# Green Future Networks

Sustainability Challenges and Initiatives in Mobile Networks

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# Sustainability Challenges and Initiatives in Mobile Networks

## by NGMN Alliance

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# EXECUTIVE SUMMARY

The NGMN Green Future Network project expands on the discussion of sustainability as outlined in the NGNM 5G White Paper 2 and is focused on the identification and mitigation of environmental impacts generated by the network part of the Information and Communications Technologies (ICT) sector.

This is the first White Paper resulting from the NGMN Green Future Networks project phase 1. It introduces the subject of sustainability in mobile networks and provides context of this broad and complex topic. The background, measurement and sector targets for greenhouse gas emissions impacting climate change are described, along with the exploration of renewable energy as a key strategy for service providers to tackle emissions, high level Key Performance Indicators (KPIs) to measure the environmental performance, standardization work, energy efficiency in networks, as well as operator and vendor net-zero initiatives.

The United Nations (UN) Sustainable Development Goals (SDG's) are the blueprint to achieve a better and more sustainable future for all. Economic, social, and environmental aspects are the three pillars of the SDG's. The environmental pillar covers areas such as clean water, clean energy, responsible production and consumption, climate action, life below water and life on land. One of the key elements of the environmental concerns (impact categories) is climate change. Human activity releases over 50 billion metric tons of Green House Gases (GHGs) into the atmosphere annually. Our planet's temperature is rising continually due to this at a global scale. This White Paper deals with the emissions related to the mobile networks. A primary source of emission from networks is the electricity or energy required to power the network during lifetime operation. Environmental KPIs described in this document can be used to track the performance as they provide a common understanding of key metrics and help to increase transparency as well.

Emission reduction can be achieved by using renewable energy in combination with energy efficiency outstripping business growth. Renewable energy is an essential strategy to tackle emissions although they are not a complete solution in all the markets. The challenge of renewable energy relates to availability (in markets) and their variability.

Whilst the network component of ICT only contributes a small portion of overall emission and energy use, it is widely believed that it has a big part to play in modernising and creating efficiencies in the high impact industries such as energy generation, manufacturing, transport and agriculture. The "carbon handprint" or "enabling effect" provided by ICT sector can contribute to lower the "carbon footprint" of high impact industries.

Many Standard Developing Organizations (SDOs), including ETSI, ITU-T, 3GPP, and ATIS are working on the energy efficiency of ICT equipment and services, circular economy, waste management, and methodologies for environmental impact analysis, i.e., Life Cycle Assessment (LCA).

In order to decarbonize, there are multiple axes of work including improving the energy efficiency, eco-design of the network equipment, use of renewable energy, and compensation through investment in carbon sinks. This White Paper focuses mainly on the energy efficiency, renewable energy and carbon sinks.

The energy efficiency in latest generations of mobile systems can be attributed to multiple advancements. The enhancements in data transmission, efficiency in control messaging and signalling, and ability to use sleep modes based on traffic and load conditions, are among the capabilities introduced in the products by design. Furthermore, the granular architecture, with increasing disaggregation, cloud native architectures, virtualization and softwarization, increase agility and reduce footprint. This path towards intelligent and dynamic orchestration, programmability, life cycle management, and full automation has great potential to be leveraged towards achieving energy efficiency goals. In addition, product deployment and operational strategies, have already focussed on innovative ways to increase energy efficiency. Advancement in energy efficiency must be considered from an end-to-end perspective. This can broadly include specifications and design, such as those related to distributed architecture, cloud, re-configurable RAN and Edge, telemetry with AI-driven cognitive and autonomous architecture for the operation of energy efficient infrastructure, devices and site support systems.

Many mobile operators are announcing their carbon neutrality strategies. Some have positioned themselves on a goal of achieving carbon neutrality in their own operations in the coming decade. The objective of carbon neutrality is built on a strategy that is more or less completely depending on the operator, which most often responds to the same pattern: Minimizing carbon emissions (increasing energy efficiency, using renewable energy, saving energy on energy-intensive items), and creating a circular economy (by recycling, refurbishing, re-manufacturing or reusing the equipment, improving eco-design, and carbon offsetting).

Renewable energy is at the heart of the reduction of network carbon emissions. As an example, several mobile operators have already committed to achieving 100% renewable energy consumption. Some have achieved this through the purchase of green certificates or guarantees of origin. Other operators have decided to opt for a mix, combining long-term contracts with the purchase of certificates of origin. The main renewable energy strategies are based on solar energy, wind energy, fuel cell and biomass each of which has pros and cons in terms of Capex, savings, logistics and storage.

