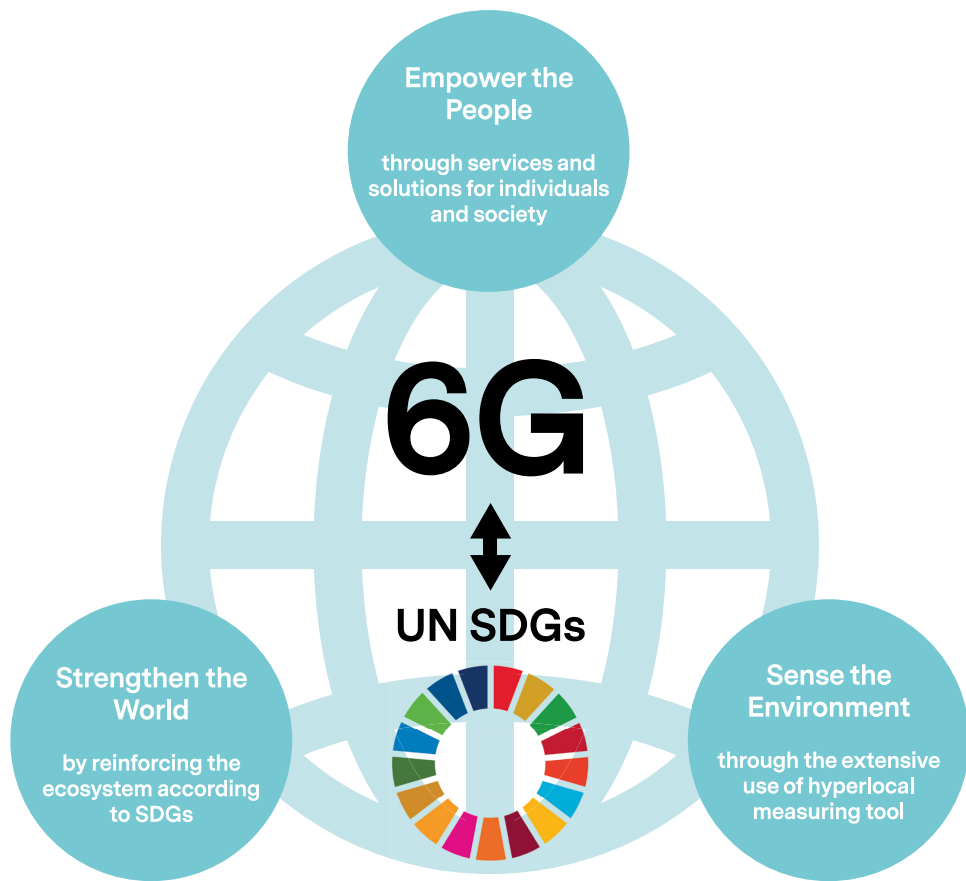
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Figure 2-1. Relationship between the UN SDGs and the elements of 6G vision.

Figure 2-2. Three pillars linking 6G with the UN SDGs.

and introduces hyperlocal specialization with very high level of granularity especially exploiting higher carrier frequencies. All these will be essential building blocks to support the UN SDGs across administrative boundaries. However, in our 6G Vision some building blocks exist already or are part of the 5G evolutionary journey to 2030. Possible examples of these aspects include context awareness and situational reasoning. It should be noted that all the focus areas embrace not only technical characteristics, but their potential should be understood in the wider context of transformational services, new ecosystems and value chains.

Fig. 2-2 summarizes the aforementioned connections between 6G and the UN SDGs. By supporting the UN SDGs, 6G aims to take a leading role by a) empowering the people by providing services and solutions to individuals and society, b) sensing the environment by carrying out extensive hyper-local measurements associated with essential indicators and c) strengthening the world by reinforcing the ecosystem according to the SDGs. These three roles of 6G are further elaborated in Chapter 4.

Exemplified by the current COVID-19 pandemic, prioritizing use cases that have the greatest potential to improve the lives of people around the globe could lead to rapid solutions if different stakeholders are prepared to

work in unison. During the 2020 pandemic, we have seen automotive companies developing emergency ventilators for critically ill patients in intensive care. Conversely, the inability to collaborate could lead to chaos, which also seems to be present to some degree during the current crisis. The choices people make in their everyday lives—whether common citizens, politicians or CEOs of global companies—do matter. We as humans often forget that open collaboration is essential, even though we may disagree on certain views. Therefore, we include in our vision that 6G development should facilitate open collaboration and open standardization between different stakeholders in a multi-disciplinary manner, ultimately to create true partnerships for the benefits of all.

The way in which data is collected, processed, transmitted and consumed within the wireless networks will be a key driver for 6G as highlighted in [Latva-aho & Leppänen 2019]. Exploiting this data, ensuring privacy at the highest standard, we envision 6G will open a new era of an 'Internet of Intelligence' with connected people, connected things, and connected intelligence. AI will become a native feature of 6G. AI reasoning and inferring capabilities will be embedded everywhere in 6G networks to drastically enhance the network capability, and the communication architecture will be revisited to facilitate the collection and spread of intelligence.

Many widely anticipated future services would be critically dependent on instant, virtually unlimited wireless connectivity. Resources, specifically through the utilization of higher and broader spectrum and larger arrays of antennas will continue to be exploited. 6G will provide a framework of services, including communication services where all user-specific computation and intelligence may move to the edge cloud. Natively integrating sensing with communication using specialized virtualization techniques will bring another leap in the network capabilities. Capacity, latency reduction, and positioning accuracy will improve, providing truly immersive aural, visual, haptic and sensory communication experiences. The support of energy harvesting mobile devices involving charging via radio waves or laser beams and by utilizing energy from solar cells or body movements will also play a major role.

To ensure coverage including all remaining unconnected areas in the world, 6G relies on seamlessly integrating non-terrestrial networks such as UAVs (unmanned aerial vehicles), drones, and very low orbiting satellites into cellular communication systems. New hardware, new devices, and new user interfaces will come into play, exploiting all possible types of renewable energy, and transforming the way human beings interact with the digital world.

While pushing many technological boundaries on the journey to 6G, the UN SDGs are an important lens to help prioritize development. Technology standards which support those use cases that hold the highest promise for improving human lives and protecting the environment need to be advanced first. This journey will need to consider mechanisms to help policymakers around the globe to advance the UN SDGs by positively influencing the behavior of people. The 6G ecosystem will provide solutions that empower individuals and communities to adopt self-correcting processes and steer actions towards long-term sustainability. 6G will also provide the means for sufficient data collection—with strict privacy protection rules and in line with values of civil society, corporate accountability and government transparency—to enable the monitoring of SDG indicators that are or will become relevant in the near future.

Fig. 2-3 depicts the three high-level aspects in the 6G vision, namely: a) people/society, b) machines and things and c) resources. These are in line with the 6G goal *everyone connected, anything connected*, and *any resource*, respectively. Resources refer to assets that can be exploited either directly or in a shared fashion. These resources can be tangible or intangible. Tangible resources include concrete physical assets, whereas intangible resources concern immaterial resources such as knowledge and energy. 6G will connect these aspects using both local and wide wireless networks to create a hyperconnected world bringing communities ever closer to a globally connected world.

Since the world is not homogeneous, any development to achieve the 6G vision must support an open architecture, crowd sourcing, and enablement of a third-party application and service ecosystem to meet local needs. At the same time 6G will not provide unlimited capabilities, but rather provide for real needs, such as high-capacity networked islands where and when needed and focus on a sustainability perspective.
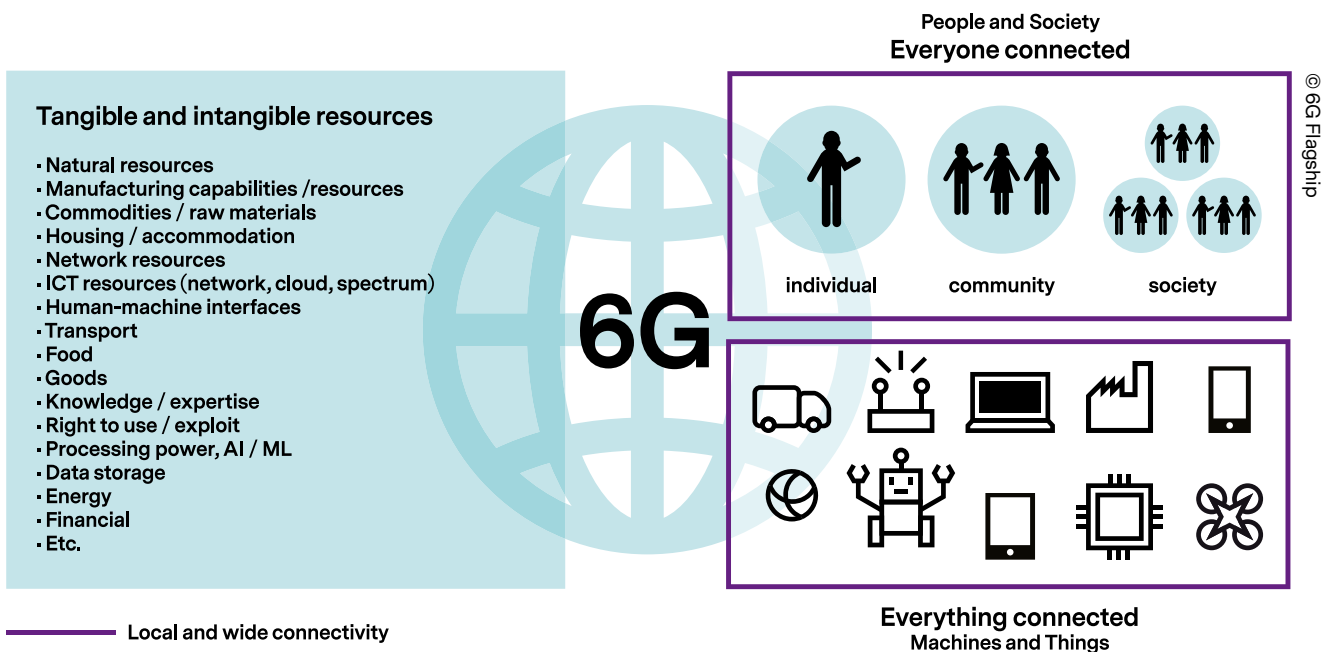

Tangible and intangible resources

· Natural resources
· Manufacturing capabilities /resources
· Commodities / raw materials
· Housing / accommodation
· Network resources
· ICT resources (network, cloud, spectrum)
· Human-machine interfaces
· Transport
· Food
· Goods
· Knowledge / expertise
· Right to use / exploit
· Processing power, AI / ML
· Data storage
· Energy
· Financial
· Etc.

People and Society
Everyone connected

individual   community   society

6G

Everything connected
Machines and Things

—— Local and wide connectivity

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Figure 2-3. Key high-level 6G aspects interconnected by wireless and mobile networks.

