Sustainability and Role of 6G

Rev 1

Sept 2024

5GIF 6GCG

1 PREFACE

The 5GIF 6G Cooperation Group (5GIF 6GCG) is created as a collaborative body for developing mindshare around 6G and creating positions around the prioritization of research and development, requirements, globally harmonized standards development and of market readiness in India.

The 5GIF 6GCG facilitates to advance and share the knowhow on technologies and trends; to further interests among stakeholders in India that will be driving the development of 6G and its applications over the next few years.

This report is consolidation of views from 6GCG members on “Sustainability and the role of 6G” in a wider context of various sustainability goals and specifically the expectations from the ICT and telecom industry. The next generation cellular technology 6G is also expected to contribute towards the sustainability goals, including the design and development of 6G itself. The whitepaper introduces the key components of “Sustainability” and how the different players in the telecom value-chain can take the right steps towards the sustainability goals while designing 6G.

Table of Contents

2 Overview

Today´s society faces major challenges, including the pandemic, distrust and global warming, which all need to be addressed while creating innovation-led opportunities for economic prosperity and job creation in a circular, green and digital economy.

Sustainability mainly relates to SDG11 for sustainable cities and communities and SDG13 for climate action, since high energy efficiency, can be directly translated to lower CO2 emissions. The Paris Agreement of the United Nations Framework Convention on Climate Change seeks to cap global warming in this century at well below 2°C, with aspirations to keep it under 1.5°C. *Carbon neutrality has become a key strategy post-Kyoto and Paris agreement. Net-zero emissions* – when the carbon emitted into the atmosphere and the carbon removed from the atmosphere are in balance, results from combined efforts in emissions reduction and offsetting methods such as afforestation and carbon capture. All industries, including telecom, need to strive for carbon neutrality to effectively tackle the climate change.

Sustainability, or more specifically environmental sustainability in the telecom sector refers to its capacity to reduce ecological impacts both within the industry and across other sectors through its extensive connections. Within telecom, both networks and devices are continually improving to minimize greenhouse gas emissions and other environmental effects throughout their lifecycle. Key initiatives include enhancing energy efficiency, reducing natural resource consumption, and promoting practices such as recycling, repair, reuse, and extending product longevity.

The digital transformation of society and industry is inherently a low-carbon journey, with the telecom sector playing a key role in achieving Net-Zero ***Green House Gas (GHG) emissions***. Telecom companies are not only making ambitious Net Zero pledges but are also among the largest purchasers of renewable energy, leading the race toward sustainability. A major contribution of the telecom industry to climate change mitigation is the development of energy-efficient products and solutions that help reduce the energy consumption, costs, and carbon footprint of mobile networks. By breaking the energy curve for customers, telecom solutions are creating a more sustainable future for energy-intensive industries.

Carbon pricing assigns cost to emissions motivating businesses and individuals to switch to low-carbon options and sustainable practices. Carbon reporting mandates that organizations disclose their GHG emissions enhancing transparency and accountability.

Caron reduction through incentive-based regulations (ex: ZEV program) also motivates such initiatives.

Beyond the telecom sector, connectivity offers numerous opportunities to mitigate climate impact. For instance, technology-driven solutions in agriculture can optimize water usage, reduce input costs, and enhance land and resource efficiency, contributing to a positive environmental footprint. Similarly, telecom connectivity enables sustainability advancements in industries such as mining, healthcare, energy, and manufacturing. According to this research paper[1], ICT solutions alone have a potential to reduce GHG up to 15%.

Technologies like 5G, artificial intelligence (AI), and the Internet of Things (IoT) enables transformation of industries such as transportation, manufacturing, and energy utilities, making infrastructure smarter to make them efficient and productive. As a result, telecom advancements will not only stimulate economic growth but also serve as critical tools for combating climate change and promoting social inclusion through enhanced connectivity. Although the carbon emissions from telecom is only a small part, however, wireless connectivity is at the core for many industries and hence there is a dependency and expectation on telecom industry to contribute to various sustainability goals.

In a study[2], the estimated ICT sector's contribution was 1.4% of overall GHG emissions in 2015, and these levels were also estimated to be a quite stable until 2020. This level has also been agreed as a sector baseline for the decarbonation trajectories developed jointly by ITU, GSMA and GESI and applied by SBTi. From the global perspective, the embodied/use stage emissions ratio is closer to 50/50 for aggregated user devices due to short life spans and less intensive usage, compared to network and data center equipment for which use stage emissions represent most emissions due to longer life spans and as the equipment is used 24/7.

---

[1] Malmodin, Jens & Bergmark, Pernilla, "Exploring the effect of ICT solutions on GHG emissions in 2030", 2015. https://www.ericsson.com/en/reports-and-papers/research-papers/exploring-the-effects-of-ict-solutions-on-ghg-emissions-in-2030

[2] https://www.ericsson.com/en/reports-and-papers/research-papers/the-future-carbon-footprint-of-the-ict-and-em-sectors

The increased use of mobile broadband and digital solutions will likely require densification of the network to increase the capacity. It may also require manufacturing of more devices (including IoT devices). This could lead to an increase of overall emissions unless energy efficiency continues to be addressed together with behaviors and the transition to renewable electricity supply. Supporting this, ITU [3], GSMA, GESI and SBTi have jointly developed trajectories which establish that the ICT sector should reduce its environmental footprint by 45% between 2020 and 2030.

Key areas to ensure long-term sustainability, includes improved energy efficiency, renewable energy sources to power operations, digital inclusion through expanded access to services, supply chain sustainability via responsible sourcing and minimized waste, and environmental stewardship to minimize the industry's carbon

The ITU-R framework[4] for IMT-2030 (6G) includes sustainability as one of the overarching design principles, it is expected that 6G networks should contribute to a range of environmental, social and economic aspects and is expected to have some minimal performance requirements to be met by the Radio interface specifications. Hence, sustainability in the context of 6G have become one of the main research challenges and a core value of 6G design; with a holistic objective to include environmental, social and economic aspects, and must be built around meeting the target goals without compromising the application needs of future.

[3] https://www.itu.int/en/mediacentre/Pages/PR04-2020-ICT-industry-to-reduce-greenhouse-gas-emissions-by-45-percent-by-2030.aspx

[4] ITU-R Recommendation M.2160 – Framework and overall objectives of the future development of IMT for 2030 and beyond

Apart from considering *Energy Efficiency* as one of quantitative performance requirements of a 6G radio interface, Key Value Indicators (KVIs) are also envisaged in the 6G Architecture by 5GPPP[5]. The Next G Alliance also have identified *environmental sustainability indicators* for Radio Access Network[6] as well as Core Networks[7] that include various data centre.