Companies are using carbon sinks in the compensation of their unavoidable emissions. To do so, they invest in these solutions over the long term. The carbon sink market is currently a tight one, due to a rapidly growing demand that is coming up against a limited supply.

Several network equipment vendors and their supply chain are promoting and driving environmental footprint reduction through specific actions. Among others, these actions involve technology innovation and products, material, packaging and waste management, defining metrics, standardization, renewable energy promotion, product recycling and contribution to circular economy, operation management, and ecosystem collaborations. Mobile operators, vendors and their suppliers need to work in partnership to eliminate carbon emissions from the entire value chain.

The goals of sustainability and carbon reduction targets can be achieved with end-to-end measures of identification and mitigation, involving all actors and players. The 5G roadmap and the journey towards 6G should include these as key drivers, as well as design, development and operation goals in a circular economy. This NGMN White Paper is complemented by additional documents on eco-design, energy efficiency, and metering.

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# 1 INTRODUCTION AND CONTEXT

Over the last two decades, mobile industry has created a significant impact on the way users interact with technology covering a broad range of applications from business, education, entertainment, social media, gaming and much more. Mobile technology is clearly an important part of global economy which is increasingly becoming essential with each new technology generation. With the advent of fifth generation of mobile technology (5G), many new application areas are opened which were not even imaginable few years ago. 5G enables a higher performance in terms of lower latency and high throughput which ultimately leads to a large amount of data traffic and end user devices. It is important to note that this is enabled by a densification of the existing mobile network. Since this infrastructure needs to be powered constantly, one of the biggest challenges which mobile operators are currently facing is how to build an energy efficient 5G network. However, the energy requirement to power the network infrastructure is only one part of the puzzle, other elements are the material required to produce the network equipment such as radio units, baseband units, servers, routers, cables; manufacturing processes; logistics and, last but not least, packaging of all these equipment.

Consumers are much more focussed on sustainability as compared to the previous decades, they also demand sustainable products and services from their mobile operators. This is also one of the reasons that ICT sector has stepped up its game and many companies have already set-up their climate protection goals in alignment with the Paris Agreement which basically means that they will achieve carbon neutrality by 2050. This includes both direct and indirect emissions.

Achieving this goal is not going to be easy considering the advancement in the demands of more and more data transmission through the networks. Therefore, companies are adopting different strategies to reduce their carbon emissions. One thing is certain, that all the players in this ecosystem need to work together in order to achieve their climate protection goals as the interdependencies are very strong and we all are striving for the same objective. That is why there is a need to develop a common approach and methodologies, where different companies can work together to build sustainable solutions. Here, the aim should be the development of holistic solutions which, for instance, accounts for the full life cycle of services offered by the mobile operators including the devices which consumers use to access those services.

NGMN Alliance has set sustainability as one of its strategic pillars for 2021 and together with its partners, it is leading a project named "Green Future Networks" to address climate action demands across the telecommunication ecosystem. This project expands on the discussion of sustainability as outlined in the NGNM 5G White Paper v2.0 [1]. The project members from 24 companies including mobile operators, vendors, research institutes and application providers focus on topics such as eco-design of network equipment, network energy efficiency and metering. This project aims at helping mobile operators and vendors to achieve their climate protection goals complementary to the work being done by other Standard Developing Organizations (SDOs).

This is the first White Paper resulting from the "Green Future Network" project and it intends to introduce the subject of sustainability in mobile networks and provide context of this broad and complex topic to the audience. It presents a comprehensive overview on the climate protection strategies and goals adopted by the telecommunication sector including details around the climate change background, measurement and standardization activities. Different approaches of decarbonization for mobile operators are elaborated later in the paper, covering aspects from the best ways to become energy efficient, using renewable sources of energy and their carbon impact as well. We also provide an explanation of key terms associated with renewable energy market and explore a variety of renewable solutions for the mobile sites. High level Key Performance Indicators (KPIs) to measure the networks' energy performance and carbon related emissions are suggested. This paper also considers the contribution from standards developing organisations, as well as several operator and vendor carbon neutrality initiatives.

In addition, it provides a detailed analysis of both sides of the emissions in the network - emissions generated by the network, followed by the emissions avoided by the network including the meaning behind the concept of carbon footprint and handprint. An indication towards the other sectors for achieving their SDGs [2] is also provided later in this document. Finally, a conclusion is given which highlights the recommendations towards the telecommunication sector for the reduction of carbon footprint. Additional White Papers in this project are about eco-design, network energy efficiency and metering.

