6G: The Joint Communication and Sensing Infrastructure
Expert Workshops by Thinknet 6G and MÜNCHNER KREIS

Workshop 4: Sustainability and 6G

31 March 2022

Executive Summary

This document is a summary report of the workshop "Sustainability and 6G", which was held on March 31st, 2022. Participants were from both the cellular/wireless industry and from other sectors that will benefit from the most important use cases for 6G, such as manufacturing, healthcare and mobility.

The main topics that were discussed were how to use 6G to improve sustainability in other verticals, how to improve the sustainably of end devices, and how to improve the sustainability of the 6G network infrastructure. The most important clusters that came up during the workshop were:

- Multi-stakeholder collaboration
- Economically attractive sustainability solutions
- Legal frameworks, regulation and standardization
- Research and system design for end-to-end sustainability
- Optimisation of energy usage
- End device recycling and refurbishment
- Sustainability-centric business models
- How to handle legacy systems
- Global alignment on priorities
- A systemic framework to include all stakeholders
- KPIs for environmental impact
- How to handle exponential growth

6G is set to become a pervasive and critical infrastructure, and it will include more devices and transmit more traffic than ever before. As the network expands to handle exponential growth in the number of devices and amount of traffic, sustainability becomes critical. The recommendations from the workshop are:

- Conduct multi- and interdisciplinary research to develop a common understanding of the sustainability challenges of verticals and to explore potential 6G based solutions.

- Explore opportunities to make 6G-based sustainability solutions economically efficient and viable.

- Provide harmonized legal and regulatory frameworks to support and to enable 6G-based sustainability solutions.

- Spread awareness to the end users about the different resources in a device, possible recycling options, and sustainable alternatives.

- Use legacy systems to your advantage.

- Keep the device as simple as possible and as powerful as necessary.

- Change business models related to 6G to incorporate climate and sustainability aspects

- Insist that priorities for 6G design and operations include input from all stakeholders, and that they are aligned globally.

- Develop a framework and processes to include ALL relevant stakeholders. Ensure that the 6G network is capable of adapting to new requirements as these change or as new technologies develop.

- Develop and standardize KPIs to measure the impact (both handprint and footprint) of IT applications on the UN SDGs.

- Tackle the problem of increased total energy consumption. Despite technological improvements in energy efficiency in the 6G network, exponential growth in the use of mobile communication will otherwise lead to increased overall energy consumption. Use 6G and other information technologies responsibly, to contribute to sustainability.

Motivation and Goals of the Workshop

While deployments of the 5th generation of mobile communication are still underway, research for the follow-up generation, 6G, has already begun. 6G will expand the speed and capabilities of the networks further to enable applications with significantly higher networking requirements, such as real-time digital twins and full autonomous driving. Also, 6G moves the focus from machines to human beings and to their interaction with the physical and virtual environment around them, by supporting highly available, reliable, and secure communication.

Implementing this 6G vision over a development cycle of 10 years requires a strategic plan that defines what is needed in terms of research, technology developments, service and application enablers, standards, policies and government actions, and the building of ecosystems to create and capture value.

Thinknet 6G at Bayern Innovativ (www.thinknet-6g.de) and MÜNCHNER KREIS (https://www.muenchner-kreis.de/) have jointly organised a series of four workshops focussing on 6G as the joint communication and sensing infrastructure, to provide orientation and input for developing a strategic plan. The goal is to answer the questions:

- What are the future opportunities and threats for society and mankind that could be addressed by 6G in the 2030s?
- What are the services and use cases that you think would be of highest value for you in 2030s?
- What are the key indicators of value and performance to describe the business impact you would want to see from 6G in 2030s?
- What do you expect from governments and regulation in the context of 6G?
- What should be the key topics of 6G research?

The series of workshops covered the topics:

- The 6G Network as a Multi-Sensor
- AI/ML-enabled 6G network services
- Security, privacy, trust and resilience in 6G
- **Sustainability and 6G**

To ensure that input from multiple sectors was included, roughly half the participants were from the cellular/wireless industry and the other half were from other sectors that will be the use cases for 6G, such as healthcare and mobility. This provides a 360-degree view on 6G, to include opinions from outside the 6G bubble.

The report at hand describes the results of the fourth workshop focusing on sustainability and 6G. A summary of the previous three workshops is available on the Bayern Innovativ website[1] and on the MÜNCHNER KREIS website[2].

[1] https://www.bayern-innovativ.de/en/networks-und-thinknet/digitization-overview/thinknet-6g/page/whitepaper-six-insights-into-6g-en

[2] https://www.muenchner-kreis.de/publikationen/

Introduction to the Topic “Sustainability and 6G”

Digital infrastructures, including 6G, influence sustainability and environmental impact via two main mechanisms. On the positive side (handprint), the 6G network provides the communication infrastructure that underlies digital applications to improve sustainability in various sectors, such as smart buildings, smart mobility, and smart cities. On the other side, the production, operation and decommissioning of devices, networks, and data centres use rare metals, and generate electronic waste and Greenhouse Gas (GHG) emissions. For example, some studies[3] estimate that the telecommunication industry was responsible for 2,3% of the global GHG emissions in 2020.

This workshop explored both the opportunities that 6G can offer to improve the sustainability in various sectors, and the ways to make 6G itself more sustainable. This includes, for example:

- How to use the 6G network as a sensor to collect data in order to enable sustainability applications in other sectors (e.g., to monitor reforestation efforts)
- How to support new or extended use cases for other sectors to enable them to reduce their GHG (e.g., automation and optimization in manufacturing and supply chains, or use of Augmented Reality and Virtual Reality)
- How to reduce e-waste, the use of raw materials, and water consumption for 6G devices and infrastructure
- How to reduce total energy consumption in the 6G network despite growing demand for connectivity and bandwidth, and induction and rebound effects
- Standards, policy, and regulatory measures that should be considered for building and operating a sustainable 6G infrastructure
- Which actions are needed to better understand sustainability requirements in the 6G context?

To give the participants a solid understanding of some of the sustainability topics relevant to 6G, the workshop included a keynote by Prof. Dr. Dr. Marja Matinmikko-Blue, Research Director of the Infotech Oulu Institute, Director of Sustainability & Regulation at 6G Flagship at the University of Oulu, Finland, and Adjunct Professor in spectrum management.

Some of the topics she covered in the keynote were:

- Stakeholder roles will change in 6G, as compared with the current wireless business ecosystem, and new roles will emerge.
- Many business, regulatory and technology aspects related to local and private networks are still open. Divergence between countries is high.
- Sustainability includes three main components: social sustainability, economic sustainability and environmental sustainability.

[3] https://www.bitkom.org/sites/default/files/2020-05/2020-05_bitkom_klimastudie_digitalisierung.pdf

- The United Nations Sustainable Development Goals (SDGs) include only seven ICT indicators in the framework of 169 targets and 231 indicators. However, the link between ICT and the SDGs is much stronger than this low number indicates. ICT contributes to all of the SDGs.
- The "6Rs" of environmental sustainability (Reduce, Reuse, Recycle, Recover, Redesign and Remanufacture) are all relevant in the wireless industry, and there are both requirements and open research questions for 6G in all six of these areas.
- Concrete recommendations for sustainable 6G and sustainable spectrum management were listed, and are in the slides included as Appendix B below.

Workshop Procedure

After an introduction and welcome from MÜNCHNER KREIS, Marja Matinmikko-Blue from the Infotech Oulu Institute and the University of Oulu, Finland, presented an overview of some of the work in sustainability and 6G to date, important topics that need to be considered, and some concrete examples of how decisions the industry is making today will affect both long-term sustainably and our ability to dynamically react to improve the sustainability as new technologies develop. The slides from this keynote are included in Appendix B below.

40 participants from multiple sectors took part in the workshop. Roughly half the participants were from the cellular/wireless industry and the other half were from other sectors that will be the use cases for 6G (e.g., healthcare and mobility) or who will be relevant to improving sustainability in 6G (e.g., end device manufacturers). All participants were senior-level experts in their fields. Since the workshop was held under the Chatham House Rule, the participants will not be identified in this report.

The participants were divided into three groups, who worked in parallel on three different aspects of sustainability for 6G:

1) How 6G will enable sustainability in verticals
2) Sustainability for end devices
3) Sustainability for the 6G network infrastructure

Each of the three groups worked on the same two questions, with a focus on the particular aspect being addressed in that group:

1) What opportunities and obstacles do you foresee with respect to enabling sustainably in verticals / sustainable end devices / sustainable network infrastructure?
2) What do we need to do in order to realize these opportunities or to overcome these obstacles?

At the end of the workshop, each of the three groups presented some highlights of their discussion as summarized below.

Key Insights from Group 1 (How 6G will Enable Sustainability in Verticals):

Group one focussed on looking at the role 6G could play in enabling sustainability in vertical industries. 6G being deployed as public infrastructure and as private industrial networks offer manyfold opportunities to support sustainability in a broad range of application areas. For example, members of the group mentioned that 6G will enable massive digital twining which in turn can be used to optimize sustainability and energy efficiency in factories and buildings. 6G is also seen as an enabler of Metaverse that could, for example, improve remote work experience and thus save emissions from commuting. Also, the seamless interworking of 6G with non-terrestrial networks (NTN) will result into better coverage in underserved areas and by that will enable sustainability applications for instance in agriculture.

In addition to 6G NTN, the following 6G capabilities were identified to offer opportunities for enabling sustainability in verticals: the combination of communication and sensing, the support of low-energy and RFID devices, the application specific tailoring of network slices and solutions as well as the pooling of resources and intelligence in the network rather than having it distributed across devices. However, it is essential that verticals and ICT develop a common understanding about the sustainability opportunities offered by 6G. Security, data and privacy protection as well as high entry costs for new players were considered as further major obstacles for using 6G-based sustainability solutions. Also, the business and economic feasibility to realize and deploy those solutions need to be validated for different verticals.

The ideas and proposals how to seize opportunities and to remove roadblocks included legal, regulatory and standardization related aspects, the cooperation among multiple stakeholders, vertical-specific views including especially supply chain as an important application area, and sustainability as a system design criterion. For example, legislation and/or regulation could make it mandatory to connect energy intensive devices to 6G to track their energy consumption and emissions and to provide this data - properly anonymized - to energy system operators. A legal framework for data trading could be an additional measure to facility the exchange of sustainability related data.

Having a common understanding of the sustainability opportunities offered by 6G is fundamental. This common understanding can be developed for example by working jointly on common standards and regulations across verticals. Those standards and regulations should cover not only the capabilities of a 6G system, but also sustainability aspects in a broader sense including the definition of key value indicators for measuring sustainability across verticals. Important for a successful cross-sectorial collaboration will be the alignment of technology roadmaps of the different verticals and stakeholders and applying a system approach that ensures that sustainability is designed into 6G applications along the whole lifecycle. Research will be needed to explore and develop those sustainability-by-design approaches.

Overall, the group agreed that 6G can play a significant role in supporting sustainability goals across verticals. Global standards, open multi-stakeholder ecosystems and proper legal and regulatory frameworks will be crucial to explore and develop 6G based solutions that address the global challenges of climate change.

Key Insights from Group 2 (Sustainability of End User Devices):

The discussion in group two had a wide variety of topics including new business models, the design of the end user device, use and consumption of raw materials, and the aspect of complexity for 6G in general among others. In the beginning of the discussion, it was stated that the need for more sustainable devices is also a driver but at the same time also a hurdle for the upcoming 6G technology.

On the one hand, a need for more sustainability leads to a rethinking of the design and the power consumption of the end user devices. Do we really need this kind of big smart phones? Maybe smaller ones which are tailored to the individual needs of the user could be designed. Or design the devices with a sustainable longevity in mind. Make them modular and change the business model to "a right to repair". Repair instead of buying a new one. And enable users to change or update specific parts of the device after they have broken down.

On the other hand, the production of an end user device is the most energy-consuming part in the product lifecycle and most of these devices require rare minerals for their manufacturing. Finding renewable sources and energies for this step should be one of the upcoming goals towards more sustainable end user devices.