The operational environment for international 6G research and development consists of multiple stakeholders with varying goals and roles including, e.g. research and educational organizations; governmental, regulatory and standardization organizations; users; industry; and verticals, as depicted in Fig. 2-4. Research and educational organizations have an important role in driving 6G research and educating professionals, see e.g. [Latva-aho & Leppänen 2019]. Governmental organizations including national-level decision makers create the incentives and national conditions for 6G networks and services. Regulatory bodies at various levels are in charge of many critical 6G deployment aspects including regional and international spectrum matters. Standardization organizations enhance the adoption of necessary technology for sustainable development, see [ISO 2018; IEC 2020]. Industry encompasses various stakeholders such as mobile network operators (MNOs) and digital service providers, all investing in the infrastructure, and other telecommunication industry players developing 6G technology and applications. Verticals include stakeholders from e.g. automotive, health, energy and other sectors that use the technologies in specific application areas, see [Pouttu 2020] for more details on verticals for 6G. Given the challenges and economic impact of adopting the UN SDGs, various verticals need to engage earlier in the process compared to in the development of previous generations of mobile communications. Additionally, special purpose 6G networks will be operated in verticals and the various applications tailored for verticals' use will be running on the 6G networks. Finally, we want to mention the role of the users of the future systems. To prevent a digital divide, people need to have the devices required to use the services and they also need to have the skills to use them as well as the available services. Furthermore, people need to understand technologies and they need to learn appropriate technological skills to actively transform disruptive technologies into advancing empowerment.
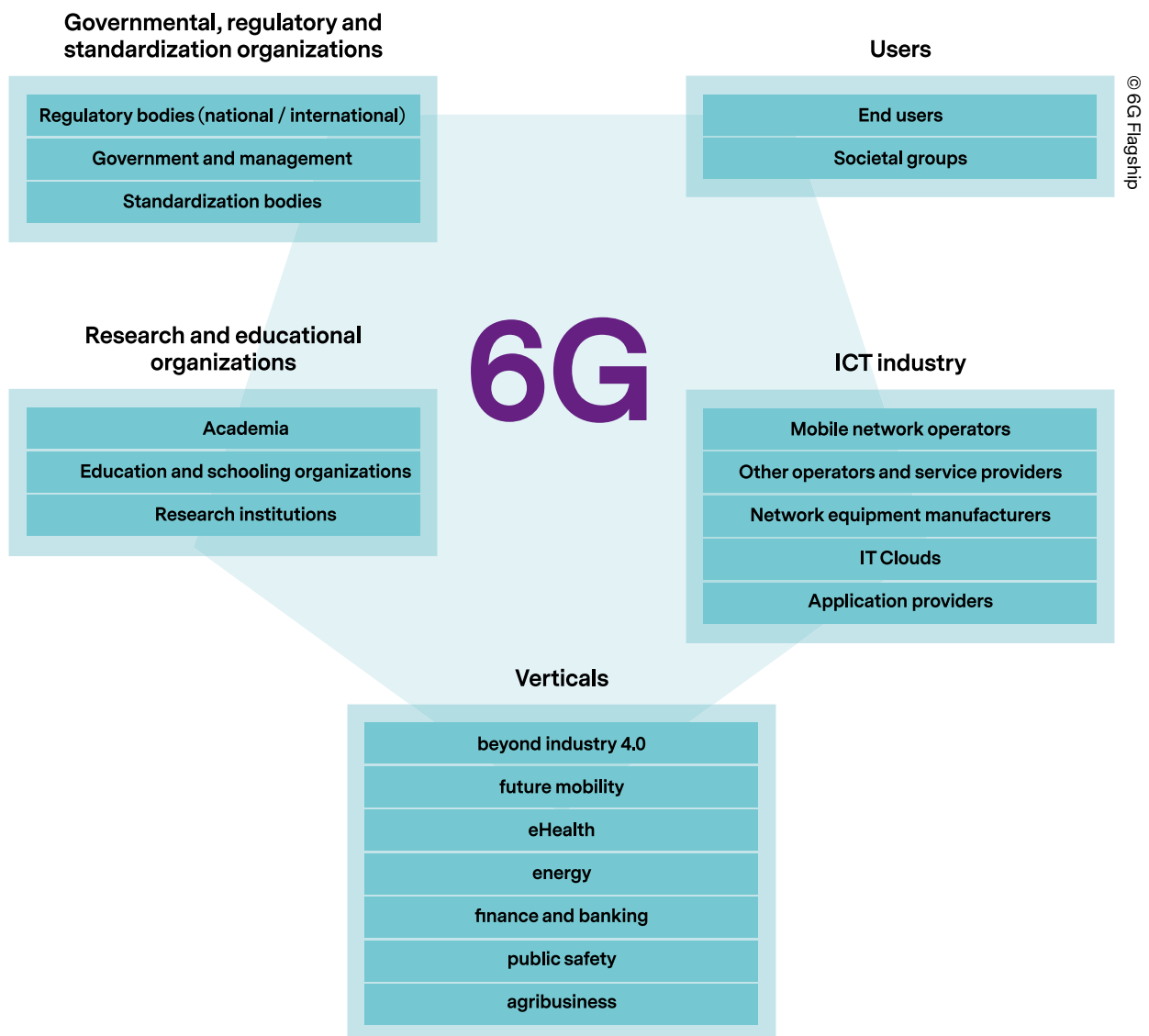

Governmental, regulatory and standardization organizations

Regulatory bodies (national / international)

Government and management

Standardization bodies

Users

End users

Societal groups

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Research and educational organizations

Academia

Education and schooling organizations

Research institutions

6G

ICT industry

Mobile network operators

Other operators and service providers

Network equipment manufacturers

IT Clouds

Application providers

Verticals

beyond industry 4.0

future mobility

eHealth

energy

finance and banking

public safety

agribusiness

Figure 2-4. Operational environment for 6G.

Megatrends driving 6G research

3

6G research and development are unfolding against the background of global megatrends which will shape our world over the coming decades. Megatrends are change-related phenomena and are transformative, global forces that define the future world. They have impacts on businesses, societies, economies, cultures, and personal lives. Although the COVID-19 pandemic dominates the current news, climate change is probably the most topical megatrend today, and phenomena including population growth and demographics, increasing environmental pollution or global competition for resources are also current megatrends [Dufva 2020].

The United Nations Office at Geneva (UNOG), as well as the Government of Norway, have pointed out the challenge of the digital divide as one of the global challenges. The governmental report [GovNorway 2020] on "Digital transformation and development policy" identified the following four barriers to digitalization (i) access, (ii) regulation, (iii) digital competence and (iv) exclusion, as priorities for the government. In a similar matter, United States Agency for International Development (USAID) has added "last mile connectivity" as the main priority for development policy. From the perspective of digitally empowering users globally, it should be emphasized that digital inclusion is the catalyst for achieving the UN SDGs, implying that we also need to address how everyone in society can benefit from basic information in the digital world available free on the web. Furthermore, certain UN SDGs require global cooperation to be successful leaving aside national interests, such as environment and ecological reconstruction and controlling spread of diseases.

3.1 The Quintuple Helix model for sustainable development of 6G

The trends identified in the White Paper on Business of 6G in [Yrjölä et al. 2020] were taken as the baseline and categorized according to the Quintuple Helix model [Carayannis et al. 2012]. The Quintuple Helix model aims to support a win-win situation between ecology, knowledge and innovation, creating synergies between the economy, society, and democracy. It can be seen as "a cooperation system of knowledge, know-how, and innovation for more sustainable development" [Carayannis et al. 2012].

In the Quintuple Helix model (see Fig. 3-1), there are five subsystems (helices): the political system, the education system, the economic system, the natural environment, and media- and culture-based public society (civil society). Each subsystem has its own asset, capital, at its disposal and forming within the helix, resulting from the actions in the helix itself. Knowledge in this model is treated as a resource that circulates between the subsystems and changes into innovation and know-how in a society and for the economy. All subsystems are seen to influence each other through knowledge. Knowledge acts as an input to the subsystems and is a resource for new knowledge creation in the subsystem. As an output of a subsystem, new knowledge arises in the form of know-how that continues circulating in the system or takes the form of new inventions [Carayannis et al. 2012].

The education system contains all levels of education. Its asset is embodied in humans who either go through the system (students) or work within it (teachers, researchers etc.) as human capital, resulting from diffusion and research of knowledge. Knowledge creation within this subsystem consists of education in different educational institutes, for instance, as well as research. The economic system consists of different elements that comprise the economic structure of a community, such as institutions, industries, companies, services, banks. Its asset is economic capital, i.e. everything that makes it possible to perform economically useful work. This includes for example machinery, production processes, resources, and money. The natural environment has as its asset

natural capital, i.e. nature itself and the resources it provides, such as soil, water, air, living organisms, minerals, and metals. The assets of the media- and culture-based public subcategory are a combination of civil society and the media and include information and social capital which are integrated and combined in the subsystem. This capital includes on the one hand, information- and media-related assets such as television, newspapers, and information sharing networks, and on the other hand culture-related assets such as art, traditions, values, and life-styles. The political system's assets are political and legal capital. Political capital refers to the accumulation of resources and power by politicians, parties, and other stakeholders, and legal capital is understood as the legal system and laws and regulations. [Carayannis et al. 2012] In the Quintuple Helix model, the circulation of knowledge between the subsystems happens within a nation-state but also between states [Carayannis et al. 2012]. Next, we will examine the megatrends we have identified as relevant from the point of view of the sustainable development of 6G. The trends largely cross the boundaries of nation-states; thus, the Quintuple Helix model needs to be understood on different levels as well, both at the nation-state level as well crossing these boundaries.

3.2 Identified megatrends

Following Sitra's report on megatrends [Dufva 2020], there are five trends that will be vital in the future for 6G: 1) the need for ecological reconstruction, 2) the strengthening of relational power, 3) the ageing and diversification of the population, 4) the redefinition of the economy, and 5) technology embedded in everything. The megatrends in [Dufva 2020] have been derived to help understand the visible changes in the world, especially from Finland's perspective, but are not limited to a single country. Next, we link these five megatrends to the corresponding helices of the Quintuple Helix model and add to that trends identified in the white paper on business of 6G [Yrjölä et al. 2020] that also fit this white paper. See Fig. 3-2 for the mappings and further details in the following sections.

3.2.1 Trends related to the natural environment

Arguably the key trend influencing our future is the need for ecological reconstruction, which raises the question: how do we respond to climate change, decreasing biodiversity, the dwindling availability of resources and waste-related problems? Other trends need to be viewed against this backdrop as well. For example, the political system should be able to make decisions quickly—but will these be made through the centralization of power or inclusive decision-making or political correctness?

Other trends concerning the natural environment include aspects such as sustainable materials, which in turn contribute to concepts such as the innovating to

zero concept and the circular economy. By 2030, companies will have shifted focus and developed products and technologies that innovate to zero, including zero-waste and zero-emission technologies. While technology offers new solutions for the production of energy it also simultaneously increases the demand for energy. This creates a conflict, posing the question as to what extent technology promotes ecological reconstruction and to what extent technology hinders it. 6G net positive impacts on the environment and sustainability are expected due to increased efficiencies and improved environmental performance. Technologies of computing will be miniaturized to the extent that they can be sustained on the power generated through everyday human activity. Everyday activities such as walking, jogging and everyday housework could produce energy to support a person's information devices, which in turn will be able to monitor a person's vitals as well as cater to information and entertainment needs through over-the-top connectivity.

At the same time, environmental awareness among people and companies has increased, which is reflected in a growing number of people and communities changing their habits and companies taking corresponding actions to offer better customer experiences. Dissatisfaction with the current measures taken with respect to climate change and biodiversity has motivated a growing number of people to voice their opinions and participate in demonstrations. Responding to the increased environmental awareness requires changes in culture and practice and has been accompanied by a polarization of views.

By 2030 smart grids will be extended to a variety of sectors including electricity, the Internet and healthcare. All of these have been hyperconnected and completely automated. They will be serving as a middle layer between humans and natural environments enhancing the capabilities of both. These networks will be put together using a public-private-personal ownership funding model with a view towards sustainable growth and the usage of a digital infrastructure.

3.2.2 Trends related to the political system

We are moving from a multipolar world to a "poly-nodal" world, where the strengthening of relational power is vital. In *geopolitics* the tension between the globalization, networking power and the urgency of ecological reconstruction is linked to the balance between centralized decisions and the strengthening of inclusion and democracy. By 2030, the *power configuration* will have transformed from a *multi-polarized world to a poly-nodal* world in which power will be determined in economic, technological and cultural networks and through interaction. Power is determined by relational influence and is being held not only by states but also by companies, regions, communities and transnational organizations. Societies will struggle to find a balance between fast-mov-

ing decision making, community engagement and the reassertion of democratic values and commitments.