**The eco-design** White Paper focusses on two important sustainability subjects in the ICT sector, a comprehensive view on the processes for equipment eco-design, and an overview of the current status on the development of a methodology to measure the service footprint. Eco-design consists of incorporating a network product's environmental impact into its design from the very beginning, taking into account the network product's entire life cycle. The eco-design part presents the Life Cycle Analysis (LCA) as the mean to drive the network equipment footprint. Specifically, some examples are presented on how to use the existing ITU-T recommendation L.1410 [3] to assess the environmental footprint based on a set of Impact Categories, and on how to evaluate the circularity score thanks to the ITU-T recommendation L.1023 [4]. It also deals with the concepts of refurbishing, Lean Smart Packaging (LSP), critical raw material supply risks and provides detailed insights on the current eco-rating, eco-labels, and eco-information about the products in this sector.

**The network energy efficiency** White Paper highlights how network elements can become more efficient in terms of energy use as data rates and usage grow. It provides a detailed study of several available and new energy saving features and their potential when deployed. It also defines the next steps on advances in sleep modes and power management of equipment. In addition, it explores the on-demand network dimensioning by using Artificial Intelligence (AI) techniques, followed by a study of energy efficiency in different types of hardware, architectures, and site solutions.

**The metering** White Paper is about addressing and developing innovative use cases that leverage transparency through intelligent measurement of energy consumption in different equipment and functions of the mobile networks. This enables an automatized collection and transportation of the energy consumption data to the Operation & Management Systems, where it can be easily accessed and processed by the operators, in order to appropriately manage the improvement of the energy efficiency and reduction of Green House Gas (GHG) emissions at all levels of their respective networks.

## 1.1 Climate Change Background

Human activity releases over 50 billion metric tons of GHG into the atmosphere annually [5]. Our planet's temperature is rising continually due to this and is currently 1°C higher than the historical norms. The primary GHGs are carbon dioxide, methane and nitrous oxide. Each gas behaves differently in terms of its effect on global warming. Therefore, in order to simplify the accounting, methane, nitrous oxide and other gases are converted to their equivalent in carbon dioxide ($CO_2$) for the purpose of creating a single indicator for analysis known as $CO_2$ equivalent ($CO_2e$). In the telecommunication ecosystem, emissions occur at all stages of the network product lifecycle.

The International Panel on Climate Change (IPCC) [6] is the UN body of experts responsible for assessing the science related to climate change. The IPCC Paris Agreement is a binding agreement aimed at keeping the global temperature rise well below 2 °C compared to the pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5 °C. In order to achieve this, emissions need to drop significantly by 2030 and be eliminated by 2050. For the ICT sector, the ITU-T recommendation L.1470 [7] (further discussed in the Section 1.3) defines a decarbonization trajectory which is compatible with the Paris Agreement.

The ICT sector represents around 1.4% of the overall global emissions which includes activities across the life cycle of mobile networks and user devices as well [8]. At global scale, a primary source of emission from networks is the electricity or energy required to power the network during lifetime operation due to the use of fossil fuels in the energy supply [5].

## 1.2 Emissions Measurement

The GHG Protocol [9] is a widely used international accounting tool for government and corporates to quantify and manage emissions. Measurements are categorized as Scopes 1, 2 or 3 emissions to help organizations differentiate among direct and indirect emissions. Separating the emissions in these scopes also increases transparency for each company and ensures that companies do not account for the same scope more than once. Scope 1 and Scope 2 emissions are essentially a company's own emissions and those from the electricity used, called direct emission and indirect emission respectively, while Scope 3 emissions are those incurred because of a company's business activities, also referred to as indirect emissions. Further details about these scopes are explained in the Section 3.

## 1.3 Emission Reduction Targets for Networks

In tandem with the measurement tools of the GHG Protocol, many ICT companies have committed to Science Based Targets (SBT) [10]. An emissions reduction target is defined as science-based if it is developed in line with the scale of reductions required to keep global warming below 2°C from pre-industrial levels. These companies use publicly available methodologies (Sector/Absolute/Economic) following the criteria defined and verified by the Science Based Targets Initiative (SBTi).