An icebreaker question in the beginning of the discussion read "How many old phones do you have lying around in a drawer?". Not one of the ten participants answered with a number smaller than three. This led the discussion to the topic of proper recycling and refurbishing of end user devices. It was stated that there is a lack of information where to bring these old devices and how to recycle them properly (national as well as international). In view of the results from the icebreaker question, the idea of a deposit on phones was introduced and discussed. This would raise awareness and would allow old devices to be recycled or refurbished and put back into the cycle.

In summary, it was demanded unanimously that the topic of sustainable development of end user devices should be made priority number one. In terms of KPIs as well as in terms of R&D, standardization, awareness, and modularity.

Key Insights from Group 3 (Sustainability of the 6G Network Infrastructure):

The discussion in group three focused very much on conflicting priorities and that we need to find methods and processes to resolve these conflicts. Different countries/regions have both different starting points and different priorities, for example, they have different energy mixes, different spectrum in use, and different challenges in providing complete coverage in their region. As such, a solution for sustainability that is globally optimal will most likely be sub-optimal at the local level, which will lead to conflicts between the local industry & regulators and the attempt to optimize sustainability globally. This could lead to fragmentation of the standards and the market, and to technical solutions which are sub-optimal. There will need to be tradeoffs between the environmental, social and governmental goals, for example between environmental impact versus resilience, particularly for critical infrastructure. Many of these questions are not engineering questions, but issues that need to be discussed with society, with other verticals, and with regulators.

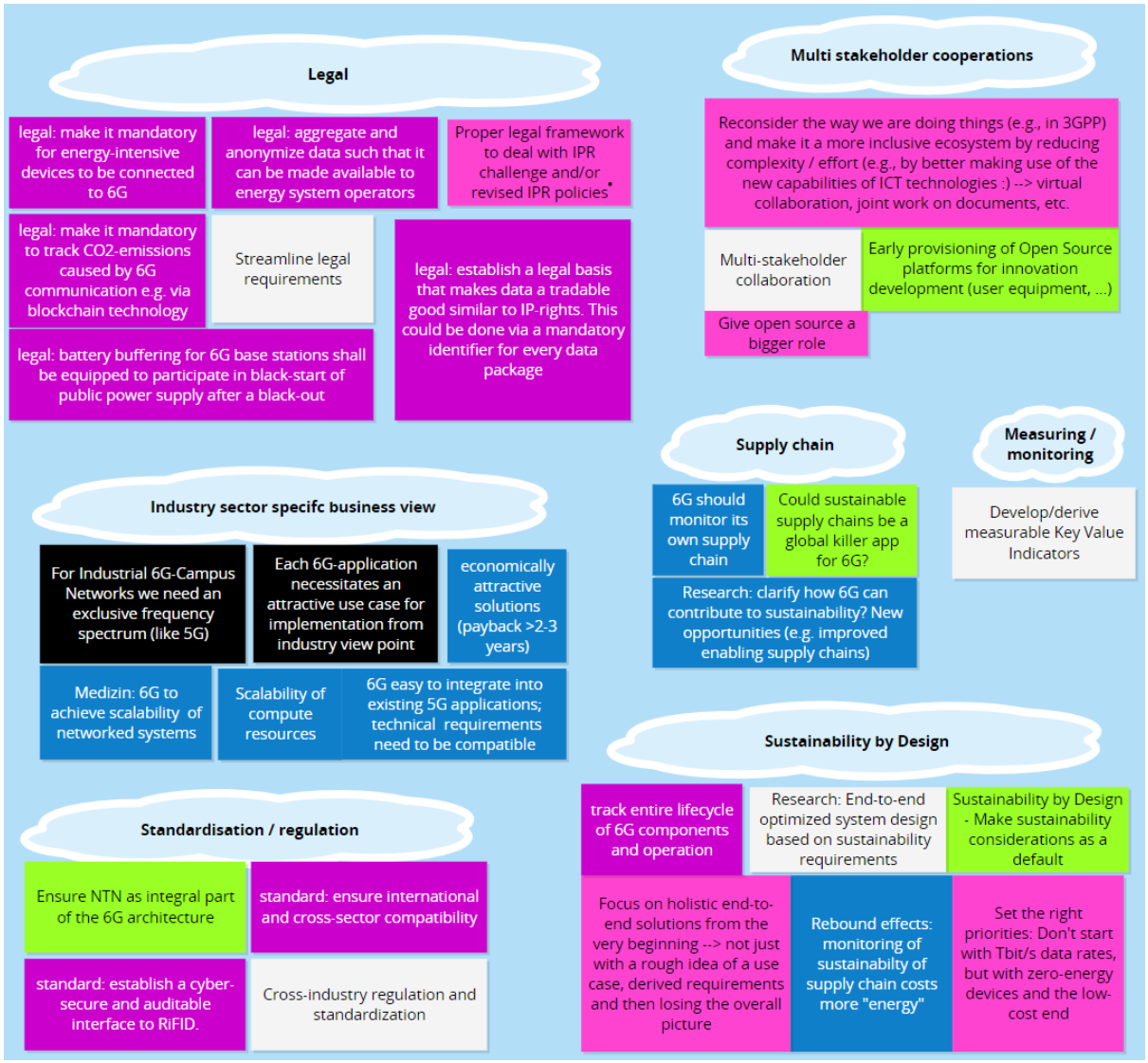
Improved environmental sustainability could become a unique selling point for operators, as consumer interest in their own ecological footprint increases. However, monitoring and reporting the environmental impact of the 6G network requires agreed and established KPIs for measuring the impact, which currently do not exist in an adequate form. In addition to KPIs, the wireless industry will need to develop tooling to measure the impact of 6G, and processes to provide transparency into these values.

An important and very complex topic that came up was that we need a systemic framework to include all relevant stakeholders (users, producers, engineers, society, regulators, …) into a system that takes into account all of the dimensions that need to be considered, and that can resolve the inherent conflicting priorities. The 6G network itself will need to permit dynamic, iterative improvements and tuning, similar to DevOps, as we gain more information or as new requirements appear.

In summary, we need a “communications transition” that will involve similar and very difficult discussions as the current “energy transition”: What are the global/regional/national priorities? How do we improve sustainability without splintering a global communications network? How do we guarantee resilience? What actions now will best serve society long-term? How do we transition away from existing technologies to new technologies? Are we even researching and developing the right new technologies? How do we discuss these questions with society and include their input in the 6G design?

Example Screenshot from the Workshop

The workshop was held using a tool called Conceptboard. Here's a screenshot of part of the board during the workshop:



Summary of the Workshop Results:

The tables below provide **examples** of the individual topics that came up during the workshops, to give an impression of both the breadth and depth of the discussion.

Key Insights from Group 1 (How 6G will Enable Sustainability in Verticals):

Opportunities	**How to realize the opportunities?**
• 6G is a key enabler for achieving systemic sustainability across many application areas and use cases (e.g., monitoring energy assets such as heat pumps and charging stations) • 6G capabilities (joint communication and sensing, interworking with NTN, support of low-energy and RFID devices, tailored network slices, scalability of networked systems) are seen as important enablers for new services useful in the context of sustainability • 6G private wireless networks deployed in industrial settings help to achieve sustainability goals in factories and buildings • 6G enables digital twining and Metaverse that in turn can help to enable, monitor, simulate, and optimize sustainability related measures	• Consider sustainability as design criterion for 6G as well as vertical specific systems based on 6G • Select promising pilot use cases (e.g., sustainable supply chains) to showcase the benefits of 6G-based applications • Put special emphasis on making 6G-based sustainability solutions economically attractive – investment payback should happen within 2-3 years • Ensure exclusive frequency spectrum for 6G campus networks • Provide a legal framework for exchanging and trading sustainability related data • Develop joint open source projects and platforms involving verticals and ICT to nurture innovative sustainability solutions

Obstacles	**How to overcome these obstacles?**
• No “common language” across verticals and ICT • Concerns about security and data protection when deploying 6G and collecting data • Lack of global standards to meet the various requirements of multiple verticals • Different and misaligned technology roadmaps of verticals and 6G	• Working jointly on regulation and standards to agree on KPIs and Key Value Indicators for measuring sustainability • Legal framework and regulation clarifying ownership of data and how data usage should be controlled • Open up 6G standardization and involve verticals in the specification of standards to better match their needs

Key Insights from Group 2 (Sustainability of End User Devices):

Opportunities	How to realize the opportunities?
• Space for new thinking and new design ideas including zero energy devices or a design for long(er) usage • Recycling and Refurbishment will undergo new ideas • New business models in the field of recycling, device upgradability, or device lifecycle could emerge	• Energy efficiency and sustainability should be implemented by design when it comes to production • Communication and sensing helping mutually • Intelligence in the edge, means no need for highest performance in the field • Minimizing the size of devices with the help of AI, to find the “right” size • Optimized compute split between sub-device tethered to smartphone could allow energy-optimized function split • Strengthen sustainability as a purchasing/procurement criterion • Increase energy efficiency

Obstacles	How to overcome these obstacles?
• Only limited amount of rare non-renewable resources • Higher complexity with probably higher energy consumption. 6G to become way more complex than 5G • Since there will be “billions” of IoT devices, it bears a risk for the environment and in sum, all these devices have a high energy consumption and material usage • Short innovation cycles often require new hardware • Almost no refurbished or remanufactured devices by now • Lack of binding global frameworks for recycling/refurbishing	• On-device intelligence for optimized energy usage • Energy efficiency / modularity, and a definition of sustainability as a requirement in standardization • Collaboration between different ecosystem(s) players • Research & Development should start from application needs before defining the technical requirements • Orient material selection to recycling / recyclability / environmental compatibility

Key Insights from Group 3 (Sustainability of the 6G Network Infrastructure):

Opportunities	How to realize the opportunities?
• Sustainability can be a competitive advantage and unique selling point for vendors and operators • Improved acceptance by the public when the infrastructure is more sustainable • Prevent misuse of the infrastructure for short-term profit (e.g., for bitcoin mining)	• Define and standardise KPIs for energy efficiency and emissions for wireless networks • Create tooling to measure energy/emissions KPIs in a standardized manner • Provide transparency into the energy/emissions KPIs, so operators can demonstrate their sustainability to regulators and to the public • Reuse existing infrastructure for as long as possible, which could mean delaying rollout of new technologies • Define certifications for ESG-related topics, for applications and infrastructure, to make both best-practices and misuse (e.g., bitcoin mining) visible

Obstacles	How to overcome these obstacles?

• Conflicting priorities
  ○ Between different countries/regions
  ○ Between financial and ESG goals
  ○ Between technologies to improve network KPIs versus environmental KPIs
  ○ Between network KPIs (e.g., coverage) and energy/emissions KPIs
• Difficult to determine the optimal function split between end-devices, edge and cloud
  ○ E.g., Energy requirements to compute in the end-device versus energy requirements for communication between end-device and cloud plus compute in the cloud
• The topic is currently being driven by the wireless industry, with only limited input from the use-case verticals and from society. Including input from such diverse stakeholders is difficult for engineers because it's not how the standardization process currently works.
	• Work towards global alignment on the priorities
	• Cooperation to develop a systematic framework to:
	  ○ include the needs of multiple, very diverse stakeholders
	  ○ balance conflicting priorities
	  ○ mitigate the effects of national/regional interests
	  ○ ensure resilience
	  ○ ensure flexibility and the ability to iterate the network
	• Consider and define the singular highest-priority goal for 6G design. If sustainably is the highest goal, then research/design/implement accordingly.
	• Raise awareness amongst regulators, standardization bodies and engineers, that sustainability requirements can lead to a fragmentation of both the standards and the market, leading to sub-optimal technical solutions
	• As an industry, develop more concrete ESG goals, based on a refinement of the UN SDGs

• Decisions are being made today (e.g., about spectrum allocations) that create long-term lock-in effects, which could prevent the rollout of more sustainable solutions for years.
• There is an inherent conflict between sustainability goals and resilience goals, especially for critical infrastructure, e.g., between the use of a volatile energy mix versus guaranteeing connectivity even during catastrophes
• There is an inherent conflict between sustainability goals and coverage/data-rate goals, e.g., putting parts of the infrastructure in sleep mode to save energy versus providing instantaneous connectivity
• Consumers are not aware of their "communications footprint"
  ○ Difficult to change consumer behavior when we offer them flat-rates and always-on
  ○ Lack of interest on the part of some consumers
• The entire IT industry, including the wireless network, is experiencing exponential growth in demand. But nothing can grow exponentially without eventually reaching "right size" or collapsing
	• Develop methods for flexible spectrum sharing
	• Develop methods to handle extreme systemic complexity
	• Develop methods to balance speed, pragmatic "let's get it done", and complexity
	• Discuss how to reduce exponential growth in demand, for example, by
	  ○ Educating consumers about the footprint of IT infrastructure
	  ○ Educating consumers about their personal IT footprint
	  ○ Educating consumers on how they can reduce their footprint (e.g., download favorite video once rather than stream 100 times)
	  ○ Making the true cost of exponential growth visible (e.g., by eliminating flat-rate contracts and charging by use)

Each group organised and clustered their topics. The full list of topics and clusters is available in the appendix. In the following, some of the topics discussed in the working groups are described in more detail (not in any particular order):

From Group 1 (How 6G will enable sustainability in verticals):

Multi stakeholder collaboration

6G offers a broad range of opportunities that can help to improve sustainability in and across various sectors. One of the main initial challenges in realizing this potential consists of developing a common language and a mutual understanding between all the stakeholders required to create a 6G-based solution for verticals. Involved parties need to understand what 6G can offer and how 6G features can contribute to build applications that meet the sustainability requirements of the verticals.