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 harbors and airports), advanced health services, logistics and transport, smart cities, public safety and critical infrastructure. Smart society builds dependable systems and communications and stan-

dardized data is utilized by walled garden platform monopolies across verticals. The focus on smart cities will be extended to rural inclusion. 6G will transform urban and rural life and will also be influenced by geopolitics, the growth of nationalism, rights to information transparency and information citizenry. *Resource orchestration and configuration* relates to the power over the development and adoption of innovations and technology that is ubiquitously embedded in society and our daily lives. Technology is increasingly seen as a geopolitical issue of power and the questions about future resource orchestration and power are emerging. The key questions

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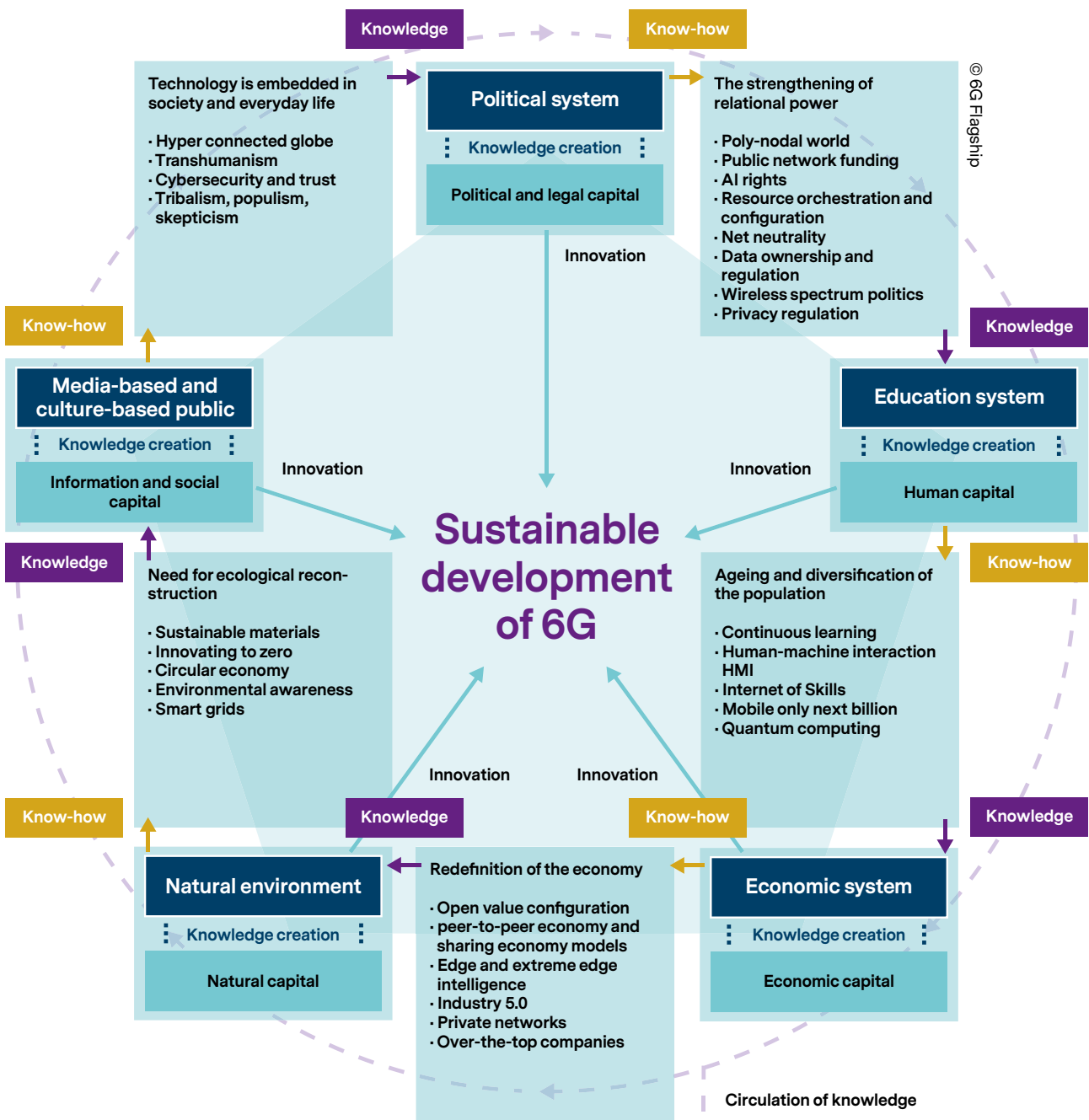
Figure 3-1. Megatrends in the context of the Quintuple Helix model. Framework adapted from [Carayannis et al. 2012, p. 7].

arising are: who will own the continuously accumulating data, who will get to decide on technology and who will set the rules and regulations?

Data ownership and regulation. 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 analyzed 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 platform data economy, peero-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. Trends in *artificial intelligence rights* 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. Alternatively, in the future this may drive inequality, inadvertently divide communities, and could even be actively used to deny human rights.

Wireless spectrum politics and spectrum management in the 6G era will reveal a new level of complexity that stems from the variety of spectrum bands and spectrum access models with different levels of spectrum sharing. Local deployments of networks by a variety of stakeholders is expected to further grow in 6G. Furthermore, in national technology politics, spectrum regulation will be used to gain competitive advantages. According to a recent *net neutrality* ruling Internet access providers should treat all traffic equally irrespective of the sender, receiver, content, service, application or device in use. At the same time, in 5G evolution a network that can be extremely tailored to a use case intending to treat traffic differently for each use case is already being developed. This legislation creates uncertainties by impacting companies' capabilities to create and capture value in virtualized network-based services between telecom operators and cloud providers.

3.2.3 Trends related to the education system

We see two trends in the area of diversification of the population: the ageing in well-established societies, and young generations in developing economies trying to catch up with the welfare of established economies. In well-established societies, the population is not only ageing but also becoming more diversified in terms of backgrounds, opportunities and habits [Dufva 2020]. A highly functional educational system is needed to provide equal opportunities for all. Continuous competence development is not required only from the work force but from all citizens. Learning capabilities will play a key role in the future, which creates pressure to re-evaluate educational structures and policies.

New technological innovations may revolutionize education in the future. Redefining the human machine and brain user interface (UI) is an emerging opportunity which could connect people and the biological world in novel ways. So called holopresence systems will be able to project realistic, full-motion, real-time 3D digital twin images of distant people and objects into a room, along with real-time audio communication, with a level of realism rivaling physical presence. Images of remote people and surrounding objects will be captured and transmitted over a 6G network and projected using laser beams in real time. The pervasive influence of AI will not just reflect what something looks like but also its context, meaning and function, creating an Internet of skills, an Internet of the senses and digital twins [Latva-aho & Leppänen 2019].

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. With its unprecedented scale and growing impact on people's daily lives, mobile technology is a powerful tool also for achieving the SDGs and as a driver of sustainable economic growth.

Academia is a crucially important stakeholder not only providing education, but also fostering groundbreaking research. Alternative concepts and models for computing such as quantum computing could disrupt segments such as finance, intelligence, drug design and discovery, utilities, polymer design, AI, Big Data, and digital manufacturing. Quantum computing involves sorting information, finding prime numbers, simulating molecules, and optimization, and thus could dramatically affect these segments. For long the technology will be limited to selected sectors, such as the military, national laboratories, and aerospace agencies, while other alternative approaches to computing to help handle

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[3] *www.basicinternet.org*

greatly increasing level of parallelism in algorithms may be available more widely.

3.2.4 Trends related to the economic system

The redefinition of the economy is also linked to sustainable development. The key question here is whether the environment should be regarded only as a resource or whether the economy should aim to improve the state of the environment.

Urbanization will bring 5 billion people together to live in cities by 2030 occupying 3 per cent of the Earth's land but accounting for 80 per cent of the energy consumption and 75 per cent of carbon emissions. 95 per cent of urban expansion in the next decades will take place in the developing world where 883 million people live in slums today. Rapid urbanization is exerting pressure on fresh water supplies, sewage, the living environment, and public health. Cities are hungry, global economic engines and the economic powerhouses of the global economy. In 2015, 85% of the global GDP was generated in cities. Cities are increasingly functioning as autonomous entities, setting social and economic standards. Urban identity will grow in importance compared to national identity. Open value configurations and open source paradigms may provide a powerful avenue to reinvent civil society participatory processes and regulatory capabilities. Utilizing the sharing and circular economy will lead to co-creation and the utilization of existing resources and processes. 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. Towards 2030 platform ecosystems will provide an infrastructure on which innovation and transaction platforms are built. Crowdsourcing and crowdfunding are expanding the space for new forms of organization and innovation. Component prices have already decreased significantly, and more sophisticated components will become cheaper, while new ones are invented. Low component prices will provide opportunities for both local businesses as well as international ones. This will encourage frugal innovations that will be supported by a global do-it-yourself culture where the sharing of blueprints and working processes will be the norm and these will counter inequality in the world. In a heterogeneous society, social networks and the trust and reciprocity they foster will be highlighted from the perspective of well-being as well as working life. Novel decentralized business models do not necessitate a focal point but depict the design of transaction content, structure, and governance to create value.

Via edge and extreme edge intelligence the proliferation of ever more powerful communication, computing and analytics resources at the edge of the network will transform the architecturally disaggregated 6G access networks into a rich service provisioning and access platform. Hyper-local services, such as augmented reality scenarios, do not require connectivity to distant service platform but, instead, perform better with local real-time service access. Furthermore, users will be supporting shared information processing and edge intelligence networks that will address collective challenges for humanity, such as genome sequencing (citizen science), through shared resources. The individual will emerge as a node in the network of intelligence relations rooted in the local physical world while connected to hyper-real 6G intelligence networks. This adopts a viewpoint of a common good through the digital infrastructure of 6G supported through an ecology of information devices, products and services of Internet of Things (IoT)/Internet of Everything (IoE).

Over-the-top companies will utilize their customer data, cloud infrastructure and AI/ML capabilities to challenge traditional operator's customer relationships as users perceive connectivity as a basic utility. In addition to the media space, OTT players will offer basic telco services such as voice or messaging services and will be active in growth areas, such as cloud space and other services, competing with telcos for clients and revenue. They will tie customers to their own ecosystems with carrier-neutral connectivity, while making reliance on traditional operators a thing of the past.

Towards 2030 industry 5.0 will allow collaborative *human-machine interaction (HMI)* across services and industries as human intelligence becomes more harmonized with advanced, cognitive computing. With real-time data, effective data monetization and digital automation of the manufacturing process, businesses will be able to shift their focus towards generating higher revenues from the servitization of products. Advanced manufacturing capabilities will help to overcome design complexities with the ability to facilitate extreme mass customization and further return control back to customers and in a haptic way. Private networks driven by industrial digital automation will call for standalone networks with high reliability, high performance in terms of both bandwidth and reliability, secure communications and data privacy, fulfilling business and mission critical needs.

3.2.5 Trends related to the media-based and culture-based public system

Technology will become an embedded enabler in everything. This includes knowledge creation and the circulation of knowledge. Technology is becoming a part of society and everyday life. The sense of community created by 6G technology and the ability to directly collaborate with others will enable humans to participate and act in society in an unprecedented way. A hyper connected globe will continue to feel ever smaller in

2030: Globally 90% people will be able to read and have access to the Internet and this trend will involve mobile technology. It will be essential to recognize that 6G will transform urban and rural life and this will be affected by geopolitics, growth of nationalism, rights to information transparency and information citizenry. Thus, once the infrastructure of 6G is in place, there will be content growth in terms of supporting multiple social and technological identities of people through a variety of media. This will require decision making and regulation of future, data, information, media and network usage with a view to the sustainable growth of the economy. Thus, people in the 6G world will be increasingly sophisticated in terms of their media and service consumption, while being rooted in their local economies. Connectivity is therefore not only virtual and digital, but also physical, and the physical world will seamlessly meet the virtual world with novel ways of interacting between the human and the biological world. Once 6G technology has penetrated most parts of the world, IoT devices and sensors controlled by AI will be an integrated part of environment. The automatic collection of various kinds of data (from people: functioning of the human body, biometrics, biosensor data, etc. as well as from our environment etc.) and its analysis will be used for highly sophisticated products and systems that will make people's lives easier and provide better user experiences through convenience as everything is automated.

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 will emerge around various imaginary groups representing a wide variety of values, places of residence, political opinion, consumption choices or lifestyles. With weakened and fragmented future prospects, the absence of togetherness and the polarizing effect of social media may have led to a rise in populism, skepticism towards changes in the environment and in the worst case, extreme attitudes. The concept of transhumanism reflects the rise of technology-driven evolution at an unprecedented speed of change, propelling deeper questions into what it is to be human from the biological, behavioral and human-machine evolutional perspectives. There may also be a cognitive intelligence revolution via the ascendancy of sentient tools and further, possibly human, orchestrated, self-directed selection in biological, neurological, and physical evolution.