For the ICT sector, the ITU has worked jointly with GSMA, GeSI and SBTi to define the trajectories to be followed when setting emission targets reflecting the period with the baseline of 2015 until 2030 as mentioned in ITU-T L.1470 (01/2020) [7]. For operators of networks and data centres these targets are further reflected in Supplement L.37 and the associated SBTi sector guidance[10] This gives a methodology on how to set targets aligned with the Paris Agreement and set absolute targets for Scopes 1 and 2 emissions 2020-2030 for mobile operators, fixed line operators, and data centre operators. For Scope 3 emissions, it is recommended to follow the same ambition, but general guidance defined by the standard SBTi criteria can be used [11]. ITU has also developed a similar guidance for equipment providers, which is reflected in Supplement L.38 [13]. Intensity targets for Scopes 1 and 2 can be used, such as carbon emissions per subscription or per bit, but only as long as the emission reduction is in line with the overall absolute reduction required. These must also be updated if the intensity changes compared to the absolute path.

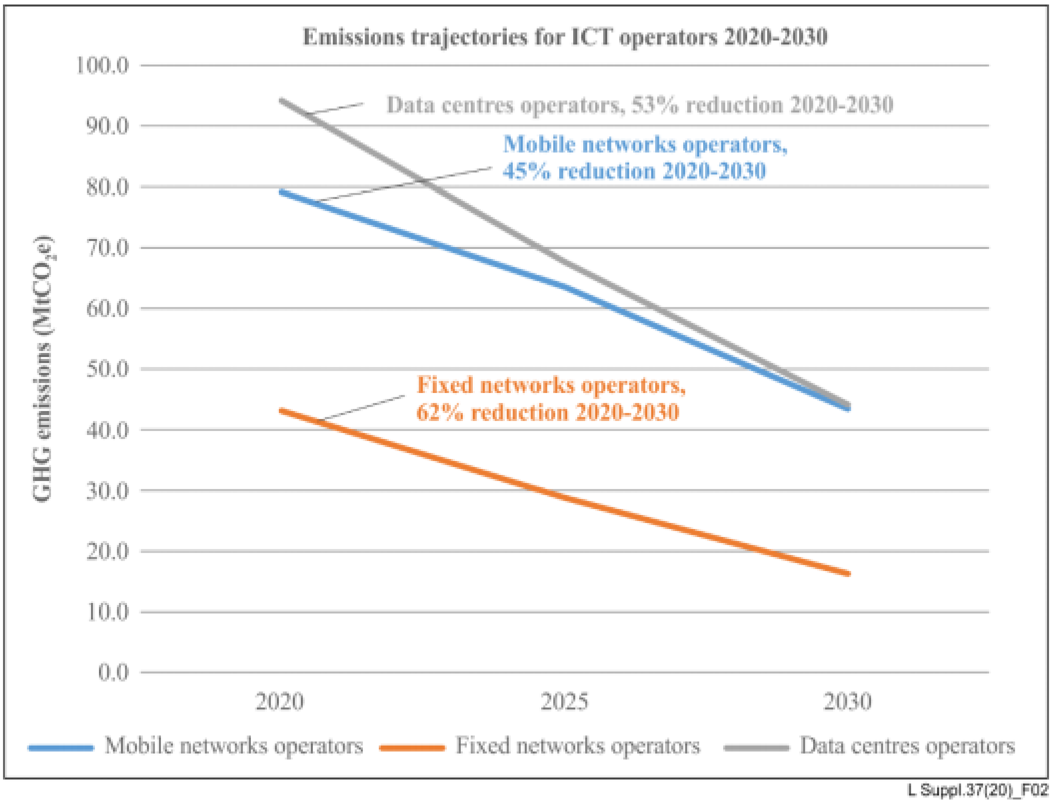


**Figure 1:** ITU - Emission Trajectories for ICT Operators 2020-2030

## 1.4 Footprint and Handprint

The telecommunication networks (including fixed, mobile and data centre) component of the ICT sector is only a small part of the overall energy (1.8%) of global electricity use. According to the International Energy Agency (IEA) Tracking Clean Emery Progress [14], this sector is one of the few areas on track with the IPCC goal. [14]

Furthermore, energy consumption of the overall ICT sector has only increased slowly over time despite exponential data growth rates, and the emissions have been roughly stable over the last decade. Some of the primary factors have been, Moore's Law, the increasing efficiency of network technologies, IP transmission with full optical fibre in networks and consolidation of data centres into Hyperscale (Cloud) with improved overall efficiency.

The concept of "carbon handprint" or "enabling effect" whereby a small amount of emissions by an ICT solution can contribute to lower the "carbon footprint" of a high impact industry is well documented [15][16]. The ITU's Area of Action, Environmental and Climate Change highlights this area as "greening through ICT" [17]. Companies use this concept to demonstrate the environmental benefits of using their products. ICT companies can help other sectors in reducing their carbon footprints, which essentially makes an impact on their handprint. Examples of ICT handprint include e-commerce, e-learning platforms, e-healthcare, audio/video conferences and many more.