Multi stakeholder collaboration in ecosystems is the way to build the common understanding and to prepare the ground for innovative sustainable solutions. For example, standardization like the one

driven by 3GPP[4] form those ecosystems. However, participating in this kind of standardization work requires investing a certain level of effort and time. Small- and mid-sized companies often cannot afford this effort. Therefore, new ways for collaboration and doing standardization work should be considered – new ways that lower the barriers for joining a more inclusive ecosystem. For example, increasing the use of virtual collaboration tools could save time and resources and by that lower the barriers for participation. Open source projects and platforms should play a larger role because they are more open by definition and thus facilitate a more inclusive multi stakeholder collaboration.

Economically attractive sustainability solutions

It has become important for companies to implement a sustainability strategy. Embedding sustainability in corporate goals can add value to the brand and can provide competitive advantages. Implementing related activities can reduce cost, for example, through lower energy consumption or recycling of rare metals. Focusing on sustainability can also provide new business opportunities.

6G needs to support the implementation of a company's sustainability strategy in an efficient way so that investments pay off not only in the long-term but also show benefits in the short-term. For example, 6G needs to be backward compatible with 5G so that new 6G-based solutions can easily be integrated into existing 5G-based systems. 6G should support scalability of networked systems and compute resources so that varying workloads can be managed in an energy-efficient way. Dedicated spectrum should be available for industrial 6G campus networks as it is the case for 5G.

Sustainable supply chains have an immense impact on the environment and could serve as an area in which 6G can demonstrate its full potential for supporting sustainability within and across verticals. 6G could actually monitor its own supply chain.

Legal frameworks, regulation, and standardization

Legal and regulatory enactments are already in place to protect air and water quality or to govern the treatment and disposal of waste. It is expected that there will be further environmental legislation and regulation related to 6G and the use of 6G in verticals. Actions could include the obligation to monitor and control energy-intensive devices via 6G, to track the emission caused by 6G, and to use batteries of 6G base stations as energy buffers integrated into an electrical grid.

Gathering and analysing sustainability-related data is essential for managing the transition towards a more sustainable future. For example, remote monitoring of the condition of machines and predictive maintenance of machines can reduce greenhouse gas emissions; data-driven algorithms can optimize overall performance and availability of grid systems; trusted data exchange enable the integration of small private solar power plants into the transmission systems of large energy system operators. Again, legal and regulatory frameworks are needed to set the rules for collecting and sharing data in this context or to make data a tradable good.

It will be important to harmonize and streamline these legal and regulatory frameworks across verticals and at an international level to avoid fragmentation. For doing so regulation would need to go hand in hand with standardization to ensure that the underlying technology is interoperable across verticals. For example, blockchain-based systems could provide the unified platform to

[4] https://www.3gpp.org/

uniquely identifying data records and to exchange the data in a trusted way. Standardization would also need to agree on sustainability metrics and KPIs that are common across verticals.

Intellectual Property Rights (IPRs) might become an area of conflicting interests. On the one side, IPRs protect and incentivize innovations addressing environmental challenges. On the other side, strong protection might have negative impact. It can increase prices of the protected technology and cause barriers for using the technology to develop other innovations. It might be a need to revise IPR policies to mitigate this conflict potential.

Research and system design of end-to-end sustainability

Research is needed to explore and better understand the inherent complexity of sustainability and to identify how 6G could help to achieve sustainability goals in various verticals and scenarios. It will be important to develop a holistic end-to-end view on sustainable systems and not only to create rough ideas about some use cases and to derive requirements on 6G from them.

Sustainability-by-design will be a major research area. How to design 6G based solutions that are sustainable and support sustainability in diverse verticals? What are the principles that need to be followed when designing sustainable products and systems? What are the many aspects that need to be taken into account, including economic and social aspects? Which vertical specific environmental standards need to be supported? And there are many more questions.

Multi-disciplinary and interdisciplinary research will be needed to get answers on those questions and to develop blueprints how 6G can best be used to support sustainability.

From Group 2 (Sustainability for end devices):

Optimization of energy usage

The end user devices should include energy efficiency by design. This is not a trivial requirement, since the devices are becoming more and more powerful. The idea of zero energy IoT devices without any “batteries” comes to mind.

To achieve this better energy efficiency, one must improve the efficient design of a device. The capacity (both in terms of functionality and power consumption) of a device should depend on its use case. Deciding where to place the intelligence, at the edge or in a data center, will have a significant impact. There is no need for a high-performance device at the edge if the use case doesn’t require this. It should be possible, with the help of AI, to minimize the size and capacity of a device based on its use case to find a better “right” size for it.

On-device intelligence can also help with optimizing the energy usage of said device. Communication and sensing are mutually beneficial. If a device is not needed/ not addressed directly, it can switch into a power-saving state, so no energy is wasted.

Recycling/ Refurbishment

A smartphone or end user device consists of up to 62 different metals[5], a high percentage of which are very difficult or very expensive to recycle. So the question arose, whether the use of biological recyclable parts is possible.

The question of a "clean slate" 6G also came up, where legacy restrictions and technologies (e.g., NB-IoT, GSM IoT) could be retired and some of those parts/metals could be harvested and reused for more sustainable devices. On the other hand, interoperability with legacy technologies could increase longevity of devices and could encourage refurbishing for newer devices.

At the moment, there are very few refurbished or remanufactured devices on the market. This problem is not only a hardware/mineral problem, but also a social problem. Users tend to buy new and bigger phones with better cameras and better processors instead of buying secondhand devices. Increased user awareness is needed to mitigate this problem. This includes providing more information to consumers regarding the topic of sustainability. The discussion must include concepts like right-to-repair and design-to-repair. The responsibility lies not only with the end users, but predominantly with the manufacturers.

Sustainability-centric business models

The discussion about recycling/refurbishment led to a discussion about possible new business models, for example, building upon concepts like right-to-repair. Different examples were discussed, but Fairphone stood out, in particular. Fairphone's principles correspond closely to the topics discussed in the workshop:

- Considering sustainability at the beginning of the lifecycle, not after manufacture
- Good working conditions: employees are compensated fairly, have a voice in their own workplace, and work in a safe environment
- Fair materials: complex decision-making process is implemented to create demand for materials that are better for users and the environment.
- Recycling and circular economy: promote recycling and repair of devices, commission research on recycling options for electronics, and reduce electronic waste
- Durable design: highly modular devices that permit repair and replacement of individual components

New business models could also include repair and refurbishment shops, or companies which manufacture very specialized components (e.g., professional-level cameras for phones)

Reliability for Critical Systems

End user devices in various fields such as civil infrastructure monitoring, smart power grids and smart healthcare are of paramount importance to our society and require reliable performance. However, guaranteeing application-specific reliability is still an open research issue. Many of these Internet of Things (IoT) devices are low capacity devices, and are subject to harsh environmental conditions such as heat, mechanical shock, electromagnetic radiation and physical attacks. In addition, many of the IoT devices are legacy devices that cannot be easily upgraded or exchanged.

[5] https://www.techradar.com/news/phone-and-communications/mobile-phones/our-smartphone-addiction-is-costing-the-earth-1299378

Conventional methods for protecting these devices rely heavily on redundancy, a concept that is in direct conflict with goals for environmental sustainability. Methods and tools to predict, increase and/or guarantee the reliability of these devices need to be developed. Ideally, it should be possible to increase reliability without needing to increase the amount of materials and power consumption of the devices. Multiple scientific disciplines will need to collaborate, to develop IoT end-to-end systems that balance the need for reliability, the need for environmental stewardship, and the needs of the users and society. Improving the reliability of the 6G network is a necessary but insufficient step: the end devices must also be improved, and the overall end-to-end system architecture must be sustainable.

From Group 3 (Sustainability for the 6G network infrastructure):

Global Alignment on Priorities

There will be multiple kinds of trade-offs required in the 6G network: for example, between global optimization and local optimization, between economic and sustainability goals, between resilience and sustainability goals, between complexity and pragmatism…

Local/regional legal requirements related to sustainability could lead to significant fragmentation in the market, as equipment manufacturers are then required to develop or customize their products for each local market. This will lead to solutions that are economically unfeasible and technically sub-optimal. In addition to the legal requirements, the local situations are very different, which will lead to conflicting priorities. For example, different countries have a different energy mix, different spectrum in use, different population distributions and densities, so the best way to improve sustainability will differ for each situation. It will be important to make sure the industry takes a truly global perspective, not biased by western views.

Agreeing on the priorities is not an engineering issue, but rather one that must involve all of society, worldwide. The discussion related to 6G design goals will involve difficult questions, similar to the current discussion about the energy transition. We will need to agree upon and define priorities, accept and promote major changes in technologies and how we use them, influence consumer behaviour, balance lobbyism from special interest groups with the society's best interest, and counteract misinformation.

Systemic Framework

Related to the aspect of global alignment above, it is necessary to develop a framework and processes where input and priorities from all stakeholders are included. In this case, stakeholders would include (amongst others) energy providers, users, engineers, society, other vertical sectors, other players in the IT industry, regulators, etc. The discussion about 6G and about sustainability in 6G is currently being driven by the wireless industry. This discussion must expand to include requirements from society and from use case verticals. However, this kind of discussion doesn't match how standardisation processes currently work.

The 6G network will also need to be capable of adapting to a dynamic environment. The network will need to permit iterative improvements (similar to DevOps), as requirements change, and as new technologies develop. The wireless industry is currently making decisions (e.g., spectrum allocation)

that could lock us into one solution for years, thereby preventing the use of more sustainable solutions (e.g., improved spectrum sharing), unless we ensure that methods to adapt the network are available.

KPIs for Environmental Impact

The wireless industry needs to develop and standardize KPIs to measure the impact (both handprint and footprint) of the 6G network on the UN SDGs. These KPIs should include energy usage, but also factors that influence the SDGs, such as percentage of the population covered by a mobile network, and whether or not the data rate is adequate to permit access to essential services (health, education, …). Best practices for e.g., power saving should be standardized into the 3GPP specifications.

The data collected should be made available to:

- Regulators, to provide transparency into the status of the SDGs and to provide real-time monitoring of the situation in their country
- Energy providers, to optimize energy delivery and usage
- Academia, to improve the network and resulting KPIs
- End users, to help them understand their own environmental footprints

Ideally, the KPIs will cover not only the communications network, but also all of the software components in use, including in the end device, at the edge, in the cloud, and at the application level. This would enable certification for best-in-class applications, providing a unique selling point for efficient applications and permitting consumers to choose applications with less impact. This would also permit operators to identify and limit the misuse of shared infrastructure for short-term profit over long-term sustainability (e.g., bitcoin mining).

End users are currently not aware of the environmental impact their smartphone usage really has, and there's no easy way for them to find out. The industry should provide tools and should communicate how to determine an individual's footprint and how they can reduce that footprint by changing their behaviour.