Developing a linkage between the UN SDGs and 6G and related indicators

4

The UN Agenda 2030 for Sustainable Development introduces 17 goals and 169 targets that are measured with 232 individual indicators as presented in [UN 2017]. Prior studies on the linkage between the UN SDGs and the mobile communications sector, or more generally the ICT sector, have identified that contributions can be made to all the SDGs. There are ongoing activities related to mobile communications and UN SDGs carried out by governments, regulatory bodies, standardization organizations, trade associations, companies, etc. In the following we provide an overview of relevant ongoing activities in different forums working towards the achievement of the UN SDGs, followed by our new linkage between 6G and the UN SDGs.

The global indicator framework [UN 2017] for the goals and targets of the 2030 Agenda for Sustainable Development defines 232 individual indicators of which seven are defined to address ICT related topics. Overall, the indicators describe today's situation and very few are ICT specific, which calls for the stakeholders to look into the development of a new set of more specific indicators which do not currently exist and are applicable to future mobile communications systems. In particular, there is a need to develop new indicators to guide 6G research and development towards 2030.

4.1 Prior work on linking UN SDGs with mobile communications and indicators

The International Telecommunication Union (ITU) is the UN specialized agency for ICT and has identified the role of ICT in achieving the different UN SDGs, see [ITU]. Similarly, for several years the mobile communication industry itself has evaluated its impact on the achievement of the UN SDGs, see e.g. [GSMA 2018; GSMA 2019]. The prior work on the linkage between the UN SDGs and mobile communications and related indicators are discussed next.

4.1.1 Existing linkage between UN SDGs and mobile communications

The identified linkage between the UN SDGs and the mobile communications sector or more broadly the ICT sector are summarized in Table 4-1 and more details are provided in Annex 1. The mobile industry's contribution to the achievement of the UN SDGs is primarily considered through three levels: 1) the deployment of infrastructure and networks forming the foundation for the digital economy, 2) providing access and connectivity allowing people to use mobile communications, and 3) by enabling life-enhancing services and relevant content for people [GSMA 2018]. The Broadband Commission for Sustainable Development directed by the ITU and UNESCO has set its own seven broadband targets for 2025 including a universal broadband policy, making broadband affordable, getting people online, achieving digital skills and literacy, using digital financial services, getting businesses online and achieving gender equality [Broadband Commission 2019].

The ITU has developed "the Connect 2030 Agenda" to contribute to the UN SDGs [ITU 2020]. It defines five goals: growth (enable and foster access to and increased use of telecommunications/ICT in support of the digital economy and society), inclusiveness (bridge the digital divide and provide broadband access for all), sustainability (manage emerging risks, challenges and opportunities resulting from the rapid growth of telecommunications/ICT), innovation (enable innovation in telecommunications/ICT in support of the digital transformation of society) and partnership (strengthen cooperation among the ITU membership and all other stakeholders in support of all ITU strategic goals). Additionally, the ITU and Digital Impact Alliance (DIAL) have developed a framework for SDG digital investments to select technological solutions [ITU – DIAL 2019]. The framework consists of four interrelated layers: SDG targets defining high-level objectives,

use cases defining the steps to achieve a business objective contributing to one or more SDG targets, workflows defining generic business processes supporting the delivery of a use case, and ICT building blocks that enable work flows and use cases. The framework provides a method for mapping ICT building blocks to specific UN SDGs. Most recently, the UN road map for digital cooperation [UN 2020] recognizes the importance of digital cooperation in achieving the SDGs and sets out actions on global connectivity, digital public goods, digital inclusion, digital capacity-building, digital human rights, AI, digital trust and security, and global digital cooperation.

Although the mobile communications community has recognized the important role that mobile communications play in achieving the UN SDGs, the approach taken so far has been mainly economically driven. A purely commercially-driven roll-out will not always serve the under-represented groups in the community, e.g. those who do not see the value in the Internet. Instead, community networks are often established as individuals see the necessity for connectivity although the economic viability may not be in place. Therefore, communities need to be made an integral part of any policy making and decision-making bodies.
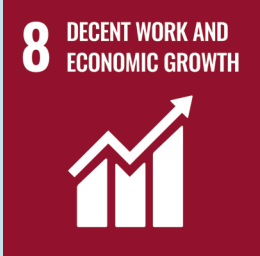
In this white paper, the scientific community together with other actors further develop the linkages between the technological solutions and the UN SDGs. The paper maps out how mobile communications can enable the achievement of UN SDGs from a wider, societal perspective, paying attention to issues such as equality, both on the individual and institutional level. As an example, we could take education. On the individual level, it is vital to have access to schooling no matter where you live. On the institutional level, this means society needs to provide an infrastructure in order for schooling to be arranged. This is especially the case if online access to classrooms is necessary, for example in remote areas, or in situations like the COVID-19 pandemic when students cannot physically attend school due to government restrictions. In practice, institutions need to offer access to online services, and students need a mobile device. Technological solutions and services, and the technology needed, is developed and provided by the academic community and industry. The communications technology industry, societies and public institutions have to join forces to achieve the goals the UN has set for education.

The UN SDGs	Existing linkage with mobile communications/ICT	Existing indicators from UN SDG framework	Other existing indicators
1 NO POVERTY	Mobile communications can provide a communication infrastructure to stimulate local economy growth in poor communities. It can lower the barriers to access economic resources by providing access to mobile money and micro-financing and generate employment opportunities for people living in extreme poverty [GSMA 2018].	-	2G/3G/4G coverage; mobile penetration of the poorest 40%; mobile money penetration; number of transactions per account; average transaction volume; mobile money registered accounts [GSMA 2018]. Proportion of individuals using the Internet; proportion of households with Internet access; proportion of individuals owning a mobile phone; population covered by a mobile broadband network; proportion of individuals using the Internet for Internet banking [ITU et al. 2019].

The UN SDGs	Existing linkage with mobile communications/ICT	Existing indicators from UN SDG framework	Other existing indicators
2 ZERO HUNGER	ICT can help farmers improve crop yields and business productivity through better access to market information, weather forecasts, training programs, and other tailored online content [ITU].	-	Mobile penetration; receiving of payments for agricultural products via mobile; number of people using mobile access that benefit their farm or fishery; use of mobile technology to access health services [GSMA 2018]. Proportion of individuals using the Internet; proportion of individuals owning a mobile phone; population covered by a mobile broadband network [ITU et al. 2019].
3 GOOD HEALTH AND WELL-BEING	Mobile communications enable communication with medical practitioners, monitor well-being through mobile, provide access to health programs, provide digital identity service to access healthcare, and provides big data for epidemics [GSMA 2018]. It allows access to digital medical records, remote pa-tient monitoring and AR/VR for medical training [Huawei 2019].	-	Proportion of individuals owning a mobile phone; countries having adopted a national e-health record [ITU et al. 2019].

The UN SDGs	Existing linkage with mobile communications/ICT	Existing indicators from UN SDG framework	Other existing indicators
4 QUALITY EDUCATION	ICT powers a revolution in digital learning; mobile devices allow students to access learning assets anytime, anywhere; teachers use mobile devices for everything from literacy and numerical training to interactive tutoring; mobile learning has the ability to help break down economic barriers, divides between rural and urban, as well as the gender divide [ITU].	Proportion of schools with access to the Internet for pedagogical purposes [UN 2017]. Proportion of schools with access to computers for pedagogical purposes [UN 2017]. Proportion of youth/adults with ICT skills, by the type of skill [UN 2017].	Proportion of individuals using the Internet; enrolment in basic computer skills and/or computing courses in secondary education; proportion of graduates in ICT-related fields at post-secondary levels; Individuals with ICT skills by the type of skill; percentage of youths/adults who have achieved at least a minimum level of proficiency in digital literacy skills; learner-to-computer ratio; proportion of educational institutions with computers for pedagogical purposes; proportion of educational institutes with Internet for pedagogical purposes [ITU et al. 2019].
5 GENDER EQUALITY	Use of mobile phone can help women in low- and middle-income countries feel safer and more connected, and provide access to in-formation, services and life-enhancing opportunities [GSMA 2019]. Mobile can connect women to sharing economy and allow access to female-specific (e-health) services [GSMA 2018]. ICT enables women to gain a stronger voice in their communities, their government and at the global level [ITU].	Proportion of individuals who own a mobile telephone, by sex [UN 2017].	Proportion of individuals using the Internet; proportion of individuals owning a mobile phone [ITU et al. 2019].

The UN SDGs	Existing linkage with mobile communications/ICT	Existing indicators from UN SDG framework	Other existing indicators
6 CLEAN WATER AND SANITATION	ICT enables smart water management, facilitat-ing the measurement and monitoring of water supplies as well as necessary inter-ventions, and enabling practitioners at the local level to ensure the equitable and sustain-able exten-sion of water, sanitation and hygiene services and optimize operations [ITU].	-	Total access gap (water, sanitation) [GSMA 2018].
7 AFFORDABLE AND CLEAN ENERGY	Mobile communications can help via providing data analytics to deter-mine viability of renew-able energy sources, online resource for clean energy procurement, smart grid solutions, distributed energy sys-tems, and smart meter-ing [Huawei 2019].

ICT and energy efficien-cy are connected in two ways: 'Greening of ICTs' and 'Greening through ICTs' [ITU]. | - | Number of people benefitted from access to clean and reliable energy in their homes; IoT utility connections; number of people in developing countries using mobile technology to pay utility bills; energy use by business area of MNO [GSMA 2018]. |

The UN SDGs	Existing linkage with mobile communications/ICT	Existing indicators from UN SDG framework	Other existing indicators
8 DECENT WORK AND ECONOMIC GROWTH	Mobile communications can increase market size by online channels with consumer connectivity and provide access to mobile financial services for companies [GSMA 2018]. ICT transforms the way that business is being done everywhere and create new employment opportunities [ITU].	-	Proportion of individuals using the Internet; prop. of individuals owning a mobile phone; population covered by a mobile broadband network; individuals with ICT skills by type of skill; Internet traffic in exabytes; prop. of individuals using the Internet for Internet banking; business using the Internet for Internet banking / for accessing other financial services; business use of broadband subscriptions; internat. trade in digitally-delivered services as % of total services trade % [ITU et al. 2019].
9 INDUSTRY, INNOVATION AND INFRASTRUCTURE	Mobile networks are a critical infrastructure to provide affordable access to voice and data services and connect remote areas to em-ployment opportunities. IoT solutions can be used for sustainable manufacturing. [GSMA 2018; GSMA 2019]. Broadband is essential infrastructure due to its capacity to power industry and innovation [ITU].	Percentage of the population covered by a mobile network, broken down by technology [UN 2017].	Mobile subscribers; mobile Internet adoption; 2G/3G/4G coverage; cost of 500 MB data plan; average download speed; average upload speed; average latency [GSMA 2018]. Proportion of individuals using the Internet; prop. of households with Internet access; population covered by a mobile broadband network; Internet broadband subscriptions per 100 inhabitants; educational institutes (schools) with Internet; ICT prices as a % of gross national income per capita; international Internet bandwidth (bps) per Internet user [ITU et al. 2019].