Global systems for Mobile communication Association (GSMA)[8] have developed industry standards for industry specific *ESG* (Environmental, Social and Governance) *metrics* and guidelines for telecom operators.

The Europe's 6G Flagship project - Hexa-X; in its deliverable report D1.2[9] have identified that *sustainability* needs to have both KPIs as well as KVIs (sustainable 6G and 6G for sustainability).

While studying the role of 6G in sustainability, its *first order effects* must be holistic; and include the entire life cycle of various 6G system components like core, transport/aggregation, access, and user equipment/devices. Though, 6G is expected to be designed native be more sustainable than previous generation, overall net gains in terms of environmental impact should also consider that there will be old generation of network still deployed and will also be in operation.

[5] The 6G Architecture Landscape - European Perspective by 5GPPP
[6] Evolution of Sustainability Indicators for Next-Generation Radio Network Technologies - NXGA
[7] Evolution of Sustainability Indicators for Data Centers and Next Generation Core Networks - NXGA
[8] ESG Metrics for Mobile - GSMA
[9] Hexa - X D1.2 - Expanded 6G vision, use cases and societal values

3 Sustainability Goals and Initiatives in India

India being a strong believer in the mantra of “Vasudhaiva Kutumbakam – One Earth, One Family, One Future” has accorded highest priority to sustainability, and is one of the major economies currently on track to meet the Paris Agreement goals, based on their pledged targets for 2030 (Climate Vulnerable Forum-CVF report, Times of India Delhi 16.10.2023) and as also reflected in the Panchamrit announcement and G-20 Delhi Declaration [3]. Keeping in view that circular economy model of sustainable development is the Way Forward, Government of India in March 2021 formed 11 Committees in various Sectors (including Electronics and Electrical) to expedite the transition from a “Linear Economy” to a “Circular Economy” [6].

In the telecom/ICT sector, e- waste generation and its responsible and safe disposal is a big challenge, as e- waste doesn't biodegrade and accumulate wherever dumped. The Indian Telecom sector is one of the fastest growing sectors of the economy and has hugely added to the economy. Telcom’s contribution to the economy is 6% of India’s GDP [5]. However, since telecom networks are expanding rapidly and since obsolescence is very fast in telecom, there is huge consumption of resources as well as generation of large amounts of e- waste [5].

Telecom companies encouraging biofuel and adopting alternate energy can reduce carbon emissions in day-to-day operations. Traffic offloading from cellular networks to Wi-Fi access points, smaller outdoor BTS, and free cooling systems at tower locations can further reduce carbon emissions during daily operations [8].

Circular economy in Telecom is "restorative and regenerative by design and aims to keep productive components and materials at their highest utility and value at all times, while reducing waste streams, i.e., ideally net zero”[10]

Policy initiatives for circular economy in telecom in India include:

1. TRAI - approach towards green telecom [7] (published 2011)
    a. Encourage the use of energy- efficient buildings and network systems
    b. Highlights the disposal requirements for mobile phones, batteries, chargers etc.

[10] See ITU-T Recommendation L.1020 : Circular economy: Guide for operators and suppliers

2. TRAI 2017- approach towards Sustainable Telecom
    a. Focus on adoption of energy efficient equipment/ practices in operation
    b. Suggested improvements in network planning and optimisation

2. TRAI 2019-CE in Data Centers
    a. Suggested establishment of green data centers that can reduce emissions by using more efficient off- the- shelf- technology and better energy management
3. ERSO (Electronic Repair Service Outsourcing) Pilot Project 2023
    a. This project was launched by MEITY (Ministry of Electronics and Information Technology) to assess the feasibility of India as a global repair hub
4. National Digital Communication Policy (NDCP), 2018
    a. Emphasis on adoption of renewable energy in telecom
5. **Ministry of Consumer Affairs (MCA)**: To support retail and end use consumers in product life extension, MCA has deployed a Right- to- Repair framework allowing consumers to repair their products cost- effectively instead of replacing them with new products.

6. **Inter-ministerial committee** recommended that an additional incentive of 1% in Production Linked Incentive (PLI) scheme be given if circularity is there in the products. The committee also recommended to set up the National Centre for Circular Economy in Communications. It has been recommended by the above committee that 'Circular Economy in Telecom' should be included in the AICTE course.

India's Mission on Net Zero includes initiatives across multiple sectors and ministries aimed at reducing emissions and promoting sustainability. ***National Hydrogen Mission*** focuses on developing green hydrogen technologies to decarbonize industries. ***Renewable Energy Expansion*** – International Solar Alliance to targets 500 GW of non-fossil fuel energy by 2030, with solar, wind, and hydropower projects. E-Mobility and EV Transition under the ***FAME India Scheme*** promotes electric vehicle usage, with infrastructure for charging stations and battery manufacturing. Afforestation Programs such as the **Green India Mission** focus on forest restoration to enhance carbon sinks. Circular Economy Initiatives like ***Extended Producer Responsibility (EPR)*** encourage waste reduction and recycling in sectors like plastics and e-waste. Industrial Decarbonization through energy-efficient technologies in sectors like steel, cement, and chemicals. Sustainable Agriculture promotes climate-resilient practices and efficient technologies like drip irrigation and more mission on Carbon Market, Green Building, Transport etc.

The DoT order number 16-06/2011-CS-III dated 07/01/2019 & 20-271/2010 AS-I, Vol-II dated 15th May 2019, desired that the Telecom Service Providers would adopt a Voluntary Code of Practice encompassing energy-efficient Network Planning, infra-sharing, deployment of energy-efficient technologies and adoption of Renewable Energy Technology (RET) including the following elements:

(a) The network operators should progressively induct carefully designed and optimized energy efficient radio networks that reduce overall power and energy consumption

(b) The target for reduction in 'Average Carbon Emission (tons of CO_2e per unit Petabyte)' shall be 30% by year 2019-20 taking base year as 2011-12 and 40% by the year 2022-23 taking base year as 2011-12. For TSPs, whose service had started after 2011-12, the base year average carbon emission shall be considered as the average base year carbon emission of TSP with highest subscriber base in the year 2011-12.