Exponential Growth

While the energy required "per bit" has decreased significantly from 4G to 5G, the number of bits has increased faster. Exponential growth in demand and in the amount of traffic in the network are outpacing the energy savings the industry has achieved, resulting in much higher overall energy requirements in 5G. While 6G will reduce the energy "per bit" even further, demand is still growing exponentially and will likely continue to outpace the "per bit" savings. Technological advances are not keeping up with exponential growth in demand, and there's no reason to expect this to change anytime soon.

As such, the IT industry, including wireless, need to work on how to handle exponential growth in demand, without relying on Moore's Law. In nature, exponential growth is never sustainable and leads to catastrophic failure of the system. As the 6G network becomes more and more important to

society, the problem of exponential growth also becomes more important. The IT industry and society need to take a very critical look at the root cause(s) of exponential demand, and need to attack the problem at the root. This will include debating and answering some very difficult questions, such as:

- How long can we continue to use existing technology and equipment before upgrading to new technology?
- Are we adopting a new technology because it's truly an improvement or just because it's new? For example, is the use of AI/ML for a specific scenario, and the energy required to train the AI, truly a better solution than the way we're currently doing it?
- Is my flashy new IoT/smart-city/smart-mobility/smart-whatever application consuming more resources than the traditional methods? Is it providing true added value?
- Is it a good long-term strategy for providers to offer consumers flat rate, anytime, anywhere mobile communications? Is that irresponsible because it encourages wasteful consumer behaviour?
- How can we make consumers aware of the impact of their online activity? (For example, what's the difference between downloading a video once versus streaming the same video 5 times?)
- Can we create a "choice architecture" for consumers to nudge them into choosing more efficient ways of using their smartphones, to keep using their existing phones longer, and to recycle their old phone? If it turns out that nudging isn't sufficient, do we need regulation?
- How can we ensure that business case analysis for industry verticals considers not only the handprint (energy savings through digitalisation) for that vertical, but also the footprint (energy requirements in the IT infrastructure)?
- Some of the increase in demand is from people in lower-income countries connecting to the Internet for the first time or with higher-quality connections, which is part of the wireless industry's contribution to the UN SDGs. To keep the total demand under control, should richer countries "dial down" their usage to permit poorer countries to "dial up" theirs?
- Many countries have media companies who publish influential comparisons between operators in that country, ranking the operators on coverage, data rates, etc. Should the media companies be forced to include sustainability in their metrics and comparisons?

Recommendations:

- Conduct multi- and interdisciplinary research to develop a common understanding of the sustainability challenges of verticals and to explore potential 6G based solutions.

  Sustainability in verticals is an extremely broad area. It is not only about reducing energy consumption but also covers all kind of resource-saving operation, production, and construction, becoming carbon-neutral in processes and supply chains, producing carbon-neutral products, supporting the circular economy, and many more. The area is not only broad, but many of the sustainability problems are highly complex. Developing solutions in this context requires expertise across multiple disciplines including domain experts of the verticals, 6G experts, but in some cases also sociologists, lawyers, economists, and scientists knowing about complex systems.

- Explore opportunities to make 6G-based sustainability solutions economically efficient and viable.

  6G-based sustainability solutions might require significant investments not only into the networking infrastructure but also into devices, software, new processes, operating models, and education of the workforce. These investments remain prohibitive if a ROI cannot be expected within a reasonable timeframe.

  Taking a holistic view of those industry use cases might allow identifying cost-saving opportunities. 6G can contribute to the cost efficiency with a high level of automation and features that make 6G private networks easy to deploy, to use, and to maintain. As assets in many industries have long lifetimes, a key success factor for the deployment of 6G will be the ease of integration into existing systems.

- Provide harmonized legal and regulatory frameworks to support and to enable 6G-based sustainability solutions.

  6G, data, and environmental legislation and regulation should be aligned and harmonized across verticals and at the international level, and should work together to enable sustainability. This includes not only the allocation of frequency spectrum dedicated to 6G campus networks, but also, for example, rules and policies for the exchange of data essential for sustainability use cases or the obligation to monitor energy-intensive devices and systems. Harmonized regulation will help to streamline the development and integration of sustainability solutions within and across verticals.

- Spread awareness to the end users about the different resources in a device, possible recycling options, and sustainable alternatives.

  There are different, more sustainable alternatives to the standard end user device. Help increase sustainability by donating old hardware or upgrading only individual modules on older hardware, to foster the longevity of the devices. By buying refurbished devices, the lifecycle of the hardware begins anew. These new business models help to increase awareness and promote recycling. Studies show that most of users would prefer less e-waste lying around at home and would like to recycle properly.

- Use legacy systems to your advantage.

  When it comes to the decision between maintain versus modernize, it all depends on the objectives and the budget. In terms of 6G, it is a mixture of both. The advantages of legacy systems lie close at hand with their familiarity, the efficiency for specific tasks, and assuring continuity in business operations. Furthermore, replacing legacy systems is often painful, but sometimes necessary. So, to avoid building more and more newer systems, legacy systems should be updated and modernized for the tasks ahead. This is a step towards more sustainability, in trying to improve the old systems and to make them more useful for future challenges.

- Keep the device as simple as possible and as powerful as necessary.

  The device should be fit for the task: not too big, not too small, not too powerful. Just the right amount of usability. AI can help to determine the best size and capacity for the device based on its usage. When designing the devices, the use case must be the first design criteria. Also, different aspects like modularity, reusability and the easy process of recycling must be included and implemented to the best of knowledge.

- Change business models related to 6G to incorporate climate and sustainability aspects.

  According to the 2022 Deloitte CxO Sustainabilty Report[6], companies that want to accelerate their climate action must incorporate climate considerations into every part of the business, which may require a fundamental transformation of the business model. Longer smartphone and IoT device lifetimes would undoubtedly change the way the smartphone industry generates revenue and profits. For example, making "longevity" a feature: Smartphone vendors could justify higher prices if they could convince customers that their device will last longer and, perhaps more importantly, have a high residual value when they eventually want to trade it in.

- Insist that priorities for 6G design and operations include input from all stakeholders, including society, use case verticals, and wireless operators. Ensure that the priorities are aligned globally, taking into account the very different starting points and situations in different countries/regions.

  There will be multiple kinds of tradeoffs required in the 6G network: for example, between global optimization and local optimization, between economic and sustainability goals, between resilience and sustainability goals, between complexity and pragmatism… The industry must not allow conflicting priorities to fragment the market or the network, and must ensure a global optimization. This will require difficult discussions and decisions that are not engineering problems but political and societal debates.

- Develop a framework and processes to include input, requirements and priorities from all relevant stakeholders, including society, energy providers, consumers, engineers, the IT industry, vertical sectors, and regulators. Ensure that the 6G network is capable of adapting

[6] https://www2.deloitte.com/global/en/pages/operations/articles/deloitte-cxo-sustainability-report.html

to new requirements as these change or as new technologies develop (e.g. with an iterative DevOps approach).

Related to the aspect of global alignment above, it is necessary to develop a framework and processes where all stakeholders are included. The discussion about 6G and about sustainability in 6G, currently being driven by the wireless industry, must expand to include requirements from society and from other verticals.

The 6G network will also need to be capable of adapting to a dynamic environment. The wireless industry is currently making decisions (e.g., spectrum allocation) that could lock us into one solution for years, thereby preventing the use of more sustainable solutions (e.g., improved spectrum sharing), unless we ensure that methods to adapt the network are available.

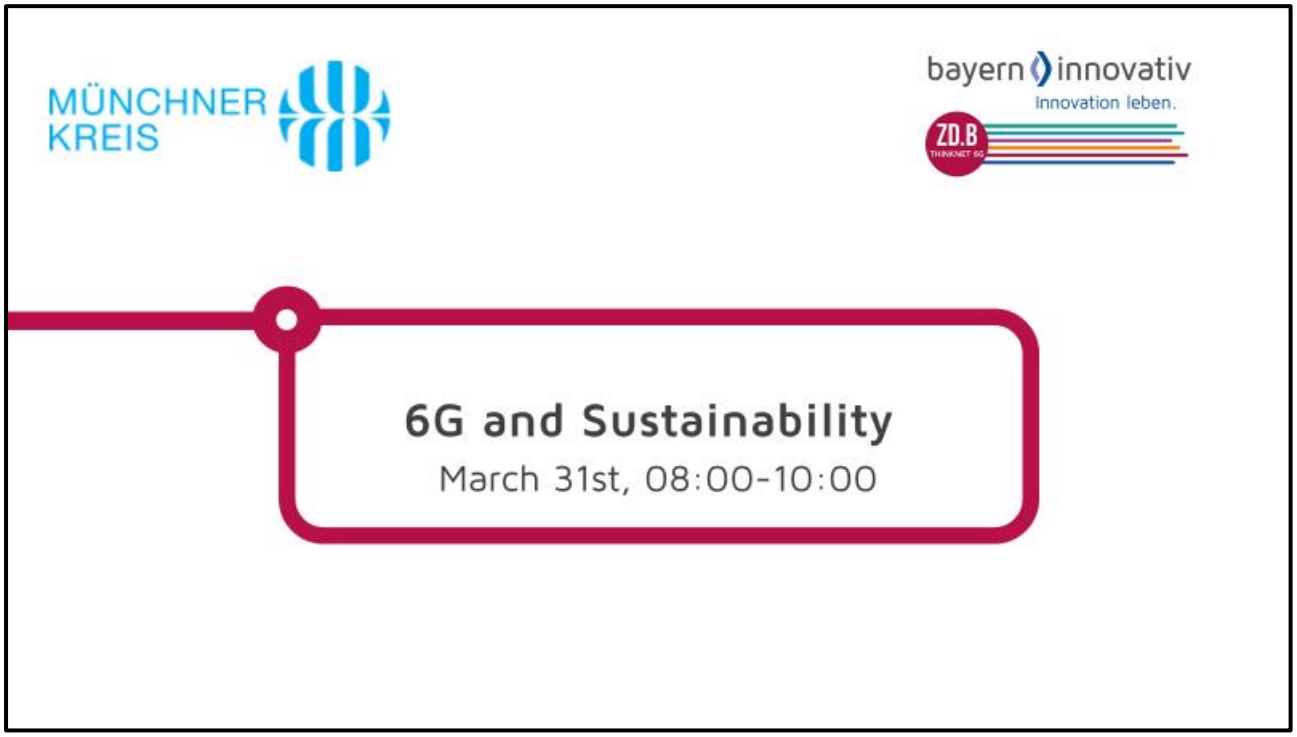
- Develop and standardize KPIs to measure the impact (both handprint and footprint) of IT applications on the UN SDGs. Include not only the wireless network, but the entire application. Measure not only energy requirements, but also factors that influence the SDGs (e.g. percent of population with mobile coverage).