The UN SDGs	Existing linkage with mobile communications/ICT	Existing indicators from UN SDG framework	Other existing indicators
10 REDUCED INEQUALITIES	Mobile communications enable access to information/social networks to promote social and political inclusion, allows access to marketplaces, and facilitates mobile money and digital identity services [GSMA 2018]. ICT enables access to information and knowledge to disadvantaged segments of society – including those living with disabilities, as well as women and girls [ITU].	-	Mobile penetration for the poorest 40% of population in developing countries; mobile money adoption among women in low-income countries; percentage of refugees living in areas covered by mobile networks, percentage of refugee households with a mobile phone, number of mobile money transactions, affordability of sending mobile money [GSMA 2018]. Proportion of individuals using the Internet for Internet banking [ITU et al. 2019].
11 SUSTAINABLE CITIES AND COMMUNITIES	Advanced communications techniques can attract and retain workers in rural areas by improving the teleworking experience, allowing for collaborative innovation systems among firms and research centres, and increasing efficiency of rural business and training of workers, drones can boost productivity of rural business, improve access to goods, and reduce productions and delivery costs [OECD 2019a].	-	-

The UN SDGs	Existing linkage with mobile communications/ICT	Existing indicators from UN SDG framework	Other existing indicators
12 RESPONSIBLE CONSUMPTION AND PRODUCTION	Increased dematerialization and virtualization as well as innovative ICT applications enable sustainable production and consumption. Cloud computing, smart grids, smart metering, and reduced energy consumption of ICTs have a positive impact on reducing consumption. ICT energy consumption and negative impacts of ICTs, such as e-waste, need to be minimized [ITU].	-	Proportion of individuals using the Internet; proportion of e-waste treated environmentally sound [ITU et al. 2019].
13 CLIMATE ACTION	Mobile communication can help avoid greenhouse gas (GHG) emissions by enabling other sectors to reduce their GHG emissions, facilitate smart traffic management, smart urban lighting, smart parking, smart logistics, building energy management systems, remote working, sharing economy, smart grids, connected health, and precision agriculture [GSMA 2019].	-	-

The UN SDGs	Existing linkage with mobile communications/ICT	Existing indicators from UN SDG framework	Other existing indicators
14 LIFE BELOW WATER	ICT facilitates conservation and sustainable use of the oceans through improved monitoring and reporting delivering timely and accurate data, while local sensors deliver updates in real-time [ITU]. Enabling technologies in the ocean economy can improve data quality, data volumes, connectivity and communication from the depths of the sea as well as facilitate autonomous ships and autonomous underwater vehicles (AUVs) [OECD 2019b].	-	-
15 LIFE ON LAND	ICT allows conservation and sustainable use of terrestrial ecosystems and the prevention of the loss of biodiversity through improved monitoring and reporting by delivering timely and accurate data on a global basis, while local sensors can deliver on the spot updates in real-time. Big data can be used to analyse short- and long-term trends in terms of biodiversity, pollution, weather patterns and ecosystem evolution, and to plan mitigation activities [ITU].	-	-

The UN SDGs	Existing linkage with mobile communications/ICT	Existing indicators from UN SDG framework	Other existing indicators
16 PEACE, JUSTICE AND STRONG INSTITUTIONS	Mobile technology for authorities (e.g., police) helps to prevent violence and adheres strict data privacy and security policies that align to national and international law [GSMA 2018]. Growing use of open data by governments increases transparency, empowers citizens, and helps to drive economic growth by record-keeping and tracking government data and local demographics. In disasters ICT can help in obtaining, communicating and transmitting accurate and timely information [ITU].	-	Proportion of individuals using the Internet; proportion of individuals owning a mobile phone; United Nations' E-participation index [ITU et al. 2019].
17 PARTNERSHIPS FOR THE GOALS	Mobile sector supports collaboration between public and private sector [GSMA 2019]. ICT is crucial in achieving all of the SDGs, since ICT acts as catalysts that accelerate all three pillars of sustainable development – economic growth, social inclusion and environmental sustainability – as well as providing an innovative and effective means of implementation in today's inter-connected world [ITU].	Fixed Internet broadband subscriptions, broken down by speed [UN 2017]. Proportion of individuals using the Internet [UN 2017].	Proportion of individuals using the Internet; Internet broadband subscriptions per 100 inhabitants; proportion of businesses using the Internet; proportion of businesses receiving orders via the Internet; proportion of businesses placing orders over the Internet [ITU et al. 2019].

Table 4-1. Existing linkage between the UN SDGs and mobile communications/ICT.

Table 4-1 clearly shows that affordable access to the Internet for everybody is critical to achieving the SDG goals as access to information is the panacea for everything and is significantly cheaper and faster than building physical infrastructures of schools, hospitals, etc. Furthermore, all infrastructures providing services can be partly offered remotely with the help of an Internet connection and appropriate applications.

4.1.2 Existing indicators

In the global indicator framework for the UN SDGs [UN 2017], there are seven indicators that are defined to be related to ICT and are systematically monitored. They are highlighted in bold in Table 4-1. These indicators present a very high-level view and are not adequate for investigating the impact of mobile communications on the UN SDGs. In order to provide a more holistic view on what can and even should be measured we need other metrics as well. The metrics can serve various stakeholders in the mobile communication industry to guide their activities into a more sustainable direction, in a more sustainable manner. Traditionally, cellular mobile communication networks have been characterized by sets of minimum technical requirements for the different generations of International Mobile Telecommunications (IMT) systems defined by the ITU. The latest systems, IMT-2020, need to fulfill requirements on the following indicators: peak data rate, peak spectral efficiency, user experienced data rate, 5th percentile user spectral efficiency, average spectral efficiency, area traffic capacity, latency in terms of user plane latency and control plane latency, connection density, energy efficiency, reliability, mobility, mobility interruption time and bandwidth as illustrated in Figure 6-1 [ITU-R 2017]. With the advent of 6G, a new set of indicators needs to be defined.

The impact of mobile communications on the UN SDGs has been measured with indicators which are summarized in Table 4-2 where the indicators in bold text are from the UN Global Indicator Framework for the SDGs.

4.1.3 Identifying opportunities of 6G

Building on the existing mapping between the UN SDGs and mobile communications or ICT, we note that future technologies, such as 6G, are not thoroughly captured in the linkages or indicators. The UN SDGs can be seen as an opportunity for 6G to make a positive impact and to be an accelerator for the advancement of the UN SDGs. Reducing inequality and securing a better quality of life for those in the most vulnerable position in a sustainable way is at the heart of the goals. Pursuing the UN SDGs is a social and societal effort and can direct public resources to, among other things, extending the network infrastructure required for 6G beyond urban centers and developed countries. A prerequisite for this is the creation of 6G use cases that support the UN SDGs and can guide the development of the standard. Implementing 6G technology should be affordable and not require disproportionate infrastructure investment. Another opportunity is to exploit the existing and evolving infrastructure, which is already being built, including the fiber optic backhaul infrastructure. An overview of the opportunities presented by 6G in assisting the achievement of UN SDGs identified by the White Paper Expert Group is summarized in Table 4-2 using the PESTLE analysis framework.

Dimension/ Perspective	Opportunities
P - Political	· Communication networks are seen as a necessity for basic standards of living. · Increasing consensus on funding networks in areas with low business opportunity. · Users can manage most personal data, even if web-scale companies still own masses of our data.
E - Economic	· Better communication infrastructure can stimulate local economy growth in poor communities by lowering barriers to economic resources by supporting access to financial services and generating employment opportunities for people living in extreme poverty. · 6G may facilitate small businesses through increased market transparency: helping to build trust in online services and supporting cross-border e-commerce through better (online) business security and data protection. · 6G may help in generating and finding employment opportunities, supporting access to financial services, facilitating access to utility services, providing digital identity services and emergency and disaster assistance. · Opportunities for entrepreneurship or cooperatives with connectivity and online mentoring. · Access to reliable online weather forecasts to reduce unnecessary watering and to define optimal cultivation time. Affordable analysis of soil quality benefitting of AI. · Data collection with online tools and support for identifying breeds e.g. with shape recognition. Also, peer-support and networking possibilities to reduce inbreeding in cattle.
S - Societal	· Mobile communications can help with illiteracy and if not that, still help in reducing inequalities due to illiteracy. · Having easy online access to land ownership or property data with possibilities to also sign and verify the authenticity of documents e.g. by blockchain could revolutionize ownership for the most vulnerable. · Remote consultations for pregnant women including measuring an unborn child's heartbeat. For risk pregnancies, e.g. mothers expecting twins, ultrasound could be replaced with novel low-cost technologies with aid of safe in-body measurement devices or similar. · Leverage 6G for smart water grid management/6G for remote water resource management and supervision. · Emission trade based on globally distributed sensors measuring real time emissions.

Dimension/ Perspective	Opportunities
T -Technological	· The access to free (or affordable) and virtually unlimited spectrum resources is among the key factors that influences the capability of mobile communications technologies to contribute to the UN SDGs. In 6G, the utilization of spectrum sub-THz and THz bands above 100 GHz may significantly relax spectrum scarcity constraints commonly encountered in preceding generations. Moreover, these THz not only support the scalability of communications, but may also be conveniently exploited for high-precision localization, sensing and imaging applications even in underserved ('under-sensed') areas. · The adoption of open source principles and/or a unified global standard and early interaction with all stakeholders in the development of mobile technologies, platforms and services may further unlock opportunities for co-innovation and co-creation within the ecosystem, with possibility of more meaningful involvement of the UN SDGs beneficiary stakeholders. The confluence of mobile technology development and open source models is becoming increasingly prominent in 5G and will likely be the norm in the 6G era. · The technical KPI enhancements (e.g. faster data rates, lower latencies etc.) envisioned in 6G (relative to 5G KPIs) may potentially bring deeper immersion and interaction for users (e.g. holographic interaction, tactile Internet etc.), even in hitherto underserved areas. Such capabilities may add value to remote service delivery (e.g. health, education etc.) in ways that far exceed tele-X solutions from legacy mobile technologies. · The envisioned migration of most computing and intelligence to the edge (closer to end users) in 6G may further contribute to bringing technology-enhanced SDG interventions closer to local points of need. To that end, 6G contributes in way that enhances service immediacy, local autonomy and adaptation to local environmental contexts (both physical and virtual).
L - Legal and regulatory	· Sustainability for driving spectrum use to ensure efficient use of spectrum and supporting different stakeholders to allow the deployment of 6G networks.
E - Environmental	· 6G has the potential to enable solutions in various disciplines, e.g. virtual learning, smart travelling etc., that eventually reduce the carbon footprint. · If the energy needs of 6G technology will be provided by low-cost renewable energy technologies, it will promote the use of clean and affordable energy technologies. · The climate change goal to limit global warming by 2 degrees from the pre-industrial era can be facilitated by using a combination of 6G technology together with clean energy technology. · Efficient and intelligent 6G networks could improve the communication and energy systems' resilience and could play a key role in achieving zero (or even negative) carbon emission solutions. · Innovative solutions to promote the circular economy are possible using 6G technology.

Table 4-2. Identified key opportunities of 6G.

4.2 Developing a novel linkage between 6G and the UN SDGs via indicators

This white paper set out to establish the mapping of 6G on the UN SDGs, a task that has proven to be rather elusive, because there is no other prior work on the topic. To address this gap, the White Paper Expert Group carefully examined the possible linkages between 6G and the UN SDGs, leading to the following ex-ante three tier analytical framework that was preliminarily introduced in Chapter 1. Specifically, the proposed framework draws linkages to the UN SDGS by viewing 6G as: 1) a provider of services to help steer communities and countries towards reaching the UN SDGs', 2) an enabler of measuring tools for data collection to help report indicators with hyperlocal granularity, and 3) a reinforcer of a new technological ecosystem to be developed in line with the UN SDGs. Next we briefly expand on the proposed three pillars.

4.2.1 6G as a provider of services

The 2030 Agenda sets forth a blueprint for tackling focal problems facing society today across the globe. It becomes evident that irrespective of geographical location or geopolitical standing, many communities are becoming progressively worse while being trapped in downward feedback spirals that prevent people, authorities, and businesses reaching their goals in a sustainable manner. For the most part, the lack of visible and viable opportunities that could otherwise facilitate people and institutions steer their actions towards community betterment cultivate meta-narratives of hate, deviance, polarization, environmental degradation, radicalization, conflict, terrorism, and war. For example, one can observe that across the Human Development Index (HDI), communities lacking access to good education cannot contribute positively to the development of job and wealth creation that leads to social change and advancement. In this context, 6G technology will deliver services and solutions that will empower individuals and communities to adopt self-correcting processes and steer actions towards long term sustainability.

Specifically, next-generation 6G wireless services built on pervasive AI and fractal network protocol stacks will have a profound effect on how individuals and communities perceive space and time. For instance, multisensory applications (virtual reality (VR), augmented reality (AR), mixed reality (MR)) will bring about new forms of human mobility that will enable individuals and large groups to break away from existing patterns of interaction and temporo-spatial understandings of the world. New smart surfaces, autonomous systems, and wireless brain-computer interactions will also reshape our perception of time and space in drastically new ways.