The target shall be reviewed in the year 2022-23. Accordingly, this Voluntary Code of practice outlines a documented approach for Service Providers to: · enhance energy efficient Network Planning · infrastructure-sharing · deployment of energy efficient technologies · adoption of Renewable Energy Technology (RET).

4 Principles of Sustainability: ICT and Telecom perspective

From the global perspective, the embodied/use stage emissions ratio is closer to 50/50 for aggregated user devices due to short life spans and less intensive usage, compared to network and data center equipment for which use stage emissions represent most emissions due to longer life spans and as the equipment is used 24/7.There are three major drivers for the future trends in first order emissions of the ICT sector: the decoupling between data traffic and energy consumption, the reduction of ICT energy consumption, and the decarbonation of ICT energy.

Regarding sustainability, even if the current contribution of (1.4%) the ICT sector to the total carbon footprint of the society is limited, the increased use of mobile broadband and digital solutions will likely require densification of the network to increase the capacity.

It may also require manufacturing of more devices (including IoT devices). This could lead to an increase of overall emissions unless energy efficiency continues to be addressed together with behaviors and the transition to renewable electricity supply.

The ITU organizes the sustainability of ICT into three orders of effects:

i) first order effects that denote the life cycle impacts of goods, networks and services (i.e., its footprint),

ii) second order effects that denote the impacts in other sectors due to the use of ICT and

iii) other effects which denote higher order effects such as those associated with behavioral changes.

In the context of telecom, the first order effects of 6G are also referred to as sustainable 6G or footprint, while 6G for sustainability refers to the second order and, to some extent, higher order effects.

With mobile networks already energy intensive, the expected 20-fold data traffic surge for 2G by 2029 compared with 2022 suggests a potential significant rise in energy use and carbon emissions [8].

Telecom operators not only bear high energy bills but also incur additional costs due to carbon taxes. Network, device, and chip vendors should also consider carbon neutrality across product lifecycles, from manufacturing to disposal.

Electricity is typically generated from a mix of renewable and non-renewable energy sources, such as gas, coal, and wind energy, each with varying levels of carbon emissions. Telecom operators are at the forefront, actively increasing their use of renewables to cut down on fossil fuel dependence and shrink their carbon footprint. Carbon Intensity, which measures emissions per unit of energy consumed (e.g., expressed in grams of CO_2 per kW·h), could be a sustainable indicator of the environmental impact of a given operation, where a low (respectively high) value represents a higher (respectively lower) proportion of renewable energy usage. The availability of detailed Carbon Intensity information within a power grid has a significant impact on the granularity of carbon awareness, particularly concerning the deployment of renewable energy.

Energy efficiency and **carbon-awareness** are the fundamental cornerstone of sustainability from a telecom network perspective.

To properly assess the system's renewable energy usage and its carbon emission impact, an additional Key Performance Indicator (KPI) is required. This KPI would create a link between the service performance (e.g., data rate) and carbon emissions, capturing both energy efficiency and renewable energy utilization.

An example of such a KPI could be the present energy efficiency (e.g., bits per unit of energy) scaled by a carbon emission factor dependent on the emissions profile of the energy sources used by the wireless entity. The development of such a KPI represents an important future endeavor, preferably as a part of the standardization process, providing a quantitative measure of the system's performance in terms of energy consumption and carbon emissions, as a key aspect to support the sustainability goals discussed earlier.

The Greenhouse Gas Protocol (GHG Protocol) is a global framework for measuring, reporting, and managing greenhouse gas (GHG) emissions. The GHG protocol offers a framework for classifying emissions into Scope-1,2,3 as below:

Scope-1 emissions: Direct emissions from sources within an organization's controls, such as on-site fuel combustion and company vehicles.

Scope-2 emissions: Indirect emissions from consumption of purchased energy like electricity, steam, or heating, produced externally but used by the organization.

Scope-3 emissions: All other indirect emissions not under direct control, including value chain activities like emissions from procured goods and services, employee computing, business travel and end-user product consumption. For network operators and vendors in particular, primary incentives lie in the reduction of their Scope-2 and Scope-3 emissions and in addressing rising electricity costs and carbon taxes.

For chip and device vendors, core motivations are improving user experience through better energy efficiency and in reducing Scope 3 emissions – foremost challenge remains improving energy efficiency for data communication. It is important to note that power saving technologies, particularly over the radio interface, are typically a fine balance between device and network support and usage. For 6G, considerations for **joint network and device energy savings** need to be incorporated from day-one.

Fig1. Illustrates the main GHG emission sources in mobile communication systems.

5 Technology Enablers for Sustainability

5.1 Sustainability Features in 5G and 5G Advanced

5.1.1 RAN- Current Methods for Network Energy Efficiency

Some of commonly used techniques to minimize network energy consumption in today's network are listed below:

- **Dynamic Cell Shutdown [11]:** Cell sites (or some carrier) can be temporarily shut down during periods of low traffic or when coverage is redundant. This feature helps reduce power consumption significantly, especially in rural areas or during off-peak hours.
- **Cell Sleeping:** A more granular approach that involves reducing the power consumption of a cell site to a minimum level without completely shutting it down. This allows the cell to remain active for emergency calls or to support roaming users, while still conserving energy.

Operators also use advanced framework like AI/ML in making such decisions for cell-sleep/shut-down to minimize network energy consumption.

In this addition, minimizing energy consumption by putting a base-station into sleep mode, there also energy saving techniques that can be used base-stations while being active. Few

[11] https://www.fierce-network.com/newswire/bt-embraces-cell-sleep-function-drive-energy-savings and https://www.ericsson.com/en/press-releases/2/2023/2/singtel-partners-ericsson-to-achieve-industry-breakthrough-in-mobile-network-energy-savings

known ones[12] are by dynamically muting some antenna transceivers and configuring the PRACH and SSB periodicity.

3GPP NR is designed with a typical (SSB) periodicity of 20 ms-160 ms. The reception period of PRACH has multiple options and can also be reconfigured. By dynamically configure the reception period of PRACH based on the network status, one can provide more sleep opportunities for the gNB in idle mode.