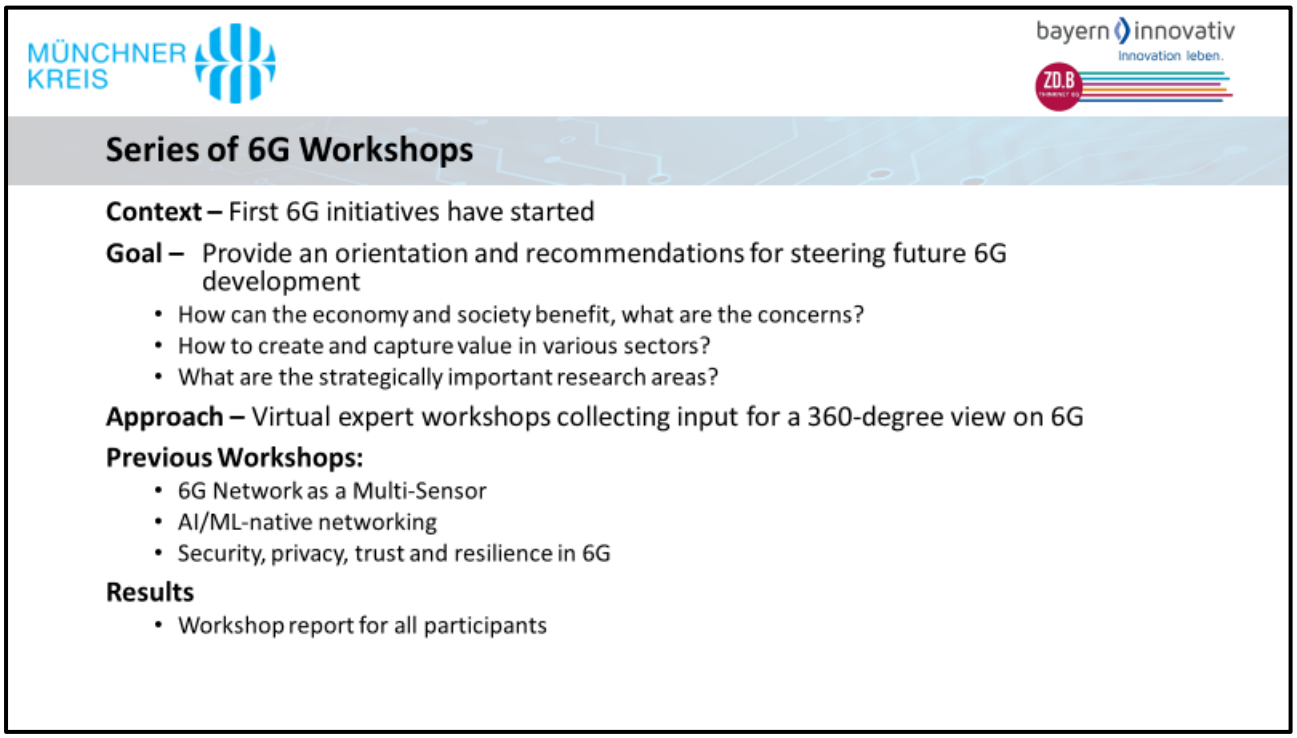
  KPIs to measure the IT industry's contribution to the SDGs should be defined, as well as the tooling needed to measure these KPIs. Ensure transparency by making the data available to regulators, providers, academia, consumers, and the rest of the industry. Develop certifications to designate and reward efficient applications, and to identify and prevent misuse of the infrastructure for short-term profit over sustainably (e.g., bitcoin mining). Help consumers determine and improve their personal footprint by providing tools to measure an individual's footprint, and tips and nudging to change their behaviour.

- Tackle the problem of increased total energy consumption. Despite technological improvements in energy efficiency in the 6G network, exponential growth in the use of mobile communication will otherwise lead to increased overall energy consumption. Use 6G and other information technologies responsibly, to contribute to sustainability.

  "Per bit", 5G is much more energy efficient than 4G, and the current vision for 6G includes further energy improvements. However, as long as the demand for IT services, including communications networks, continues to grow exponentially, the overall amount of energy required will continue to increase. Technological advances are still absolutely necessary, but they are not keeping up with exponential growth in demand, and there's no reason to expect this to change anytime soon. The industry must work on how to handle exponential growth without relying on Moore's Law, and will need to answer some very difficult questions about societal priorities, about when (if?) to adopt new technologies, and about whether current business practices are ameliorating or exacerbating the problem. All users (both private people and businesses) need to consider their usage patterns and must behave responsibly, in order to contribute to sustainability.

Appendix A: Slides from the Workshop





Agenda

6G and Sustainability			
8:00 – 8:15	Welcome and Introduction – Prof. Dr. Michael Dowling, MÜNCHNER KREIS		
8:15 – 8:30	Keynote: Prof. Dr. Dr. Marja Matinmikko-Blue, Research Director of the Infotech Oulu Institute Director of Sustainability & Regulation at 6G Flagship Adjunct Professor in spectrum management "Sustainability and 6G"		
BREAKOUT SESSIONS			
	Group 1: Verticals	Group 2: End Devices	Group 3: The Network
8:30 – 8:40	Intro	Intro	Intro
8:40 – 9:10	Key Question 1	Key Question 1	Key Question 1
9:10 – 9:40	Key Question 2	Key Question 2	Key Question 2
PLENARY SESSION			
9:40 – 10:00	• Short presentation of results – moderators of breakout sessions • Next steps and closing		

Key questions

1. What opportunities and obstacles do you foresee with respect to "6G and Sustainability"?
2. What do we need to do in order to realize these opportunities or to overcome these obstacles?

Members of the organisation team

Name	Organisation
Baeder, Uwe	Rohde & Schwarz
Dowling, Michael	MÜNCHNER KREIS
Gunzelmann, Bertram	Apple
Hafner, Matthias	Bayern Innovativ
Keller, Claudia	Bayern Innovativ
Kellerer, Wolfgang	TU München
Kornbichler, Andreas	Siemens
Merz, Peter	Nokia
Mucke, Christian	Apple
Neuburger, Rahild	Ludwig-Maximilians-Universität, MÜNCHNER KREIS
Parsons Trommler, Kimberley	Bayern Innovativ (Thinknet 6G)
Schuster, Sigurd	Nokia
Urban, Josef	Nokia

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Some rules

- Attendees are requested to only share pre-competitive and non-confidential information during the discussion
- We will follow the Chatham House Rule: participants are free to use the information received, but neither the identity nor the affiliation of the author(s), nor that of any other participant, may be revealed
- Please note that the workshop will be recorded, but the recording will be used exclusively by Bayern Innovativ and MÜNCHNER KREIS to create the workshop report. The recording will not be distributed to the participants and will not be posted anywhere online.
- Please mute when not talking

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Keynote:
Marja Matinmikko-Blue

Breakout Sessions Summary

Group 1	Group 2	Group 3
Moderator: Josef Urban (MÜNCHNER KREIS)	Moderator: Matthias Hafner (Thinknet 6G)	Moderator: Kimberley Trommler (Thinknet 6G)

Next Steps

- The link to conceptboard will remain open for one week. Please feel free to add additional comments
- Thinknet 6G and MÜNCHNER KREIS will prepare a written report with the results of the workshop
- The report will be sent to all participants


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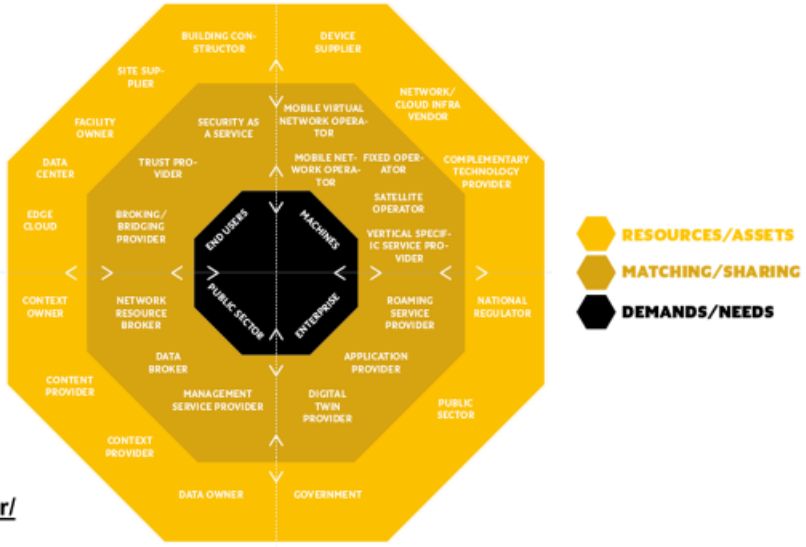
THINKNET 6G
Thinknet 6G
www.thinknet-6g.de
www.linkedin.com/in/thinknet-6g
thinknet-6g@bayern-innovativ.de
MÜNCHNER KREIS
www.muenchner-kreis.de
www.linkedin.com/company/muenchner-kreis
office@muenchner-kreis.de

Appendix B: Slides from the Keynote

Future 6G Business Ecosystem

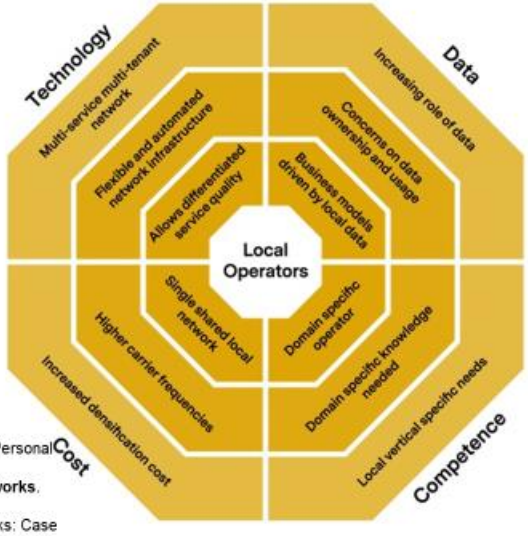
- Stakeholder roles will change in 6G compared to the current mobile business ecosystem and new roles will emerge.



http://6gflagship.com/6gwhitepaper/

Towards Local Operator Paradigm

- Different stakeholders can deploy their own local 5G/6G networks[1], independent of mobile network operators, through local spectrum access rights[2].
- This opens many business, regulation and technology related aspects to consider in research. Currently, divergence between countries is high, leading to market fragmentation[3].



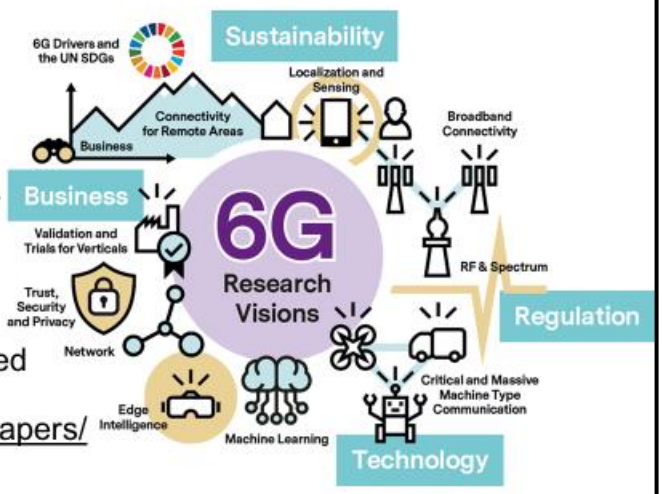
http://6gflagship.com/6gwhitepaper/

[1]M. Matinmikko, et al. (2017) **Micro operators to boost local service delivery in 5G**. Wireless Personal Communications, 95(1), 69-82.
[2]M. Matinmikko, et al. (2018) **On regulations for 5G: Micro licensing for locally operated networks**. Telecommunications Policy, 42(8), 622-635.
[3]M. Matinmikko-Blue, et al. (2019). Analysis of Spectrum Valuation Elements for Local 5G Networks: Case Study of 3.5-GHz Band. IEEE Transactions on Cognitive Communications and Networking, vol. 5, no. 3, pp. 741-753, Sept. 2019.

Second edition of 6G White Papers – Sustainability, Technology and Business Perspectives

6G

- Expert groups with **250 participants from 100 organizations and 30 countries** worked on 12 new white papers in conjunction with the 2nd 6G Wireless Summit held virtually in 2020. https://www.6gsummit.com/
- 11 new 6G White Papers were published in June 2020, and one in April 2021: https://www.6gchannel.com/6g-white-papers/



White Paper on 6G Drivers and the UN SDGs
led by Marja Matinmikko-Blue

HIGHLIGHTS:

- We identify megatrends influencing the sustainable development of 6G.
- We develop a novel linkage between 6G and the UN SDGs that are both targeted for 2030.
- We envisage three-fold role of 6G as:
  1) a provider of services to help support activities towards reaching the UN SDGs,
  2) a measuring tool for reporting of indicators;
  3) a reinforcer of developing 6G in line with the UN SDG.

https://www.6gchannel.com/portfolio-posts/6g-white-paper-6g-drivers-un-sdgs/

Sustainability and sustainable development

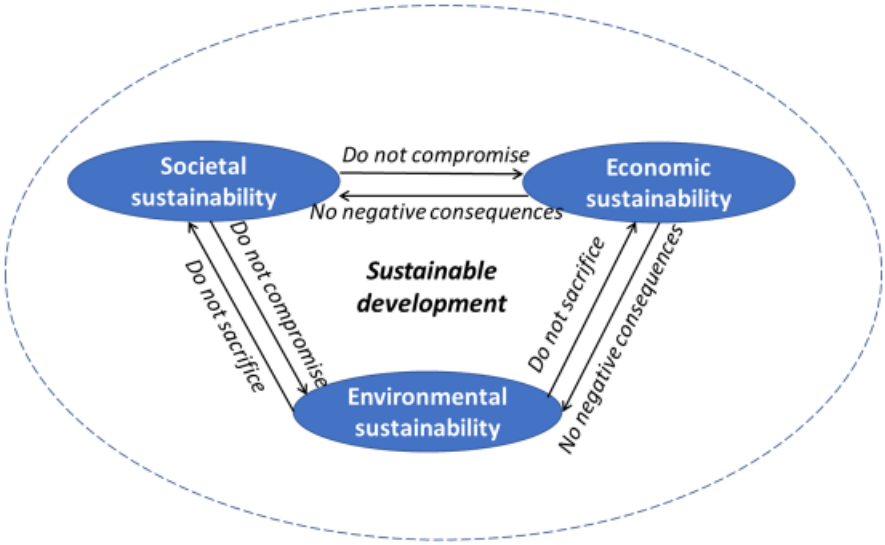
Sustainability refers to the "**principle of ensuring that our actions today do not limit the range of economic, social, and environmental options open to future generations**" [Elkington 1997].