4.2.2 6G as an enabler of hyperlocal measuring tool

Following the initial publication of the UN SDG indicators [UN 2017], many international governmental and non-governmental organizations voiced concern about existing data gaps that hinder the capacity of authorities to report on their performance. Today, of the 169 targets in the Agenda, OECD countries report data for only 105[6]. The White Paper Expert Group further examined the scope of this data-gap and conducted a systematic analysis of all available UN SDG indicators metadata, looking at how indicators are measured in the field[7]. The conclusions of this exhaustive exercise are twofold: (1) most indicators are currently being measured with asynchronous and anachronistic tools (questionnaires or household surveys) and are not up to par with current advances in data management and data retrieval; (2) there is a discord between the breadth of some indicators and the inefficacy of instruments to collect disaggregated data. Against this backdrop, this white paper anticipates the instrumentation of 6G as a scientific tool to help authorities and other stakeholders to collect data at a much more local, hyperlocal and granular level than currently. The use of 6G technology as a measurement tool will not only enable the reporting of missing KPIs, and thus reduce the data-gap, but it will also enable the monitoring of new indicators that will become relevant in the near future.

For instance, mobile coverage is a basic prerequisite for the utilization of the an IoT ecosystem that could help communities meet their goals. Sensors that capture and transmit data quickly over WiFi, 3G, 4G and 5G are becoming more accurate and efficient. The development of mobile networks helps data from the sensors to be collected and transmitted more efficiently, faster and across larger distances. An exponentially increasing amount of data is being made available from all types of geographical, economic, and social contexts, while the technologies for system and sub-system monitoring is growing to full maturity. Thus, the instrumentation of 6G technology for monitoring the KPIs is expected to achieve major improvements in increasing the sampling rate, improving the veracity and variety of the measured data, thus reducing costs. The communication infrastructure (mobile networks) can be used as a sensor and as innovative tool to monitor sustainability and efficiency in many different forms and contexts. For example, in the developed world, the penetration of home IoT devices can be treated as a sign of prosperity and well-being, enabling governments to identify those neighborhood blocks that require more support than others. Respectively, indicators such as the volume of streaming content, data consumption, and data production can all lead to better hyperlocal KPIs

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which can be monitored, reported and addressed by stakeholders in near real-time.

4.2.3 6G as a reinforcer of an ecosystem aligned with the UN SDGs

It is anticipated that 6G technology will have a disruptive impact that will bring about positive changes in the way individuals, communities and governments steer towards solutions across all aspects of life. At the individual level, the envisioned services that will be derived by the 6G wireless systems will call for a new bottom-up mandate of social relations and conduct. For example, hyperlocal monitoring of energy consumption and the CO_2 footprint can work as a reinforcing feedback loop leading to individual self-adjustment. For example, new services will provide individuals and communities with access to KPIs on their personal energy footprint. The impact of 6G will also be relatively greater in the domain of governance, public administration, and through institutions (e.g. 6G Hospitals, 6G Schools, Industry 4.0, e-government). The interconnection between people, communities, and institutions along with the increasing use of heterogenous data streams in the area of public policy decision-making, is set to reconfigure how people, governments and the industry will be governed in the future. For example, it has often been recognized that the role of 6G as an enabling technology needs to be developed in accordance with the relevant UN SDGs including, but not limited to the new governance paradigm on energy efficiency, recycled materials, non-toxic leakage, inclusiveness, partnerships, privacy/security, and democracy. Thus, high-end novel technology solutions enabled by 6G such as telepresence and mixed reality, accurate positioning, wearable displays, mobile robots and drones, specialized processors, and next-generation wireless networks will raise new questions with regards to law, privacy, values, corporate accountability and government transparency. The first 6G White Paper [Latva-aho & Leppänen 2019] outlined that the current smart phones are likely to be replaced by pervasive XR experiences with lightweight glasses delivering unprecedented resolution, frame rates, and dynamic range. But at the same time, we must ensure that 6G is developed keeping mind the UN SDGs for example to work towards maximum coverage/connectivity also in rural areas.

4.2.4 Linkage between the UN SDGs and 6G

The starting point in finding novel linkages between 6G and the UN SDGs was to see which targets, and more specifically, which indicators 6G can impact. The expert group looked into where 6G can impact the indicators by identifying what 6G can do to influence the indicators [UN 2017] to meet the given UN SDG targets. The expert group used the developed three-tier analytical framework of 6G when examining the linkages between individual targets and their indicators. First a set of goals was selected based on the input of the expert group, then the targets for these goals were examined together with the matching UN indicators, and finally a framework of how 6G can either 1) provide services to help steer communities and countries towards reaching the SDGs, or 2) enable measuring for data collection to help reporting of indicators, or 3) reinforce a new technological ecosystem to be developed in line with the UN SDGs. When doing this, the cross-cutting issues (entry points for transformation) as suggested by the UN Global Sustainable Development Report [UN 2019b] were considered. These are: human well-being and capabilities, sustainable and just economies, food systems and nutrition patterns, energy decarbonization with universal access, urban and peri-urban development and global environmental commons and are summarized in Fig. 1-1. Table 4-3 presents examples of the developed linkages for the selected goals so that they present each of the entry points. These examples serve as the starting point for a more detailed mapping of 6G with the UN SDGs that we encourage the wider community to work on.

◎ UN Targets	◐ UN Indicators	👍 6G can
1.2 By 2030, reduce at least by half the proportion of men, women and children of all ages living in poverty in all its dimensions according to national definitions	**1.2.1** Proportion of population below the international poverty line, by sex, age, employment status and geographical location (urban/rural) **1.2.1** Proportion of population living below the national poverty line, by sex and age	**Expand the connections** between people with processes, data, and businesses. **Help incorporate one-man shops** into the market. **Facilitate the use of micro-payments and digital money**. **Provide advanced life-long learning opportunities** to previously marginalized areas. **Help train local educators** with remote virtual platforms. **Maximize the use of ICT** by delivering virtual computational power to remote areas.
1.3 Implement nationally appropriate social protection systems and measures for all, including floors, and by 2030 achieve substantial coverage of the poor and the vulnerable	**1.3.1** Proportion of population covered by social protection floors/systems, by sex, distinguishing children, unemployed persons, older persons, persons with disabilities, pregnant women, newborns, work-injury victims and the poor and the vulnerable	**Achieve better prevention measures** by enabling self-risk and self-awareness through remote learning. **Extend the use of remote eHealth services and diagnostics**. **Create new labor markets for remote rural areas** enabled by smart farming and autonomous control systems. **Bolster the connectivity of production and consumption markets** with the use of autonomous vehicles. **Achieve real time communication infrastructure between institutions** (hospitals, schools, governments) to enable better analytics and predictions.

◎ UN Targets	◔ UN Indicators	👍 6G can
3.3 By 2030, end the epidemics of AIDS, tuberculosis, malaria and neglected tropical diseases and combat hepatitis, water-borne diseases and other communicable diseases	**3.3.1** Number of new HIV infections per 1,000 uninfected population, by sex, age and key populations **3.3.2** Tuberculosis incidence per 100,000 population **3.3.3** Malaria incidence per 1,000 population **3.3.4** Hepatitis B incidence per 100,000 population **3.3.4** Number of people requiring interventions against neglected tropical diseases	**Provide digital health solutions** that will increase self-awareness of risks. **Deliver eHealth monitoring services** (bloodsugar, liver, heart) to mothers and children during and after pregnancy. **Enable e-registers** for monitoring the availability of vaccines. **Help implement a global early warning alerting mechanism.** **Enable real-time communication between hospitals** for sharing of information about positive cases and availability of medical resources. **Accelerate scientific breakthroughs** with increased sharing of information and computational resources. **Support remote learning, diagnostics, and training** to medical staff and nurses. **Provide hyperlocal notifications and contact tracing capabilities** in regions where electricity and communication networks are unreliable. **Deploy unmanned vehicles** for food and medical deliveries in lockdown areas.
4.2 By 2030, ensure that all girls and boys have access to quality early childhood development, care and pre-primary education so that they are ready for primary education	**4.2.1** Proportion of children under 5 years of age who are developmentally on track in health, learning and psycho-social well-being, by sex **4.2.2** Participation rate in organized learning (one year before the official primary entry age), by sex	**Increase access to remote learning and developmental activities** to children under 5 years. **Enable improved socialization** through virtual interactions. **Improve remote access to pediatrics** in locations with poor connectivity. **Facilitate remote and virtual training** of local pediatricians. **Help improve and develop the knowledge and skills** of local medical community. **Deliver prosthetic technologies** to support handicapped children. **Permit family and experts to monitor** the cognitive development of children with Brain-Computer Interfaces. **Help coordinate virtual meetings** for preschoolers.

◎ UN Targets	◐ UN Indicators	👍 6G can
7.3 By 2030, increase substantially the share of renewable energy in the global energy mix.	**7.2.1** Renewable energy share in the total final energy consumption **7.3.1** Energy intensity measured in terms of primary energy and GDP	**Help modernize power grids** to improve efficiency and sustainability at lower cost (smart grids). **Provide support for autonomous system control** with faster distributed measurement technologies. **Enable scheduling and connectivity** with domestic appliances.
9.c Significantly increase access to information and communications technology and strive to provide universal and affordable access to the Internet in least developed countries by 2020	**9.c.1** Proportion of population covered by a mobile network, by technology	**Help telecommunication operators achieve greater mobile network coverage** enabling access also to the most remote areas. **Increase the percentage of inhabitants living within the range of mobile-broadband network**. **Improve market competition** by enabling smaller operators to participate in vertical markets.
11.5 By 2030, significantly reduce the number of deaths and the number of people affected and substantially decrease the direct economic losses relative to global gross domestic product caused by disasters, including water-related disasters, with a focus on protecting the poor and people in vulnerable situations	**11.5.1** Number of deaths, missing persons and directly affected persons attributed to disasters per 100,000 population	**Facilitate immersive virtual training** to front line practitioners. **Implement rapid deployment force of autonomous and unmanned rescue vehicles** in disaster areas to maximize the discovery of missing persons. **Help create radio technology to locate trapped victims**. **Develop hyperlocal warning and emergency alert systems** that prevent deaths. **Improve personal awareness** of risks. **Improve connectivity in disaster areas** where energy and communication sources are damaged. **Enlarge existing disaster risk reduction strategies** by providing remote training to local governments. **Improve national, regional and multinational disaster coordination system.**

Table 4-3. Mapping of 6G with UN SDG framework targets via indicators.

4.3 Possible 6G Indicators

The White Paper Expert Group produced an extensive list of indicators that either measure the development or the performance of 6G aligned with the UN SDGs, or the value it can provide to the advancement of the sustainable development goals. In order to classify the proposed 6G indicators, we used our three-tier analytical framework from Section 4.2 together with the entry points discussed in Chapter 1 and inserted the suggested indicators in the relevant categories.

It has already become visible that wealth generated by economic growth will become concentrated in the hands of a shrinking minority and that rates of growth will be low in Western countries. Boundaries to growth will be set by, for example, the ageing population especially in the Western countries and our planet's ecological carrying capacity all around the world. This means that statistical indicators of well-being and genuine development will take on a more important role[8]. Based on our work it seems that the proposed indicators for 6G already reflect this vision: most of the suggested indicators measure the services 6G can provide to enhance human well-being.
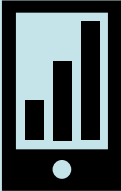
Table 4-4 presents the new 6G related indicators developed within the expert group for each of the entry points. The entry points were used in the classification of indicators because they are cross-cutting for all 17 goals and offer a more holistic view. The entry points are described in more detail in [UN 2019b, pp. 163-71] and summarized in the table. Looking at the indicators through the entry points also ensures the creation of a framework where no individual goal is overly advanced at the cost of another. Having indicators for different entry points allows us to set target values that tackle more than just one goal at a time. We present indicators that can be measured in numbers but there are many fundamental issues such as the availability of a certain 6G enabled service or the coverage that can be measured by simply answering yes/no. The latter should provide the baseline for numeric indicators.
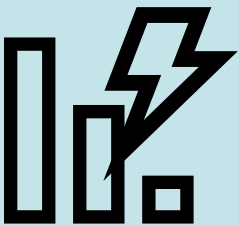
It should be noted that Table 4-4 presents a very preliminary view on possible 6G related indicators that act as the opening of the debate on what kind of indicators should be defined for 6G while taking into account the growing importance of meeting the UN SDGs. They are not necessarily specific to future 6G technologies. In addition, no target values have yet been defined for the indicators. We invite the wider community to develop 6G-specific indicators aligned with the UN SDG developments towards 2030.