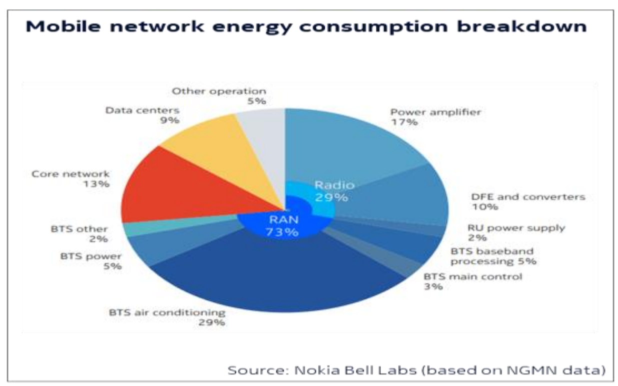
Note: The specific implementation of these features may vary depending on the network equipment vendor and the specific requirements of the telecom operator.

5.1.2 RAN -5G Advanced Features

Energy consumption is a major consideration in the RAN, so improving energy savings and efficiency are pivotal for the RAN. Energy consumption is the total amount of energy

consumed by the RAN during operations whereas energy efficiency is the data volume transmitted per unit of energy consumption, in GB/kWh, during a fixed time frame [8].

The RAN's overall energy performance comprises two main areas: climate control and base station equipment. The RAN's energy efficiency is also impacted by operational configurations such as network density, spectrum bands, and bandwidths, and the number of radio access technologies. The mobile network energy consumption breakdown is provided in the following Figure.



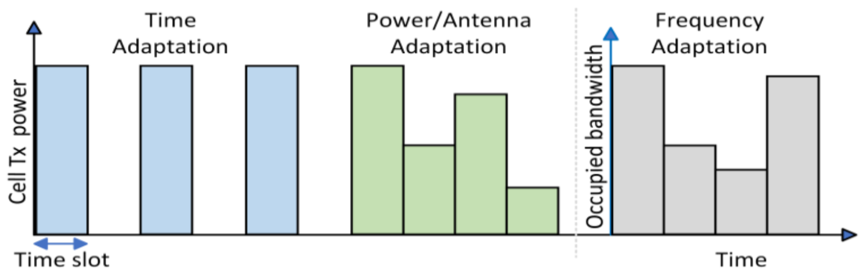
Adaptation of radio resource usage for energy efficient downlink transmission is one primary mean to achieve RAN energy saving. In this regard, the radio resource adaptation in following domains were investigated for introduction of network energy saving in 5G advanced networks.

- Time

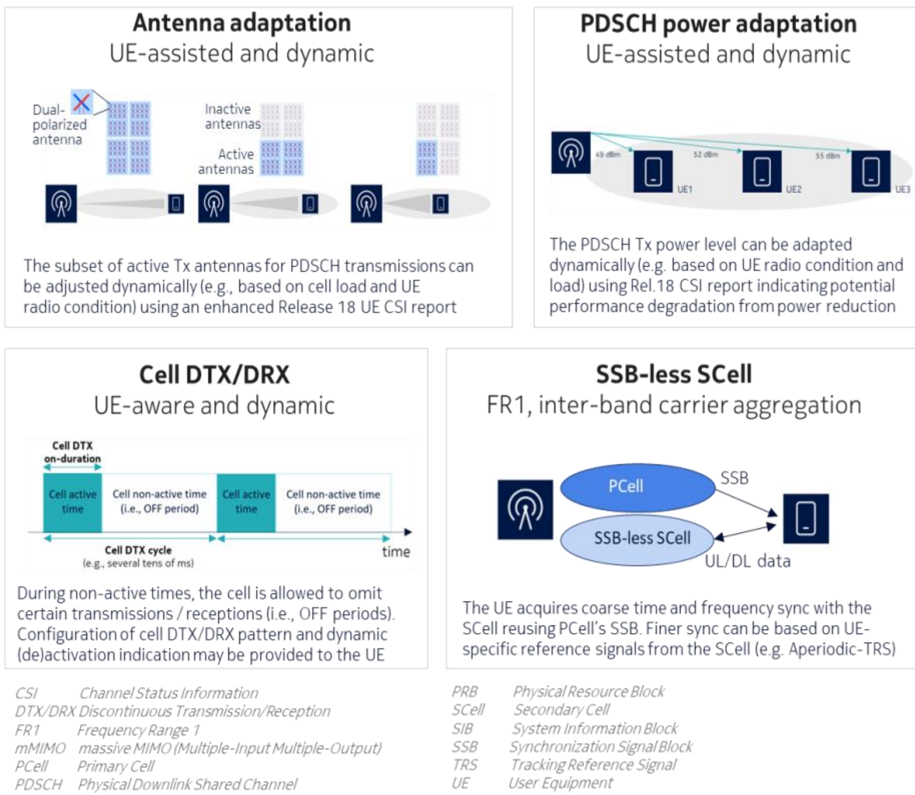
[12] https://www.ericsson.com/en/blog/2023/8/breaking-the-energy-curve

- Transmit Power
- Transmit Antenna
- Frequency

These adaptations allow to deactivate unnecessary resources during low load (and the associated hardware components), and thereby save energy.



The key challenge in introducing specific adaptation scheme is to strike the right balance between network energy efficiency and the impacts to QoS Performance. Different techniques can be evaluated against the NES gain and the impacts to user experience at different loading conditions. The technical components of 5G advanced network energy saving features are illustrated in the following figure.



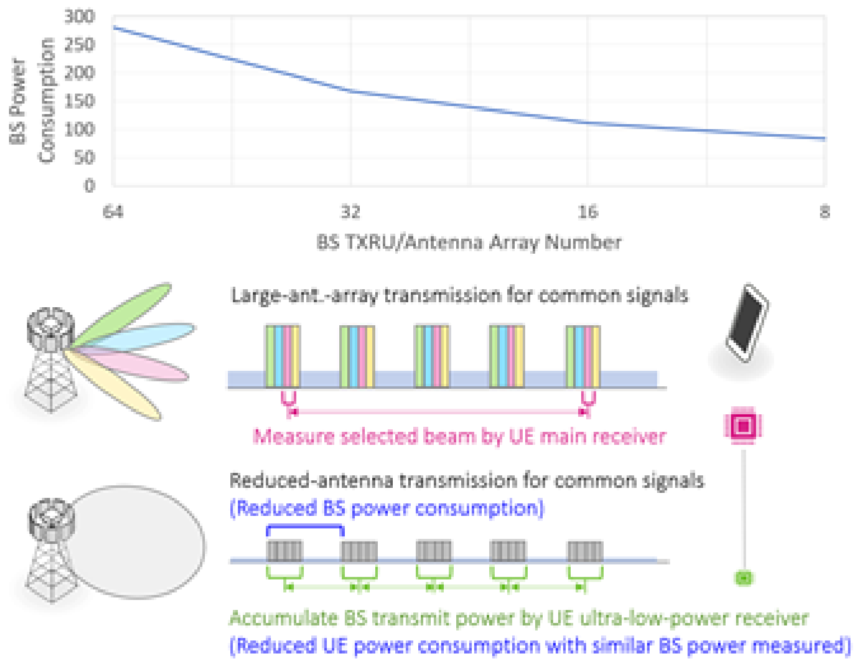
The RAN energy efficiency evaluated for the above set of features using the reference 3GPP BTS power model and simulation assumptions as per 3GPP TR38.864 indicates possibility of 15-30% energy consumption reduction in RAN. The actual network energy saving gains may differ depending on the deployment scenario, variation to the BTS power model and traffic profiles.