Sustainable development refers to the "**development that meets the needs of the present without compromising the ability of future generations to meet their own needs**" [Brundtland report 1987].

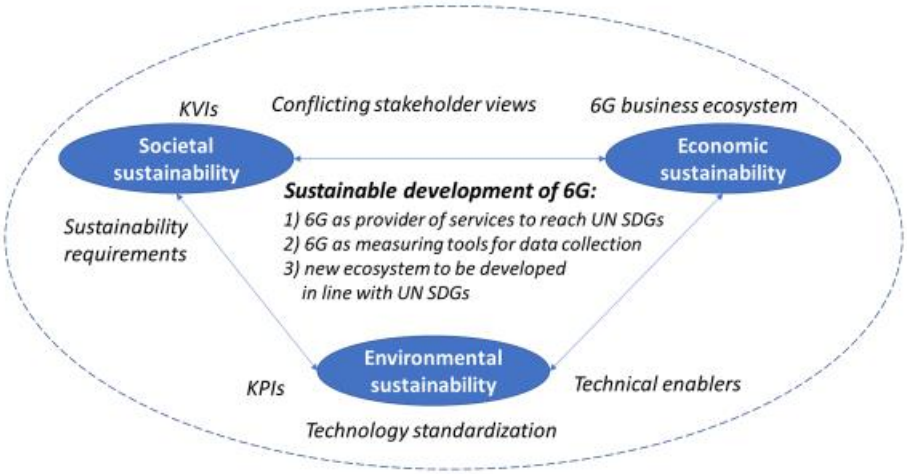
UN SDGs present a concrete framework for sustainable development with specific targets and indicators.

J. Elkington. Cannibals with forks: The triple bottom line of 21st-century business. Capstone Publishing Ltd. 1997.
World Commission on Environment and Development's Brundtland report 'Our Common Future'. 1987.

Triple bottom line of sustainability



Sustainable development of 6G



M. Matinmikko-Blue, S. Yrjölä, P. Ahokangas, K. Ojutkangas & E. Rossi. (2021). 6G and the UN SDGs - Where is the connection? Wireless Personal Communications. https://doi.org/10.1007/s11277-021-09058-y

Background: Current ICT indicators in UN SDG framework

SDG Goals / Targets

- 4.a Build and upgrade education facilities that are child, disability and gender sensitive and provide safe, non-violent, inclusive and effective learning environments for all
- 4.4 By 2030, substantially increase the number of youth and

level, and through a global technology facilitation mechanism

- 17.8 Fully operationalize the technology bank and science, technology and innovation capacity building mechanism for least developed countries by 2017 and enhance the use of enabling technology, in particular information and communications technology

SDG Indicators:

- 4a: Proportion of schools with access to the Internet for pedagogical purposes
- 4a: Proportion of schools with access to

**There are only 7 ICT indicators in the UN SDG framework of 169 targets and 231 indicators.
In reality, the linkage to ICT is stronger.**

- 17.6: Fixed Internet broadband subscriptions, broken down by speed
- 17.8: Proportion of individuals using the Internet

Background: Mobile industry's contributions to UN SDGs - GSMA

- **Deployment of infrastructure and networks:** Foundation for digital economy
- **Access and connectivity:** People can use mobile
- **Enabling services and relevant content:** Life-enhancing services for people

Source: 2021 Mobile Industry Impact Report: Sustainable Development Goals. GSMA. GSMA-SDGreport-singles.pdf

Existing linkage between the UN SDGs and mobile communications/ICT

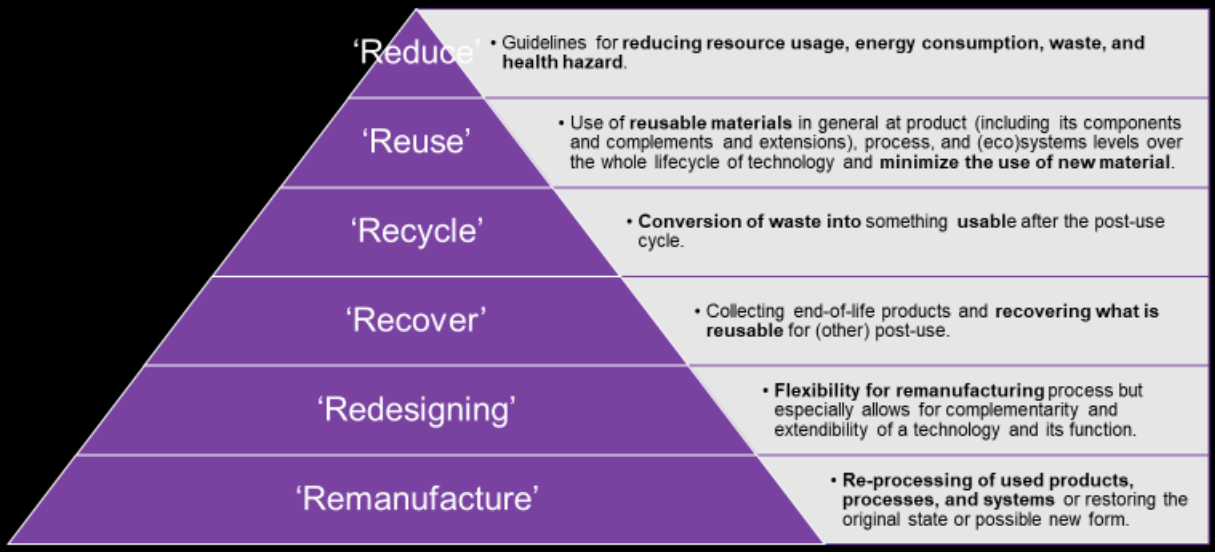
The UN SDGs	Existing linkage with mobile communications/ICT	Existing indicators from UN SDG framework	Other existing indicators
3 GOOD HEALTH AND WELL-BEING	Mobile communications enable communication with medical practitioners, monitor well-being through mobile, provide access to health programs, provide digital identity service to access healthcare, and provides big data for epidemics [GSMA 2018].	-	Proportion of individuals owning a mobile phone; countries having adopted a national e-health record [ITU et al. 2019].
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].

More about the existing linkage in our white paper:
https://www.6gchannel.com/portfolio-posts/6g-white-paper-6g-drivers-un-sdgs/

Linking 6G and UN SDGs via existing indicators

UN Targets	UN Indicators	6G can
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.

Environmental Sustainability through "6R"



Joshi K, Venkatachalam A, Jawahir IS (2006) A new methodology for transforming 3R concept into 6R concept for improved product sustainability. In: Proceedings of the IV global conference on sustainable product development and life cycle engineering, Sao Carlos.

Environmental Sustainability of 6G through "6R"

Reduce

- **End-to-end energy consumption** needs to be reduced and **energy efficiency** needs to be improved.
- End-to-end visibility and transparency on **supply chains' resource use** for circular economy.
- Measurement and **reduction of CO2 and other emissions** over the product/service lifecycle.
- Assessment, evaluation and monitoring of **human exposure to EMF.**

Reuse

- The **reuse of resources** (incl. infrastructure, spectrum) needs to increase.
- **Open source** paradigm expands to increasing the reuse of SW and data.
- Introduction of new generation mobile communication technology needs to reuse existing infrastructure.
- **Modular structure** of devices would allow reuse of components.

Recycle

- Higher level of **recycling of materials/devices/components** is needed.
- Redefining waste.

Recover

- Parallel use of different generations of **component technologies** to optimize resource use and minimize sustainability burden.

Redesign

- **User experience** needs to be at the center and rethought including different types of users.
- De-centralized (zones/communities) could emerge.
- New network architecture needs to accommodate variety of different needs for communications, computing and other services.
- The different roles of users and non-users needs to be addressed.

Remanufacture

- Increasing use of "as a service (aaS)" business models.
- Considering remanufacturing as a convenient business opportunity for developing countries.

M. Matinmikko-Blue, S. Yrjölä, P. Ahokangas, K. Ojutkangas & E. Rossi. (2021). 6G and the UN SDGs - Where is the connection? Wireless Personal Communications. https://doi.org/10.1007/s11277-021-09058-y

Research Questions on Environmental Sustainability of 6G

Reduce

- **How to measure end-to-end energy consumption?**
- What are the **energy consumption limits and energy efficiency** targets for 6G?
- How to develop **0-energy devices**?
- How to track and trace more complex supply chain ecosystem?
- How to integrate users into measuring emissions so that to reach effective, valid and reliable results?
- How to assess human exposure to EMF in the 6G era?

Reuse

- How to **share infrastructure, (virtualized) network resources and spectrum**?
- What kind of techniques could reuse energy?
- Who are the ones to co-create digital solutions for the future?
- How to integrate societal and economic perspectives to enhancing and measuring reuse?

Recycle

- How to create fully automized traceability of materials and components?
- How to transform from linear recycling of elements towards circular economy between applications and industries?

Recover

- How will different learning, interaction and communication processes be interconnected, researched and understood with new intelligent 6G technologies?
- How to exploit networks that are in different life-cycle phases (e.g. cellular generations)?

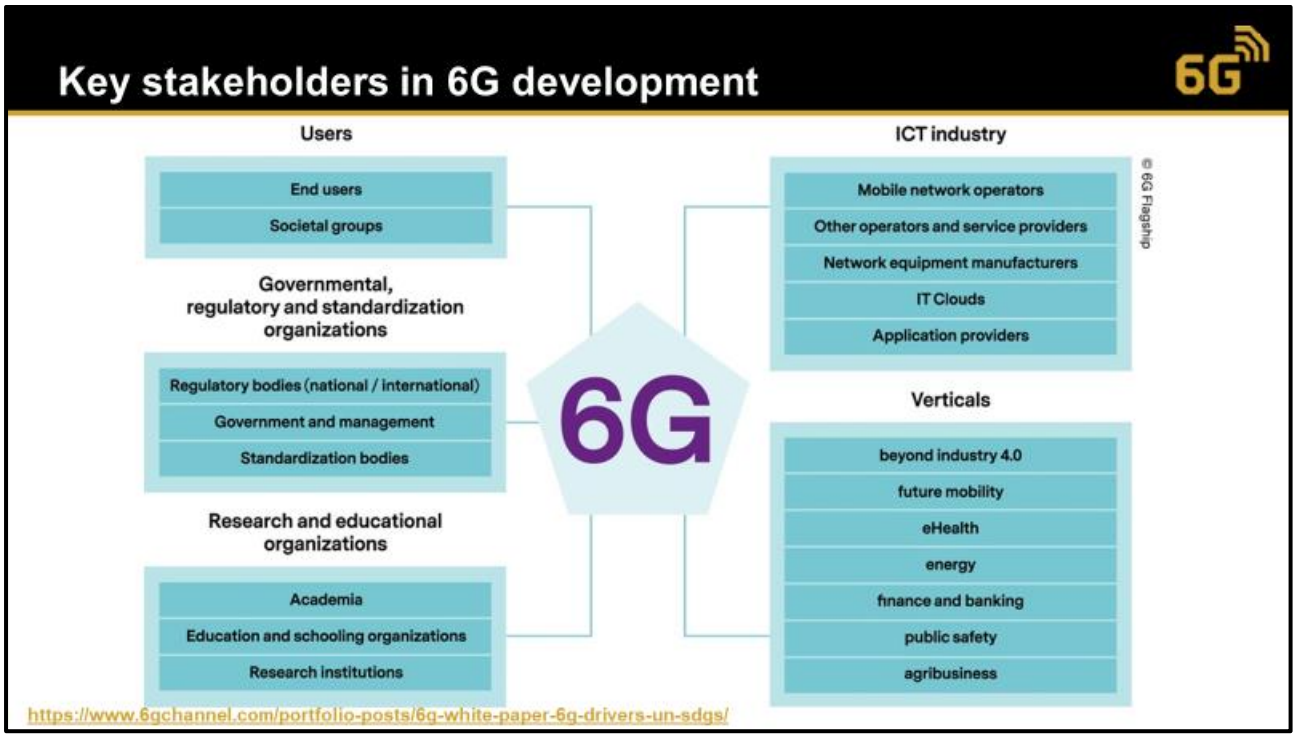
Redesign

- What are the novel human skills and capabilities and to enable a human-driven digital 6G future?
- How humans can be empowered to participate in the co-creation of digital 6G environments to make the best out of it?
- How to get non-users on board?
- How to integrate user and societal aspects to the redesigning process?