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[8] *https://media.sitra.fi/2020/03/04130112/ 2021544megatrendikortit2020enverkko.pdf*

Entry points from [UN 2019b]	6G as a provider of services	6G as an enabler of hyperlocal measuring tool	6G as a reinforcer of an ecosystem aligned with the SDGs
Human well-being and capabilities	The availability of appropriate technologies and services related to quality basic services: health, education, water, sanitation, energy, disaster risk management, ICT, adequate housing and social protection (Yes/No) and the number of provided 6G enabled services for example: the number of 6G enabled eHealth services. The number of digital mobile telecommunication education utilizing disruptive technologies. Proportion of e-learning material to be used with a mobile device with a mobile connection out of necessary learning material; proportion of accessible material (for people with disabilities), in different languages. The number of standardized procedures to report violence/ harmful practices against girls/ women, human trafficking etc. via mobile app. The number of people working remotely. The number of 6G holographic telepresence access points per population. The price of connections compared to a commodity (e.g. connection price vs. 1 kg rice).	Mobile coverage. Mobile area coverage. 6G transmitting sensor data on: living conditions (temperature, humidity, inhabitants per m^2 etc.; natural disasters, diseases (epidemics); mobility of humans & animals; quality of water, air etc. 6G sensing data using radio waves for sensing purposes.	Price of connectivity. Affordable technologies/ devices. Price of privacy.

Entry points from [UN 2019b]	6G as a provider of services	6G as an enabler of hyperlocal measuring tool	6G as a reinforcer of an ecosystem aligned with the SDGs
Sustainable and just economies	Mobile subscription considered a basic need in any given society (yes/no). Unrestricted access to Internet and mobile services (yes/no). Number of mobile birth registrations and personal electronic identification. Availability of public mobile services such as tax/license services, census, banking etc. Availability of mobile financial transactions (micro payments) (yes/no). Number of mobile services supporting circular economies.	Data subscription models available and their relative proportion. Use of data (i.e., what subscription models poor people use, do they even have access to data, who uses the data, only the rich?). Percentile of mobile devices suited for browsing and rich data consumption (chiefly: screen size and resolution) e.g. browsing/web sites, video consumption, gaming, video calls for work and social purposes. Share of value in the mobile ecosystem: distribution of monetary value gained and spent per actor in the mobile ecosystem (infrastructure providers such as electricity, operators; device manufacturers; retailers; remanufacturers; second-hand sellers; end-of life material recyclers; content providers; users; etc.).	Distribution of mobile terminals by price (how many expensive terminals are bought in a country). % global coverage covered by 6G. Business models of operators (just or not)? Circular economies in 6G devices. E-waste management of new devices.

Entry points from [UN 2019b]	6G as a provider of services	6G as an enabler of hyperlocal measuring tool	6G as a reinforcer of an ecosystem aligned with the SDGs
Food systems and nutrition patterns	Percentage of mobile devices with apps to provide information on nutrition. Availability of public mobile services such as weather forecast for farmers. Amount of food waste in kg in grocery stores/ restaurants using appropriate mobile apps to circulate food going to be wasted. Use of smart digital labels. Number of IoT devices for agriculture purposes. Percentage of farms that are covered by IoT services.	Number of registered users using apps on weather forecasts, to circulate food. Data gathered from the use of smart digital labels. Data gathered from sensors used in agriculture (for instance the use of fertilizers).	Number of non-toxic, non-leaking devices. New technologies, e.g. sensors working in harsh conditions. New sensing functions (device-free) integrated in the mobile communication systems.
Energy decarbonization with universal access	Number of mobile apps that help to reduce energy consumption.	Number of sensors monitoring energy consumption.	% reduction of energy consumption kWh. % increase of energy efficiency. % reduction of energy consumption due to new functions to avoid energy consumption.
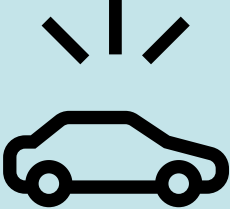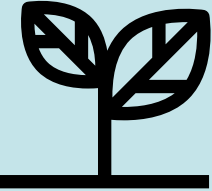
Entry points from [UN 2019b]	6G as a provider of services	6G as an enabler of hyperlocal measuring tool	6G as a reinforcer of an ecosystem aligned with the SDGs
Urban and peri-urban development	Number of autonomous vehicles. Number of seamless transport systems. Unrestricted access to internet and mobile services (yes/no).	Area coverage to include the rural areas where agriculture, forestry and tourism are big industries.	Number of operators operating in the region.
Global environmental commons	Coverage of monitoring systems used for protecting fauna and flora. Apps to report observations related to environmental changes. Coverage of IoT services for inhabitants.	Number of sensors monitoring fauna and flora. Number of people/ users reporting their local observations related to environmental changes with mobile devices/ apps. Number of homes using a certain defined level of IoT (electricity, water consumption, waste management).	Percentage of recycled materials in new 6G devices. Reductions in energy consumption in mobile phones, base stations, and batteries. Reductions in energy consumption due to 6G mobile networks.

Table 4-4. 6G indicators per entry points to UN SDGs.

Key challenges

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The UN SDGs form the blueprint for a better and more sustainable future for all [UN 2019a], and the mobile communications sector will be in a unique position to contribute to their achievement with the ongoing deployment of 5G networks and the recently started research and development of 6G. However, we also identify a number of issues that, unless properly addressed, will diminish 6G's potential contribution. Reflecting on the megatrends identified in [Dufva 2020], we can point out a number of challenges that 6G design should address. In revisiting the Quintuple Helix model [Carayannis et al. 2012] for 6G-driven sustainable development presented in Chapter 3, we can identify inherent challenges within each subsystem (see Fig. 5-1) that may contribute to undermining 6G's utility for enhancing the systemic synergy of knowledge, know-how, and innovation that is required for the sustainable development of 6G. In this chapter, the key challenges associated with each subsystem are identified and discussed in more depth.

5.1 Political, legal and regulatory challenges

Technology is embedded in political, legal and regulatory systems but it is growingly seen as a geopolitical issue of power raising concerns over future resource orchestration. Many questions arise including: Who will own the accumulating data? Who will get to decide on technology and who sets the rules and regulation? Spectrum management is at the heart of 6G and any wireless technology development and it will face challenges due to a wide variety of spectrum bands with highly distinct deployment characteristics and spectrum access models with different levels rights and the need for spectrum

sharing, see [Pärssinen et al. 2020] for more details on 6G spectrum discussions. The advanced capabilities of 6G will benefit from a fiber backhaul that connects the distributed radio network to the core network. The challenge is that even leading economies have a relatively low fiber penetration because of underinvestment in pure fiber networks. 6G will likely combine a range of radio access network technologies from macro cells to small cells with very high-capacity short-range links, the latter offering denser coverage than 5G and increased capacity and quality of service. Small cell network architectures will be deployed first and foremost to urban centers and indoors where the natural demand for high bandwidth capacity and low latency is at the highest. Dense small cell deployments have usually been hindered by various factors including regulatory barriers and inconsistent local approval processes[9]. The impact of these inhibitors may be more pronounced for the required hyperdense small cell deployments in 6G.

On the other hand, 6G technology could bring a regulatory disruption allowing advanced specialized networks in a network-of-networks topology. Such sub-networks could be operated by various municipalities, communities or enterprises. Some indications of this are already visible as cities are investing increasingly more in fiber optical infra to enable communication of sensors, which they have installed in various properties and in traffic infra.

5.2 Economic challenges

When analyzing the scenarios concerning the redefinition of the economy, a variety of factors supporting the achievement of the UN SDGs are encouraging, see

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[9] Global5G.org White Paper on Small Cells - How Europe can accelerate network densification for the 5G Era, July 2019. *http://global5g.org/small-cells*

Political, legal & regulatory challenges

Knowledge

Political system

Knowledge creation

Political and legal capital

- Connectivity at sustainable cost
- Extreme coverage
- Security, privacy and trust

Know-how

Know-how

- Geopolitical concerns and trade tensions
- Regulatory barriers to hyperdensification
- Complexities of data ownership

Knowledge

Innovation

Technological challenges

Media-based and culture-based public

Knowledge creation

Information and social capital

Know-how

Innovation

Sustainable development of 6G

Innovation

Societal challenges

Education system

Knowledge creation

Human capital

Knowledge

Know-how

- Ensuring demographic equality
- How societal aspects shapes business objectives
- Going beyond access to information

Knowledge

- Energy consumption
- Managing e-waste

Knowledge

Know-how

Innovation

Innovation

Environmental challenges

Natural environment

Knowledge creation

Natural capital

- Affordability
- Infrastructure investments

Economical challenges

Economic system

Knowledge creation

Economic capital

Knowledge

Know-how

Circulation of knowledge

© 6G Flagship

Identified key challenges within the Quintuple Helix model for 6G-driven sustainable development. Framework adapted from [Carayannis et al. 2012, p. 7].

[Yrjölä et al. 2020] for details. Open value configuration and open source principles may lead to high impacts. Similarly, crowdsourcing and crowdfunding may enable unprecedented innovations and industry 5.0 is expected to lead to revolutionary things. However, there are concerns about how the anticipated business models are realized. Given the global trend on the impact of platforms, a common concern is how local societies can be empowered.

Affordability will be another challenge for 6G as the strengthening of relative power towards the 2030 power configuration is transforming from a multipolar world to a poly-nodal world and that power will be determined in economic, technological and cultural networks and the interaction that occurs on them. Previously public network funding has been allocated to areas with low or no coverage, which has recently been changed to favor e.g. smart city development, worksites and ecosystems.

There is a real risk that the digital divide will grow between regions unless the 6G family of standards does not allow for affordable solutions, and address how barriers to digitalization can be overcome. Aspects here include community networks, a freemium model for access and information spots in rural areas to empower local communities, see [Saarnisaari et al. 2020] for more details on 6G for remote area connectivity.

Subsequent to telecommunications market liberalization in the 1990s, the deployment of mobile communication infrastructure has been driven by business perspectives, which has ensured competition and lower prices. On the other hand, the communication infrastructure should be revisited as a natural monopoly like any other essential infrastructure such as sanitation or energy with municipal governance. In addition to being fully controlled by commercial operators, mobile services could be also operated by municipalities or local communities, which could favor more equal access to the services. Naturally, this assumes that the instruments for funding the infrastructure investments exist. However, the investment would pay back in societal development by improvement of education, health care, safety or digitalized agriculture and industry. However, as can be learnt from the underperforming telco monopolies in the 60s, a superior approach may be to frame regulation in the right way while continuing with a private sector approach in line with such framework.

5.3 Societal challenges

The megatrend addressing digital empowerment and diversification of the population anticipates that learning capabilities will play a key role in the future, which means educational structures and policies will need to be revisited. Even if the educational methods take a huge leap with holopresence, AI and digital twins, high technology will not be available equally to all who need it. The trends in mobile only for the next billion users will take monumental efforts and a significant change of paradigms.

Mere access to information is not enough, rather technology should help people towards acting and collaborating to achieve sustainability goals in unison. To trigger and prioritize the actions, a change in mindset is needed from business only to business objectives framed by and consistent with societal objectives. Often, mobile communication has been considered a luxury need, but today after five decades of mobile technology there is plenty of evidence that mobile technology is a pervasive enabler of basic human needs and assuring better standard of life.

Ensuring, demographic equality is another significant societal challenge: Gender gaps in literacy and political power, and lack of diversity in the composition of innova-

tion teams may harm the development of 6G use cases concerning the attainment of sustainable development goals. Ensuring native security and data privacy is also a key challenge in 6G that calls for global standards and joint regulations. Advanced technologies should be considered as the network architectures evolve in the future.