5.1.3 Devices

Low Power improvements in UE's have evolved over multiple generations of 3GPP releases. It started with cDRX (connected mode discontinuous reception) and BW part as baseline in R15; further improving in R16 using WUS and then moving on to save power in SA mode using techniques such as Paging Early Indication (PEI); finally saving power with techniques like LP-WUS or gNB-UE collaboration to save unnecessary power when no communication. The LP-WUS, as defined in R18, is essential for improving battery life in various devices, including wearables, IoT devices, and eMBB applications

The lean-carrier design, a principle of New Radio (NR) systems, has already been proved to be beneficial in reducing interference and improving system compatibility. This design can be further enhanced for *6G as a low-power radio layer which jointly enables low-power common signal transmission* for BS energy saving and ultra-low-power receiver for UE power saving, while still maintaining system coverage and mobility performance. *This is an important initiative in favor of joint energy savings for BS and UE.*

For minimization of BS transmission power consumption, the general strategy involves deactivating unnecessary frequency bands, sites, Radio Access Technologies (RATs), and hardware components. As one example design illustrated in Figure below, reducing the number of antenna elements for common signal transmissions can result in considerable reduction in transmission and sleep power consumption according to the BS power consumption model in. The transmit power loss due to a smaller antenna number can be compensated by requesting the UE to perform more frequent power accumulation of the common signals over a shorter period. For minimization of UE power consumption, adopting time-domain or frequency-domain ON-OFF keying design for common signals utilized for synchronization, measurement and paging indication is crucial for significantly reducing the receiver complexity and enabling ultra-low-power receiver for idle-mode operations. Such energy-detection based ultra-low-power receiver can consume only one-tenth or lower than a typical 5G main receiver. With the help of the ultra-low-power receiver, more frequent power accumulation of common signals becomes possible without sacrificing UE power consumption. This then contributes to a win-win solution where both BS and UE achieve power saving without compromising the system coverage and mobility performance. The light-receiver design also helps to minimize sleep mode power for the UE which is the main power consuming mode during DRX cycle.



It is noticed that the low-power radio layer design that reduces BS and UE power consumption during idle scenarios can also assist in carbon neutralization through further utilization of renewable energy. The emission reductions achieved contribute to the sustainability goals of the telecom industry, impacting Scope 2 emissions for operators and subscribers, and Scope 3 emissions for network, device, and chip vendors

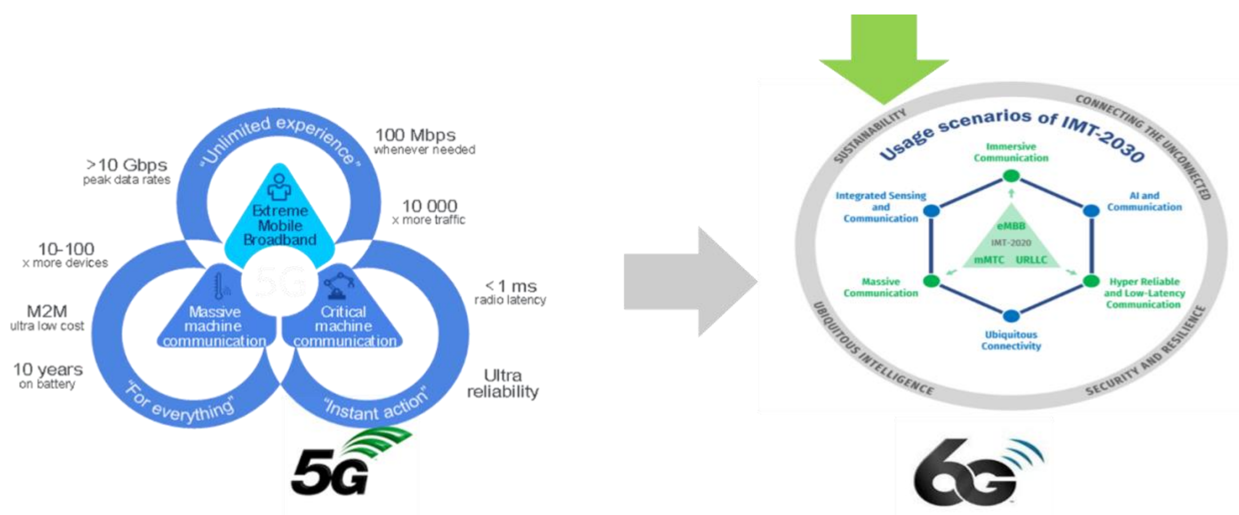
New waveforms that offer the benefits of traditional low PAPR waveforms and CP-OFDM while keeping the RX design simple are very much desirable, especially in low spectral efficiency regions – such waveforms can improve energy efficiency in use cases such as cell coverage extension, sub-THz communications and low power IoT networks. For other use cases (ex: high spectral efficiency), existing waveforms may still be preferred in terms of trade-off between performance, receiver complexity and energy consumption and the new waveforms could co-exist with them. The UE should support any new waveform design, as required by the standards, along with support for legacy waveforms so that the energy efficiency can be improved.

The use of near-zero-power lite radio and new innovative waveforms in the UE to minimize total energy consumption are just a few examples of how not only the UE power can be minimized but also benefit BS power thus working towards the energy efficiency goal of sustainability.