Remanufacture

- How to manage and orchestrate virtualized open distributed and shared 6G systems?
- How to utilize crowdsourcing and user owned data in remanufacturing?
- How to enable and incentivize frugal engineering and innovation in 6G?

M. Matinmikko-Blue, S. Yrjölä, P. Ahokangas, K. Ojutkangas & E. Rossi. (2021). 6G and the UN SDGs - Where is the connection? Wireless Personal Communications. https://doi.org/10.1007/s11277-021-09058-y


Key stakeholders in 6G development
6G
Users
End users
Societal groups
Governmental, regulatory and standardization organizations
Regulatory bodies (national / international)
Government and management
Standardization bodies
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
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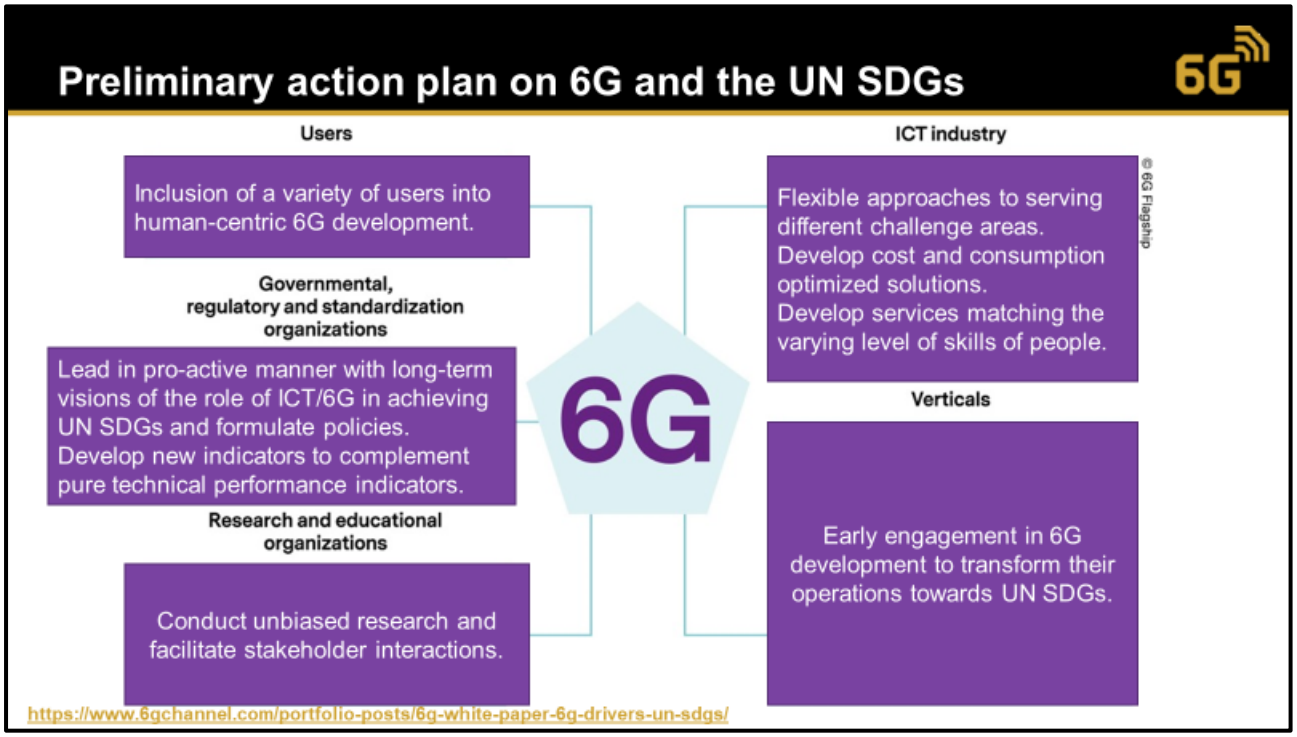
https://www.6gchannel.com/portfolio-posts/6g-white-paper-6g-drivers-un-sdgs/


Preliminary action plan on 6G and the UN SDGs
6G
Users
Inclusion of a variety of users into human-centric 6G development.
Governmental, regulatory and standardization organizations
Lead in pro-active manner with long-term visions of the role of ICT/6G in achieving UN SDGs and formulate policies.
Develop new indicators to complement pure technical performance indicators.
Research and educational organizations
Conduct unbiased research and facilitate stakeholder interactions.
6G
ICT industry
Flexible approaches to serving different challenge areas.
Develop cost and consumption optimized solutions.
Develop services matching the varying level of skills of people.
Verticals
Early engagement in 6G development to transform their operations towards UN SDGs.
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Defining sustainability in the context of spectrum management

- Sustainability refers to the principle of ***ensuring that our actions today do not limit the range of economic, social, and environmental options open to future generations***
  - Spectrum decisions lock the market for decade(s) to come.
  - No proper mechanisms exist to allow fast access to spectrum for new innovative wireless solutions and services that aim at solving major sustainability challenges except for unlicensed bands.
  - Connecting the unconnected is still challenged by spectrum decisions.

➢ Sustainability related indicators and new design principles are needed urgently.

M. Matinmikko-Blue. A new stakeholder paradigm to link 6G with sustainable development goals and spectrum management. In: M. Sims (ed.) The Debates Shaping Spectrum Policy. CRC Press. 2022.
M. Matinmikko-Blue. (2021). Sustainability and spectrum management in the 6G era. Keynote paper at ITU Kaleidoscope, 9 pages, 6-10 December 2021.
M. Matinmikko-Blue, S. Yrjölä, P. Ahokangas, K. Ojutkangas & E. Rossi. (2021). 6G and the UN SDGs - Where is the connection? Wireless Personal Communications. https://doi.org/10.1007/s11277-021-09058-y
M. Matinmikko-Blue, S. Yrjölä and P. Ahokangas. (2020). Spectrum Management in the 6G Era: The Role of Regulation and Spectrum Sharing. 6G SUMMIT conf, 2020.

Recommendations for sustainability

6G

- Role of wireless technologies for **emitting less** is equally important, as is support for **absorbing more** in other sectors.
- 6G combines communication with other services, like imaging, sensoring, and locationing, providing a **measurement tool**.
- New mechanisms are needed to reduce the carbon footprint through **sharing and optimizing the use of all potential resources**.
- **Optimization** of the collection, processing, storage and transfer of data **between different network locations** is critical.
- Significant improvement of **energy efficiency** and **reduction of total energy consumption** for 6G is needed including new measures, measurement methodologies and techniques from end to end.
- **Sharing of data and methods** on the impact of the wireless communications sector **between sectors and stakeholders** is needed to develop sustainable solutions.

Recommendations for sustainable spectrum management

- Spectrum authorizations should both **incentivize and force spectrum users to act towards sustainability,** where spectrum sharing will play a key role.
- Spectrum authorizations should allow new market entry for innovative wireless solutions combating sustainability challenges.
- Spectrum sharing should make current holders of spectrum access rights to transfer the rights to others in areas where they don't use the spectrum to help in solving major sustainability challenges.
- Spectrum sharing should allow underserved areas to be connected by suitable stakeholders.
- As a consequence, **spectrum governance rules** must evolve towards 6G.

Recommendations for sustainability and spectrum management

- Spectrum authorizations are a powerful tool to **incentivize and force spectrum users** to act towards sustainability.
- Gaining access to spectrum is lengthy and complex, while spectrum access needs for new innovative solutions combating sustainability challenges arise at rapid speed.
- There are no proper mechanisms currently in spectrum regulation to **allow fast access to spectrum for new innovative wireless solutions solving major sustainability challenges**. Their adoption is restricted by the license-exempt bands, subject to strict operational conditions.
- **Sharing based spectrum access** models can be particularly effective **to solve sustainability challenges**, e.g., to connect underserved areas by suitable stakeholders.
- Also, better analysis of the **impacts of operating frequency and other elements on energy consumption** is needed.
- While spectrum authorisations are a national matter, the approaches from one country, can through **sharing of best practices** help ICT sector to develop, trial and deploy innovative wireless solutions to solve sustainability challenges globally.

Conclusions

- Sustainability is about ensuring that our actions today do not limit the range of **economic, social, and environmental options** open to future generations.
- **Sustainability must become a visible design criteria for 6G** systems. This requires that resource efficiency is taken seriously in technical performance requirements including indicators and methodologies that can quantify sustainability impact, in addition to new indicators addressing societal aspects.
- Sustainability needs to be incorporated every topic of 6G. For example, in sustainable spectrum management, it is important to consider how long-term exclusive licenses without obligations to share fit in the new sustainability framework.

Thank you!

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Appendix C: Tables with the Full List of Topics and Clusters

Group 1 - How 6G will Enable Sustainability in Verticals
Opportunities & Obstacles
System view
System inefficiencies
Energy & cost efficiency on device-side as major design goals (--> which is still missing with 5G)
Computing can be more and more distributed
Convergence of technologies for higher resource efficiency
Overall digitalization of the society as well penetration of digital technologies
Enabler for more efficient system architectures --> pooling of resources and intelligence in the network rather than having it on every single device
enabling 6G capabilities
can we somehow establish a connectivity to RiFID? This would make it possible to locate elements without own 6G connectivity
Easy tailoring of networking solution to specific applications (local networks, modular design, SW-driven) instead of (inefficient) general-purpose solution
Integration of sensing capabilities as enabler for many new services contributing to higher sustainability (e.g., traffic situation, parking lot detection, etc.)
Standards
connectivity will not be an obstacle anymore if we have a common standard
Availability of "WiFi-type" user equipment in mobile networks, to enable innovations
Sector Applications with Industrial-6G should be based on a horizontal standard (like cybersecurity)
Getting more stakeholders beyond the classical ICT ecosystem directly involved in standardization & regulation
Global standard to support efficiency (e.g. energy, CO2 emissions, ...) for industries, mobility, …
"application areas"
Campus Networks with Industrial-6G
Next level of smartness in factories, building, etc., e.g. by massive digital twinning
6G can be a key enabler in achieving systemic sustainability across many individual energy assets like heat-pumps, charging stations, industrial processes…

6G NTN as an enabler to connect the unconnected and to address now underserved areas (e.g. for sustainable agriculture)
6G as enabler for the Metaverse --> full inclusion, no need to travel anymore
cross sector / discipline understanding
Verticals and ICT need to speak the same language
Matching the requirements of the multiple stakeholders
"Higher, faster, further" and typical >10x improvements of major KPIs do not automatically contribute to higher level of sustainability
Diverse technology deployment roadmaps from different stakeholders
Business aspects
Sustainability along the whole lifecycle has to become a design criteria for 6G-applications
The "IPR Challenge" -> higher cost, high entry barriers for new players, etc.
Business and economical feasibility to realize and deploy the technologies
Security / privacy /data
Increased availability of data everywhere
Cybersecurity considerations may limit the user willingness
data privacy risks to be a legal obstacle to many good business ideas
Proper use of the available data respecting legal requirements and ownership chains
Group 1 – How to Realize these Opportunities or to Overcome these Obstacles
Legal
legal: make it mandatory for energy-intensive devices to be connected to 6G
legal: aggregate and anonymize data such that it can be made available to energy system operators
Proper legal framework to deal with IPR challenge and/or revised IPR policies
legal: make it mandatory to track CO2-emissions caused by 6G communication e.g. via blockchain technology
Streamline legal requirements
legal: establish a legal basis that makes data a tradable good similar to IP-rights. This could be done via a mandatory identifier for every data package
legal: battery buffering for 6G base stations shall be equipped to participate in black-start of public power supply after a black-out
Industry sector specifc business view