5.4 Technological challenges

To address issues related to sustainability we may need consider both dimensions of technological capability and service attributes such as coverage, latency and reliability. In many cases quite a basic service delivered such as >100 MB/s broadband access to the entire world's population could boost the potential for business, education, health, and further. For these cases, the challenge boils down to providing connectivity at a sustainable cost, which is a big challenge but not a new one. It can be addressed by several new aspects of 6G: integration of new accesses such as satellites and high-altitude platforms (HAPs), cost efficient transport and low-consumption nodes. Other challenges can better be addressed by new specific technological components with a more dedicated coverage, for instance in homes, on streets, industries, etc. This could include new spectrum for access, new advanced antenna techniques, precise localization and sensing. Many solutions would be on an intermediate level on both scales, meaning new capabilities with a wide service coverage, such as advanced broadband provided in populated regions of the world. Global sensors would represent an extreme on both scales, requiring both extremely low consumption and extreme coverage.

The 6G era envisions device densities of 1,000 connected devices per human or 100 devices per m^3 [Latva-aho & Leppänen 2019, p. 14]. Every connected device in a hyperlocal, local community or city context presents a potential entry point to our most sensitive and personal data. The continuously evolving hyperconnected landscape will expand beyond the contemporary networks in use today. These developments will lead to new types of threats and increase the complexity of security, privacy and trust issues and the respective mechanisms to counter the threats, see [Ylianttila et al. 2020] where research challenges for 6G are discussed in more detail.

5.5 Environmental challenges

While technology is increasingly embedded in everything, resources should be used more sparingly (ecological reconstruction) and shared more fairly to close the sustainability gaps. This calls for international consensus at a time when relational power is strengthening and becoming more diverse.

When it comes to ecological reconstruction, energy consumption in all forms will be a key issue for 6G. While

technology offers new solutions for conserving energy, increasing the capabilities of technology and increasing the use of technology also simultaneously increases the demand for energy. Therefore, new standards should seek step-change improvements in performance beyond that achieved by 5G. New KPIs must also be developed for measuring the energy consumption, see [Mahmood et al. 2020]. A ten-fold increase in broadband capacity calls for a comparable increase in energy efficiency per bit to make 6G carbon neutral. Furthermore, the antici- pated 6G hyperdense network deployments and device densities would further exacerbate an already critical e-waste management challenge, necessitating more radical circular approaches.

Preliminary action plan for different stakeholders

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To truly succeed in achieving the UN SDGs, the mobile communication sector needs to undergo major paradigm shifts to enable affordable access to broadband communication almost everywhere for almost anyone. The paradigm shifts and change in thinking about our route to 6G needs to happen for all the stakeholders identified in Chapter 2: research and educational organizations; governmental, regulatory and standardization organizations; users; industry including e.g. mobile network operators, network equipment manufacturers, and application and service providers; verticals, and other business drivers. The motto that should drive all the stakeholders is: "How to provide more for less for more people in a sustainable manner?" In short, how to make the next generation of wireless affordable without diluting the performance requirements while including a new breed of social impact indicators which are not always directly quantifiable in terms of money.[10]

Pure business-driven operations where infrastructure, access and services are primarily dependent on the MNOs' business decisions have resulted in situations where the challenge areas with less revenue potential still remain underserved. Therefore, the achievement of the UN SDGs calls for new societal models including, e.g., community-driven networks whose emergence is dependent on the underlying regulatory environment. These challenge areas exist even in developed countries where the gap between rural and urban areas is not yet bridged. For example, one critical point is the availability of spectrum which is in the hands of regulators. Concrete actions are needed in making spectrum available for networks in a flexible manner and not only to the existing MNOs. Different actions are needed for rural and urban challenges.

Research and educational organizations. The global launch of the 6G research originates from the research community[11] and the need for the research community to continue driving the 6G research is evident. Unbiased research and the facilitation of stakeholder interactions for the development of 6G that are not purely commercially driven are important especially in the early stages of 6G. Novel ideas and out-of-the box thinking on various aspects of 6G need to flourish and to allow broad discussions on the most promising and even surprising combinations of technology components needed to make 6G a reality.

Governments, including policy makers and regulators. Governments need to lead from the front and in a pro-active manner with long-term visions of the role of ICT and more specifically future 6G in achieving the UN SDGs and they need to formulate policies and regulations to get there instead of being purely reactive. For example, it will be essential to formulate policies that will give a boost to locally deployed networks by different stakeholders, moving away from a one regulation one country approach to multiple regimes for the same country optimized for different target user groups and regions. Also needed will be inter-operator roaming solutions that encourage local and private networks, as well as free or low-cost use of the radio spectrum to provide coverage to rural areas. Furthermore, this will require more revolutionary out-of-the-box thinking to not just auctioning nationwide spectrum licenses to raise income for the states but to make it available in alternative and shared ways to be treated as public and natural resource, like light, air and water. This would help to bring down the cost of service for everyone. In short, public policies and regulations with long-term objectives must drive the business and deployment of mobile networks, rather than vice versa.

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[10] *https://www.accessnow.org/cant-reach-u-n-goals-sustainable-development-without-internet/*
[11] *www.6gflagship.com*

Standard developers. Traditionally, performance requirements and applications have driven the development of every generation of wireless networks and their societal impact has been an afterthought. This should change as the industry embarks on developing 6G standards. The goals to achieving the UN SDGs should first and foremost concern developing standards, and as specifically stated in the first 6G white paper [Latva-aho & Leppänen 2019] it should be about societal impact and well-being, and should include new indicators. The inclusion of crowd sourcing and user involvement (i.e., communities) should be an integral part of the future open standards development process; it should not just involve technology experts.

Users. We expect a massive expansion in human possibilities in the way humans will be able to act and interact across physical, digital and biological worlds. The transhumanism trend reflects the rise of technology-driven evolution at an unprecedented speed of change, propelling deeper questions into what it is to be human from biological, behavioral, and human-machine-interfacing perspectives. By 2030 we could find a greater societal focus on sustainability, as well as the nature of humanity, values, creativity and self/social fulfillment and empowerment, calling for a human-centered computing approach and human-centered 6G development. It is essential to consider the wide variety of humankind and potential future users of technologies: who they are, what kind of factors help in their inclusion or cause their exclusion, and how we can empower them to critically reflect and evaluate their technology-rich everyday life and role of technology in it, and in the whole society. Unless every person has access to affordable broadband Internet and uses it in their daily life, the mission of achieving the UN SDGs would remain a distant dream. Therefore, this should be a key requirement as 6G is developed. All those users who still do not use the Internet by choice or for other reasons (e.g., lack of access, affordability, digital literacy) should be offered incentives to experience the Internet for free. This would let them know how it can improve their quality of life. Governments and service providers need to launch public awareness campaigns and make investment, e.g., in every school to have digital connectivity.

Mobile network operators. MNOs need to realize that meeting the UN SDGs would increase the size of the total available market size with possibilities to offer a completely new breed of applications and services at a price point that would be affordable and yet profitable because of the increased customer base, increased brand loyalty and potentially by increasing the pricing plans as the subscribers become wealthier and better educated. Rather than planning and deploying the same network solution in rural and under-connected regions as in the urban metropolitan areas, they ought to employ a more flexible approach to network design customized for different rural and suburban sections of the popula-

tion. This should look at aspects such as the terrain, availability of the power grid, demographics and the capacity to absorb digital technologies. Some examples are the use of shared spectrum, edge computing/caching, renewable energy, and crowd sourcing to build a more cost-effective network architecture. Partnering with the government, industry and local community would ensure that everybody's expectations are met in a sustainable, secured and trustworthy manner. An eco-system of local operators to complement existing MNOs needs to flourish to enable scale and faster times to deployment with equitable revenue sharing models.

Network equipment manufacturers. Although there are equipment manufactures of all technologies, they are generally optimized for urban areas and the digitally literate section of society serving a large number of subscribers. Manufacturers should cost-optimize these network elements for low-density sparse service areas, rather than strip down the equipment designed for urban metropolitan users. To keep the capital cost of network equipment down, there will probably need to be better cost sharing between manufacturers and service providers such that the equipment is paid for over a period of time rather than upfront. There could possibly be innovations in business models concerning where the revenue is shared between the two.

Application and service providers. 6G will enable a new set of applications and services that are based on 6G networks' ability to merge communication services with other capabilities such as accurate positioning and high-resolution imaging. For the various users of 6G in developed and developing worlds, the UIs need to be more user friendly, with audio/video-based interaction, automatic language translation and minimizing text-based (involving reading and writing) input-output, primarily for those who are not literate. Solutions to authentication and security must be simplified to match the digital capacity of the users, especially in the developing world. There is also a need to move away from charging the user for the application to charging the content provider and/or relying more on advertising revenue. Many of the applications helping users improve their quality of life (through support of many of the UN SDGs) can be made available for free from the service provider cloud (as digital public goods, DPGs) or government owned content servers in the cloud.

Verticals. Vertical industries and their public sector counterparts including stakeholders from areas such as automotive, healthcare, energy and other sectors will be the future users of the 6G technology. Adopting national and international level agreements for inherent changes that need to take place to meet the UN SDGs places significant economic constraints on the verticals. To transform their operations to meet the UN SDGs, the verticals will need to take everything the future technologies can offer.

Therefore, verticals need to engage early on in the process of 6G development and not wait for the telecommunications industry to define what 6G can bring for them. Also, special purpose 6G networks will be operated in the verticals and the various applications tailored for verticals' use will be running on the 6G networks. Therefore, the verticals should take an active role in 6G.

Additionally for the whole 6G ecosystem, there is a need to think of out-of-the-box and create new collaborative business models. For example, these could include: users as part of the revenue eco-system, federated deployment and interconnection of user equipment, a barter system of credits in money and goods, as well as direct negotiation between users and content providers or industry verticals. Another good example is emerging in the power industry with micro-grids, which ought to be looked into in the telecoms industry. Freemium models and free access to the Internet for basic content (i.e., non-video content) would help accelerate the subscriber base among the digitally disadvantaged. Free Internet in areas of extreme poverty would increase the possibility for providing education and business opportunities for people without means. The use of the cloud, block chain, edge computing, AI and other technologies should be leveraged to bring about a complete transformation in the mobile industry to democratize it with some control given to the users. At the present time, the industry, i.e., the mobile service providers have a monopolistic control over the subscriber base. This has been broken to some extent with the broadband mobile Internet due to net-neutrality. However, there is still a long way to go when it comes to network infrastructure deployment and revenue sharing.

Concluding remarks

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This white paper has launched the process of developing a linkage between 6G and the UN SDGs that are both targeted for 2030. This has turned out to be a complex task as the UN SDG framework comprehensively considers societal challenges and the development of 6G is still at an early stage. However, the role of telecommunications is inevitable when aiming to meet the UN SDGs. To bridge the gap, the role of 6G is here proposed to be seen to consist of three distinct viewpoints: 6G as 1) a provider of services to help steer communities and countries towards reaching the UN SDGs, 2) to enable measuring tools for data collection to help reporting of indicators with hyperlocal granularity, and 3) as a reinforcer of a new 6G ecosystem to be developed in line with the UN SDGs. By looking into where 6G can impact the indicators defined in the UN SDG framework from these viewpoints, we have outlined connections between 6G and the UN SDGs. This white paper has also started to derive a new set of indicators for 6G which are not yet included in the UN SDG framework or in the development of prior generations of mobile communication networks. A number of research questions for the future remains to be explored including the following:

· What is the role of 6G in meeting the UN SDGs?
· What are proper indicators for 6G?
· How can the public and private sector work together to build the most powerful 6G vision with the maximum UN SDG impact?
· How to avoid global fragmentation of both the UN SDG and 6G technology evolution?
· What roles should the different stakeholders take in the sustainable development of 6G?
· What are the roles of researchers and the research infrastructures and practices in the development of a sustainable future with 6G?
· How can the development of 6G and related technologies be optimized in the specific areas of the UN SDGs, such as climate change?

· How can the goals related to human and society development be achieved and how can bridges be created between human sciences, people as users of the technology and 6G developers in academia and beyond?
· How can the young generation be empowered to contribute to human-centered 6G development targeting the UN SDGs and the needs of those being marginalized or disadvantaged?

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White Paper on 6G Drivers and the UN SDGs

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