6 Governing principles towards design of 6G

From a Sustainability-Aware 5G towards a Sustainability-Native 6G

As we transition from one wireless generation to the next, sustainability is gaining heightened exposure and significance in the way it is incorporated into the design, analysis, and optimization of wireless networks. Indeed, a "sustainability-aware" ecosystem has become deeply intertwined with 5G, encompassing the deployed architectures and site infrastructure and the advancements implemented in the network's core. Looking ahead to 6G, the principle of sustainability will be inherently pervasive throughout the entire framework. In other words, every 6G use case and facet must take the lifecycle analysis (LCA) of energy expenditure and efficiency into play, from the very first step of the design process all the way to the final commercialization and assessment step. As such, this perspective necessitates establishing both short term and long-term objectives and principles. Serving as a compass and guiding us toward a wireless generation that is intrinsically attuned to sustainability.



Environmental sustainability, security, privacy, and resiliency become integrated capabilities of 6G, enabling both the network and devices to minimize GHG emissions and other environmental impacts throughout their lifecycle. Important factors include improving energy efficiency and minimizing energy consumption and the use of resources. Examples include optimizing equipment longevity, repair, reuse, and recycling, and incorporating recycled and renewable content into the materials that make up the ecosystem.

6.1 6G RAN Sustainability Goals and Requirements

Spatial domain adaptation methods for network energy savings have been studied in current and past standardization efforts. These methods mostly target low resource utilization where network energy savings can be achieved without seriously degrading user throughput. For 6G systems, spatial domain adaptation methods should also address medium to high-load scenarios to uncover their full energy saving potential. Turning off network transceiver ports or subarrays of antenna panels reduces beamforming gain, which is important for coverage-limited users irrespective of high or low load and negatively impacts User Equipment (UE) power consumption because UEs need to stay awake longer. 6G systems should thus support a flexible base station transceiver architecture that can adapt over various spatial domain network energy saving schemes, enabling various assumptions on array gain. To address network energy savings, especially in the high packet-arrival scenario, technologies with high spectral efficiency can lower the resource utilization and provide time gaps for applying various energy-saving methods. To unleash the potential of spatial domain adaptation for network energy savings, new Channel State Information (CSI) codebook structures must allow for adapting between precoders with different assumptions on network port number. This renders the CSI training phase power consumption as scalable as that of the data transmission phase. Hence the need for a new CSI framework that embraces the fact that an experienced channel is invariant to the port number at either transmitting or receiving side. Reducing the carbon emissions in the first place rather than offsetting them later can speed up the achievement of carbon neutrality. Beyond energy efficiency, to reduce carbon emissions further, it is important to improve carbon awareness through enhanced observability of the 6G system and to increase the adoption of renewable energy in cellular networks. Due to the highly variable and unpredictable nature of renewable energy sources such as solar or wind energy, the carbon intensity (i.e., the average carbon emissions per unit of energy consumption) equally varies considerably by time and location.

Future 6G systems will need to be aware of the status of energy sources and adapt their operation to the high variability of renewable energy. The IMT-2020 Minimum Performance

Requirements[13], include energy efficiency only as a qualitative requirement. Despite this fact, 3GPP and other Standards Development Organizations (SDOs) have increasingly focused on energy efficient solutions, especially in the RAN. Some energy-saving benefits, however, are more challenging to leverage without causing backward-compatibility issues, making energy efficiency a key milestone on the path towards sustainable 6G. Hence, it is recommended to have quantitative metrics for energy efficiency in the IMT-2030 minimum performance requirements, leading to a foundational 6G design centered around energy efficiency.

Energy Efficiency Design Goals And Requirements

Different methods and metrics can be employed to establish quantitative energy-efficiency design goals. One proposal could be based on expanding the qualitative evaluations performed for IMT-2020 energy-efficiency requirements. For 6G energy efficiency, requirements could be defined for eMBB in the following scenarios:

a) Loaded Case: Full buffer traffic scenario similar to prior evaluations where average downlink spectral efficiency will also be correlated with higher energy efficiency.

b) Medium-Low Load Case: The majority of the cells in a network are mostly experiencing low to medium load. Hence, optimizing energy efficiency in this scenario could yield high benefits to deployments. An average downlink spectral-efficiency target could be established for this scenario, along with a maximum energy-consumption target. The maximum energy consumption target for this scenario could be derived as a percentage of the energy consumption of the loaded case using a base station power model with a dependency on the output power.

c) No User Plane Load: For 5G evaluations, ITU-R M-2412 proposed to evaluate potential sleep durations with a minimal control plane overhead. A similar approach could be established for 6G with a clear target sleep time and with established maximum transition times to ensure deeper sleep states can be efficiently leveraged.

d) No User Plane Load and Further Reduction in Control Plane Overhead: This new scenario would target to eventually achieve a zero-load, zero-power target.

Establishing a KPI for sleep duration in this scenario would lead to designs enabling even deeper sleep states with further reductions in energy consumption. Similar to the previous

[13] ITU-R Report M.2410 - Minimum requirements related to technical performance for IMT-2020 radio interface(s)

load state, it is essential that transition times in and out of this state are not hindered by the designed frameworks.

Evaluation methodologies including simulation assumptions, traffic models, and potential base station power models for these scenarios, along with the target values — will require further research, as outlined in 3GPP technical report (TR) 38.864 “Study on network energy savings for new radio (NR)“ [13], as well as ETSI ES 202 706-1, “Metrics and measurement method for energy efficiency of wireless access network equipment; static measurement method” [14].

7 6G Sustainability KPIs

To measure the effectiveness of any sustainability techniques, the traditional KPI for energy efficiency is defined as the ratio of data volume (in bits) to the corresponding energy consumption (in Joules). However, this KPI overlooks the distinction between renewable and non-renewable energy sources – hence an **additional KPI are needed to understand the systems carbon footprint. These KPI would measure the ratio of data volume to carbon emissions**, capturing both energy efficiency and renewable energy utilization. It should also account for the fluctuating carbon intensity that varies with time and location mirroring the specific circumstances of energy use. The development of such a KPI would represent an important future endeavor, preferably as a part of the standardization process providing a quantitative measure of the system’s performance in terms of energy consumption and carbon emissions, as a key aspect to support the sustainability goals.

In addition to focusing on the energy efficiency of individual network and device, it is essential to consider the joint energy efficiency of both the network and the device. This approach ensures that energy-efficient operations are not biased toward either the network or the device but instead strive for a balance between the two, optimizing the overall system energy efficiency. 6G should aim for "simplicity" and pursue a **joint energy efficiency of the network and device** from Day1. We envision **6G standardized solutions** from Day 1 can achieve **BS EE improvement** of more than 65% compared to NR, UE EE improvement of more than 60% compared to NR and joint energy savings of more than 60%.