For Industrial 6G-Campus Networks we need an exclusive frequency spectrum (like 5G)
Each 6G-application necessitates an attractive use case for implementation from industry view point
economically attractive solutions (payback >2-3 years)
Medicine: 6G to achieve scalability of networked systems
Scalability of compute resources
6G easy to integrate into existing 5G applications; technical requirements need to be compatible
Standardisation / regulation
Ensure NTN as integral part of the 6G architecture
standard: ensure international and cross-sector compatibility
standard: establish a cyber-secure and auditable interface to RiFID.
Cross-industry regulation and standardization
Multi stakeholder cooperations
Reconsider the way we are doing things (e.g., in 3GPP) and make it a more inclusive ecosystem by reducing complexity / effort (e.g., by better making use of the new capabilities of ICT technologies :) --> virtual collaboration, joint work on documents, etc.
Multi-stakeholder collaboration
Early provisioning of Open Source platforms for innovation development (user equipment, ...)
Give open source a bigger role
Supply chain
6G should monitor its own supply chain
Could sustainable supply chains be a global killer app for 6G?
Research: clarify how 6G can contribute to sustainability? New opportunities (e.g. improved enabling supply chains)
Measuring / monitoring
Develop/derive measurable Key Value Indicators
Sustainability by Design
track entire lifecycle of 6G components and operation
Research: End-to-end optimized system design based on sustainability requirements
Sustainability by Design - Make sustainability considerations as a default
Focus on holistic end-to-end solutions from the very beginning --> not just with a rough idea of a use case, derived requirements and then losing the overall picture

Rebound effects: monitoring of sustainability of supply chain costs more "energy"
Set the right priorities: Don't start with Tbit/s data rates, but with zero-energy devices and the low-cost end

Group 2 – Sustainability for End Devices
Opportunities
Efficient Design
Energy efficiency by design
designed for long usage and recyclable
Sustainability by Design dh im Produktdesign berücksichtigt
zero energy IoT Devices ohne "Batterie"
modular design in order to make devices better repairable
Communication and sensing helping mutually
Size of device
intelligence in the edge => no need for highest performance in the field
minimize size of devices through AI in order to find out "right" size
Recycling/ Refurbishment
Optimized compute split between sub device (glasses) tethered to smartphone & NW could allow energy optimized function split
Integration of biological recycling
Ressourcen Einsatz verringern; rückgewinnen sustainability als Kauf/Beschaffungskriterium stärken Energieeffizienz erhöhen
By a clean slate 6G (sustainable?) the legacy restrictions/technologies e.g. NB-IoT, GSM IoT could be "retired"
Neue Geschäftsmodelle
Neue Recycling Wirtschaft entsteht
Neue Geschäftsmodelle zb Device Upgrade, Device Lifecycle
flexible spectrum usage
Obstacles
Raw Materials
rare raw materials, esp. non-renewables
Complexity
keep software as smart as possible
6G to become more complex than 5G

Power Consumption
Charging every 1/4 - 1/2 day due to Metaverse native devices
Limits due to power density & compute efficiency in a handheld device
Number of IoT Devices
"billions" of IoT devices == in sum high energy consumption and material usage
IoT devices everywhere is a risk for environment
IoT business case and model, has it ever worked so far?
Recycling/ Refurbishment
fehlende Informationen über Rückgabemodelle / Orte zu hohe Transaktionskosten Angebote/Geschäftsmodelle noch in Entwicklung Refurbishing noch in Kinderschuhen
Fehlende verbindliche weltweite Rahmenbedingungen
almost no refurbed or remanufactured devices by now
most resources are difficult to recycle (esp. minerals)
Hardware
Langlebigkeit vs. Innovationen. Wann macht der Austausch eines Endgerätes Sinn?
Network for high data and Green IoT devices
Interoperability with legacy technology (2G,...)
short innovation cycles often require new hardware
Group 2 - How to Realize these Opportunities or to Overcome these Obstacles
Optimization of Energy-Usage
Software as a service
on-device intelligence for optimized energy usage
use connectivity to to keep devices maintained
Provider collaborations
Collaboration among different ecosystem(s) players
State own/ operated IoT network sort of "neutral host" ala BDBOS
Commitment ala "Paris" agreement for ICT community "circularity" by law/regulation
Sustainability = Prio1
Energieeffizienz / Modularität als Anforderung in der Standardisierung

Mehr Awareness schaffen, sustainability by design von der Hardware über das Netz bis hin zu Apps und Nutzern Mehr Angebote/Informationen
Stimulierung für zirkuläre Produkte (zb Steuererleichterung ?)
Definition von Sustainability Kriterien als Input für die 6G Standardisierung
put R&D priority to sustainability
rank sustainability high compared to other KPIs
Legacy Systems
ww spectrum allocation and usage will be the first challenge
tradeoff between coexistence, legacy support, and new clean 6G
Rohstoffe
find substitutes for non-renewables
Recycling
Right-to-Repair
Design-to-Repair, Design-to-Recycle, through the help of AI
improve recycling technologies, fx. biological recycling
Materialauswahl an Recycling / Verwertbarkeit / Umweltverträglichkeit orientieren
Handypfand Recycling etablieren
Anforderungen von Beginn an abstecken
new aspects like NTN from the beginning
sustainability supporting features from the beginning
R&D: start from application needs before defining tech requ.
integrate different domains into discussion, support their IoT needs (e.g. agriculture,,building, ...)
Zuweisung des Funkspektrums genauer auf Applikation anpassen

Group 3 - Sustainability of the 6G Network Infrastructure
Opportunities & Obstacles
Framework
What is an appropriate framework to balance the conflicting targets? How to set priorities?
multiple interests: SDGs, multiple stakeholders, must be resilient
Reuse of existing resources
Leveraging existing infrastructure
reuse heat from data centers
generate renewable energy directly at the tower (solar, wind)
Reuse existing Passive infrastructure, longer term planning
Acceptance
improved societal acceptance of cellular (6G)
Competitive Advantage
Unique selling point for operators
Competitive advantage to distinguish in the market
E2E Design
E2E thought function split network / UE, also including subsequent data processing
context of edge/cloud compute: energy per bit: wireless comm reduces slower than compute, i.e., gap increases energy savings in computing are advancing faster than energy savings in communication -- gap is widening -- what is better: compute locally or send to cloud?
impact of open source solutions
Use of latest HW technology
Making sustainability a design criterion from the very beginning
Considering the positive effects in the verticals supported by 6G
Most of the energy is used by the RAN, but this is also the hardest part to update
New tech VS reuse what we already have
KPIs for usage
Indicators for energy efficiency
Defining meaningful KPIs and measuring them

Lack of KPIs. The UN SDGs targets/indicators are a mixed bag of KPIs and of limited value for network infrastructure
Technologies can help achieve some SDGs but hinder the implementation of other SDGs
Resilience and Coverage
Use 6G to make synergetic use of all communication infrastructures in a country to improve the resilience in the case of crisis situations e.g. flooding in the Ahrtal in GER
achieve true global service coverage
There are economical obstacles, regulatory as well, technically it would be feasible
infrastructure can be attacked. But we are very dependent on it as a society
Data and Privacy
privacy concerns when collecting metrics
Data Protection issues regarding suppliers and employees
Transparency vs. data protection
Conflicting Priorities
Mgmt thinks it's too expensive --> low priority
Conflicting KPI and prioritization of others higher than sustainability
Regulation
Regulation prevents using renewable energy close to the towers (eg because it would cross property boundaries)
Regulation can't keep up with exponential technological growth
Decoupling of the entire ICT infrastructure: supply chains
how to deal with a globally decoupled NW, data, design plans, ecosystems
Lack of data/insight into usage/emissions
Lack of data (?), e.g. what is energy consumption for training AI models
Collecting Scope 3 Upstream Data along the supply chain
SA8000 relevant indicators along the supply chain
hard to collect reliable data
Exponential Growth
can't keep up with exponential growth
Data and usage growth faster than Moore's law progress
Complexity

Probably, it will be hard to predict all effects of 6G on sustainability - we simply do not know enough... - translates into need to design which can be adapted later
Complexity may overwhelm engineers during both design and operation
Lack of interoperability / standards because of geopolitics
Complexity of networks (technologies) and regulatory requirements leading to difficulty in managing resource efficiency end-to-end
Missing instruments to prevent misuse
Misuse of infrastructure for short-term profit generation (similar to bitcoin mining) is an acceptance barrier
Could create brek-through in understanding that ESG- and ethical related "certifications" will be necessary for future large-scale infra platforms
Group 3 - How to Realize these Opportunities or to Overcome these Obstacles
Global Alignment
Make sure we take a global perspective, not biased by European/Western world views
sustainability at the cost of others is not sustainable
Better global alignment
Join the relevant parties for a joint effort: Public carriers, utilities, equipment manufacturers, regulators and users
Need for international agreements on collecting data
If networks are splintered, need gateways to connect different networks
UN SDGs very holistic, but it then gets decoupled at lower (eg national) levels
Awareness that national level sustainability requirements lead to significant fragmentation in the market and economically unfeasible and technically sub-optimal solutions
must balance local perspective with the global overall perspective
redundancy for resilience: NTN integration, mesh integration
Tradeoff between sustainability, resilience and cost - different from country to country, different energy sources available, different priorities A political process
tradeoff: volatile energy mix versus reliability/resilience
Standardization process abused for national/regional political interests
more concrete measures
power cells instead of diesel as backup power (resilience) currently would be more expensive

energy consumption in data centre vs end devices. ED have a vested interest in lower consumption, but not really in data centre
Design Goals
Evaluate energy efficiency in 6G for all design aspects
Should SDGs be the highest priority goal for 6G?
Data Standards especially for privacy
Definition of "Data Tags" for Materials and "Human Rights" related data.
Distribution of data and compute may enable privacy
KPIs for ESG
Add e.g. power saving techniques and KPIs in 3GPP specs
Globally agreed KPIs for energy use, and tooling to actually measure this
Built-in ESG KPI transparency with near-real-time monitoring and context specific analysis of long-term history of usage data
Definition of missing SDG related KPIs and interpretations
make data from operators available for academia
also include lifecycle mgmt
Enable end user and operator to monitor energy consumption
tools for end users to learn their footprint, communication with end users about how to reduce their footprint
Regulation
New regulatory approach for use cases which affect ESG related policies & principles
Clarify conflicting priorities
Increased discussion with the public and with use cases to set priorities. eg what do you want more: more bandwidth or more sustainability
Common framework that brings the concepts together (resilience, sustainability, etc.) to find the balance between conflicting goals
Open question: how to balance complexity vs. speed and pragmatism "to get things done"
allow tradeoffs between QoS and deployment cost, consider specific device constraints
Awareness
Make society aware that sustainability comes at a cost
New Technologies
flexible spectrum sharing methods

Enable operators to differentiate themselves
New (dynamic, context-aware) pricing concepts for the use of 6G infra and services
e2e system design
Apply a built-in systemic approach across ALL relevant stakeholders (from user to producer, from engineer to society, from ...) - I assume that there is no generally accepted definition yet who are the stakeholders to be involved. Law: a kind of novel design philosophy for complex systems, which by default includes all stakeholders and dimensions to be considered
Despite known complexity: KISS to get to pragmatic results. Allow for iterative improvements and tuning (kind of DevOps like approach)
currently behind driven by the wireless industry. No good framework or processes to include requirements from public and use case verticals doesn't match how standardization and technical people work
very complex system -- effects and side-effects of changes not known
need to adapt dynamically to a changing environment
not an engineering topic, a societal topic
Communication Transition
the same kind of discussions about energy we have at the moment (Energiewende), we need to apply to 6G: define priorities, accept/promote major changes in the technologies and in how we use them, changes in consumer and industry behaviour, political (interest groups vs public's best interest), misinformation, battle for the truth, ...