7.1 Environmental Sustainability KPI Definitions

KPI metrics for environment and sustainability could include

GHG emissions within Scope-1, 2, 3 – ex: metric tons of CO2 equivalent – mtCO2e, Carbon usage effectiveness (CUE) measured as mtCO2e/kWh

Waste metrics such as total waste generated from direct operations (metric tons per unit and time cycle) and total hazardous waste from direct operations (% of total waste)

Waste usage/footprint such as water usage effectiveness (WUE)/kWh, sources of water used e.g. freshwater, reclaimed or groundwater

Re-use, Re-cycle and Re-furbish metrics such as assets (products) taken back by producer at End of Life (EoL), recyclability of constituent materials in equipment produced.

Land and Biodiversity such as nitrogen deposition, climate change. These KPI metrics are used to measure and report on the environmental impact of data centers, waste management, water usage, and the overall sustainability performance of products and services within the context of 6G technology and infrastructure.

8 6G Ecosystem component KPI Definitions

8.1 Role of 6G RAN

RAN remains one of the top contributors to energy consumption and hence key to measure the impact of RAN on sustainability. Some of the top KPI metrics for RAN would include:

- **Average power consumption** - this metric is calculated as a weighted sum of power consumption over different load conditions, such as those defined by the European Telecommunications Standards Institute (ETSI) average.
- **Energy intensity**: measured by the network energy consumption per unit of data traffic, expressed in kilowatt-hours per terabyte (kWh/TB) or kilowatt-hours per gigabyte (kWh/GB).
- **RAN Energy efficiency** - this is measured by the average data volume transmitted per unit of energy consumption, which can be expressed in bits per joule (bit/J) or gigabytes per kilowatt-hour (GB/kWh), assessed during the same timeframe

- **Power Consumption** at 100% Traffic Load - this measures the power consumption at peak traffic per site, in kW.

Research into RAN KPIs that evaluate power consumption at minimum load is essential. Establishing accurate RAN KPIs for minimum load conditions will aid in quantifying the path to achieving Net-Zero emissions. This involves understanding and optimizing the energy usage of Radio Access Networks (RAN) when they are not actively transmitting data or are operating under low data traffic conditions.

8.2 Telecom Core related KPI's

Majority of the KPI's used to quantify RAN sustainability can be used for Telecom core as well. Some additional KPI's could include

- **Energy consumption per CN element function** – this includes CN functions such as AMF, AUSF, SMF, UPF etc.
- **Energy consumption per customer or subscription**
- **CN Energy efficiency measured** by the average data volume transmitted per unit of energy consumption, expressed in joules per bit (J/bit) and kWh/GB, assessed during the same timeframe.
- **Network Carbon intensity (CI)** – measured by CO_2 emissions per unit of data traffic, expressed in kilograms per terabytes (kg/TBs).

These metrics are crucial for assessing the sustainability of CN operations, particularly in terms of energy consumption and efficiency, which are significant considerations given the energy-intensive nature of network operations.

8.3 Data Center related KPI's

Data centers play a critical role in sustainability as they are significant consumers of energy and resources. They are central to the operations of cloud computing and edge computing, which have seen a dramatic rise in demand since 2010. The sustainability of data centers is a matter of concern due to their carbon footprint and energy consumption. Some of the key metrics used to measure the sustainability of data centers include

- **Power Usage Effectiveness (PUE)** - This is a standard measure that has helped improve data center energy efficiency. It is the ratio of total energy consumed by a data center to the energy consumed by its IT equipment alone
- **Renewable Energy Factor (REF):** Defined in ISO/IEC 30134-3:2016, this standard specifies a methodology to calculate and present the REF, which measures the use of renewable energy in data centers
- **Greenhouse Gas Emissions (GHG)** - Measured in metric tons of CO2 equivalent (Mt CO2e), including Scope 1 (direct emissions from data center operations) and Scope 2 (emissions from purchased energy).
- **Water Usage effectiveness (WUE)** Defined in ISO/IEC 30134-9:2022, this KPI measures the water used by a data center in relation to the energy consumed by its IT equipment.

Investigating how to partition energy consumption between core networks, cloud, and data centers across different services is a critical research area. This includes overcoming challenges in identifying the energy consumption of specific services in a public cloud environment, where virtual machines from different users may share the same compute node. The separation of responsibility between application and Infrastructure as a Service (IaaS) in public clouds complicates the measurement of energy consumption by specific services.

8.4 Consumer Devices related KPI's

End-user communication devices, such as mobile phones and Internet of Things (IoT) devices, contribute significantly to the overall sustainability impact of the telecommunications ecosystem. A new smartphone could generate an average of 85 kilograms of CO2 emissions in its first year, 95% of which comes from manufacturing processes, including raw material extraction and shipping. This underscores the importance of sustainability measures in the manufacturing and lifecycle management of end-user devices. Here are some key metrics and aspects that are measured and reported for these devices.

- **Durability/Reliability**: The lifespan of the product is a major factor in its environmental impact. Products designed for durability have features like water resistance, robust design, long battery life, and come with a manufacturer's warranty and service guarantee
- **Repairability and Repair Services**: This includes the ease with which a device can be repaired, the design of the phone to support repair services, and models that extend the useful life of the product by improving its repairability, reusability, and upgradability
- **Recyclability:** The ability to repurpose product materials for productive use, such as through recycling programs, incentives for responsible recycling, and the recovery of device components and materials
- **Resource Efficiency**: The use of scarce raw materials in the device, such as gold in electronic components, and the efficient use of these materials to reduce resource depletion. The use of recycled and renewable materials is also important for maximizing resource efficiency
- **Chemical Hazards**: The determination of chemical hazard ratings for materials and substances contained in the product or used during its manufacture. This helps in responsible substitution to mitigate negative impacts on workers and the environment

There is a need for research and development to create a circular economy for the materials being used in telecom equipment and end-user devices. The printed circuit boards (PCBs), electromagnetic shielding materials, substrate materials for printed antennas can be derived from organic sources such as tree waste (coconut leaves, palm leaves, coconut shell, bamboo leaves and many more) and household wastes (tea powder, coffee powder, eggshells etc.). These organic materials can be converted into powdered form to be mixed with carbon extracted from the used batteries. The resulting products can be used as microwave absorbers for EMI/EMC applications and as substrates for planar antennas working for 5G or 6G frequency bands. This is a way to transform waste into products and reduce the use of inorganic and chemical based products for manufacturing antennas or circuits. This results in Green and eco-efficient microwave materials contributing towards sustainable future [10-11].

Understanding how sustainability KPI measures related to the communications component of equipment can be contained and reported is necessary. Research could focus on both consumer smartphones and IoT devices, which could be self-contained equipment or a module/chip-level component of another piece of equipment. The goal is to differentiate the energy consumption of the communications component from the equipment, especially in cases where the device is part of a larger system, such as connected vehicles or agricultural robots.

These research areas are crucial for developing and defining environmental sustainability KPIs for the 6G ecosystem, which will measure and report the effectiveness of 6G in achieving environmental sustainability goals.

8.5 Supply Chain and Resource KPI

Sustainability is a key consideration in supply chain and manufacturing processes. several metrics are important for measuring and improving sustainability in these areas:

- **Human rights and responsible sourcing** - Ensuring human rights are respected and responsible sourcing practices are in place, considering both human and environmental perspectives.
- **Circularity** - Reducing environmental impact by minimizing material usage and extending the lifecycle of products and materials through reuse and recycling
- **Transparency and Traceability**: Tracking the materials and energy used during the supply chain and manufacturing process to ensure sustainability. Initiatives such as the Digital Product Passport (DPP) and the Global Digital Sustainable Product Passport (GDSPP) are mentioned as efforts to provide sustainability-related information for materials used in products

9 Challenges and Recommendations

Achieving sustainability goals as outlined in previous sections faces challenges on multiple fronts. Some identified challenges include:

1. Lack of inclusive digitalization, existence of rural & urban divide with plenty of hard-to-connect communities.
2. Lack of policies and guidelines supporting sustainable digitalization such as standardization and ecosystem development supporting green transition (circular products and services).
3. No CE measurement framework within industry to measure circularity, track emissions, and achieve goals such as:
    - Telecom products and network infrastructure's material and energy efficiency
    - Mobile network including chip design, power saving software, 5G technology and energy efficiency.

Although there exist multiple challenges, however through collective efforts the eco-system can work towards achieving sustainability goals. Here are some of the recommendations for policymakers, industry, and academia:

1. **Capacity building** (developing & strengthening skills needed to transition to CE in telecom)
    a. Training sessions for regulators and policy makers
    b. Digital skill development to promote reuse & repair of network infrastructure, mobile network, telecom products, promote education and entrepreneurship.
    c. Awareness generation (to support responsible consumption and end-of-life management of products)
2. Regulatory/ Policy/ Audit

   a. Sustainable product policy supporting SDG 12 on sustainable consumption and production - including eco-design guidelines to support discussion & dialogue on supply of critical resources supply, uptake of SRM, and achieving climate targets
   b. Develop framework for EPR in telecom products with focus on upstream design for recycle, use of SRM in telecom products and infrastructure while promoting e-waste recovery, reuse, and recycling.
3. **Promote R&D with industry, academia, and think tanks** to support ecosystem for transitioning to green telecommunications with cost effective, locally manageable telecommunication technologies and processes – thereby encouraging innovators, start-ups and others in the process
   a. Develop guidelines for responsible and ethical AI & data availability, collection and security, way forward with 6G, IoT, quantum computing etc.
   b. Impact assessment studies to determine geodiversity impact of telecommunications.
   c. Intelligent aggregation of network infrastructure with help of state and city level planners to minimize power consumption
4. **Study/ knowledge creation** to understand current practices, challenges in current scenario, and identify opportunities and target areas to help transition to circularity in Telecom
   a. Analysis to determine cost of compliance across telecom value chain to ensure fairness to economic models
   b. GHG assessment studies to understand the “baseline scenario” of value chain
   c. Identify opportunities & challenges linked to upgrading mobile network, network infrastructure, products (chipsets, routers etc.)
5. **Pilot interventions to implement sustainable**, circular business models across the telecom value chain
   a. Adoption of select best practices such as harmonized standards for circularity and climate goals

b. Sustainable growth of telecom to bridge urban rural divide and replication of existing models such as the SMARTPUR models[14]

c. Circular products and services identified to be piloted by industry and producers

[14] https://smartpur.in/the-project/

10 References

[1] Malmodin, Jens & Bergmark, Pernilla, "Exploring the effect of ICT solutions on GHG emissions in 2030", 2015. https://www.ericsson.com/en/reports-and-papers/research-papers/exploring-the-effects-of-ict-solutions-on-ghg-emissions-in-2030

[2] https://research.chalmers.se/publication/527418/file/527418_Fulltext.pdf

[3] https://sesei.eu/wp-content/uploads/2024/01/arun-agarwal.pdf

[4] https://uncrd.un.org/sites/uncrd.un.org//files/11th3r_cp_india.pdf

[5] https://www.investindia.gov.in/team-india-blogs/telecom-industry-india-crosses-milestone

[6] https://medium.com/@lananthram26/circular-economy-in-telecom-sector-b34be21b0cfb

[7] https://www.meity.gov.in/writereaddata/files/Circular_Economy_EEE-MeitY-May2021-ver7.pdf

[8] Ericsson Mobility Report, https://www.ericsson.com/en/reports-and-papers/mobility-report/dataforecasts/mobile-traffic-forecast

[9] Environmental sustainability in the Indian telecom sector towards carbon emission reduction (https://www.expresscomputer.in/guest-blogs/environmental-sustainability-in-the-indian-telecom-sector-towards-carbon-emission-reduction/116152/

[10] Kumar R, Gupta SK, Wang H-C, Kumari CS, Korlam SSVP. From Efficiency to Sustainability: Exploring the Potential of 6G for a Greener Future. Sustainability. 2023; 15(23):16387. https://doi.org/10.3390/su152316387

[11] Thiel, D. V., Desha, C., & Espinosa, H. G. (2024). United Nations Sustainable Development Goals: Implications for antenna design and electromagnetics education [Education Corner]. IEEE Antennas and Propagation Magazine, 66(4), 112-118.

Change Log

Revision/Date	Short remark	Meeting/Reference
0.0	Added content to 6GCG template, skeleton and contents	From 6GCG Meeting in. Aug 2024 as well as offline
0.1	Initial contents	Chapter 2 and 3, offline
0.2	Review of structure and flow	Online formal call (Sept2024)
1.0	Editorial review and cleanup	5 Oct 2024 (offline)