# 2 MAIN KEY PERFORMANCE INDICATORS AND INDUSTRY STANDARDS

To keep track of progress towards increased energy efficiency and lower energy consumption and carbon emissions, companies may consider the use of KPIs in addition to their decarbonization targets. This section gives some examples of such KPIs and highlights key activities from various SDOs about their work on the efficiency of ICT equipment.

## 2.1 KPIs Associated with Decarbonization of Networks

The KPIs mentioned below are recommended for operators to track their environmental performance on a high level. They provide a common understanding of key metrics and help to increase transparency as well. Operators can also opt for (network) domain level KPIs in addition to the ones mentioned below:

**Renewable Electricity Ratio**

Networks are responsible for a considerable part of an operator's energy consumption. It is therefore important to find renewable powering sources and to measure them. Hence, this KPI represents the percentage out of the total energy consumed by fixed and mobile networks coming from renewable sources such as Power Purchase Agreements (PPAs), Energy Service Company (ESCO) or on-site renewable electricity production.

$$\text{Renewable Electricity Ratio} = \frac{\text{Renewable electricity consumption}}{\text{Total electricity consumption}}$$

**Energy consumption per customer**

This KPI gives a notion of network energy efficiency per client. It is calculated as the total energy consumed by the network in kWh divided by the total number of operator's clients.

$$\text{Energy consumption per customer} = \frac{\text{Total Energy consumption in kWh}}{\text{Total customers (both fixed and mobile)}}$$

Total energy considers all sources of power used by the network i.e., electricity from the grid, energy from renewable sources and fuel. Total customers reflect the sum of an operator's fixed and mobile network customers. For the fixed network, a customer is defined as an access point i.e., a subscription to a fixed line or an internet box. For the mobile network, a customer is defined as per SIM card. This includes operator's own clients, Mobile Virtual Network Operators (MVNO) ones and Machine to Machine (M2M). Indeed, MVNOs might represent a significant part of the customers for some operators and, therefore, a non-neglectable source of energy consumption. The same happens with M2M, for which number and transmissions are expected to rapidly growth.

**Network energy consumption per data volume or Energy Intensity**

This KPI gives a notion of network energy efficiency per unit of data in Tera Bytes. It is calculated as the total energy consumed by the network divided by the total data transmitted in the network.

$$\text{Energy Intensity} = \frac{\text{Energy consumption in kWh}}{\text{IP data volume transmitted in Tera Bytes}}$$

**Network Carbon Intensity**

This KPI shows the $CO_2$e emissions in proportion to the transmitted data volumes in Tera Bytes. It takes into account the total $CO_2$ emissions for all energy sources such as gas, fuel, and grid electricity. The data volume is composed of the total transmitted IP data volume including VoIP, Internet, and IP-TV.

$$\text{Carbon Intensity } = \frac{\text{Carbon dioxide equivalent in kg}}{\text{IP data volume transmitted in Tera Bytes}}$$

**Percentage of refurbished network equipment**

Some operators are increasingly developing the use of refurbished equipment in their networks. This KPI allows to measure the proportion of reused hardware out of the total amount of network equipment installed.

$$\text{Percentage of Refurbished ICT Equipment} = \frac{\text{Refurbished hardware installed in the network} * 100}{\text{Total amount of hardware installed in the network}}$$

A refurbished hardware is an equipment that has already been used in other networks and has been returned to the provider or a specialized company and which after being tested and re-certified is sold for a second use. The refurbishing process consists of:

- Cleaning and visual inspection to identify and repair problems due to common wear and tear damage.
- Testing /quality assurance - all components are tested in accordance with design specification to secure full network functionality and compatibility as well as regulatory compliance.
- Equipment improvements to secure full functionality, including software updates when available.
- The refurbished equipment should be packed to minimize risk for damages during transport and storage (electrostatic discharge, humidity, shock, etc.). Where possible the original packaging material is to be reused.

The refurbished equipment is to be differentiated from new products by having some easily recognized code added to the original product number.

## 2.2 Standardization Activities

Many SDOs are working on efficiency aspects of ICT equipment and services. In what follows, a short description of the activities in this area of different SDOs is given.

**European Telecommunication Standard Institute (ETSI)** with its Technical Committee Environmental Engineering (TC EE) is active on standardization, covering aspects related to environment condition definition (EE1), power supply and monitoring (EE2) and ecological matters (EEPS). TC EE published standards related to monitoring of infrastructure and telecommunication equipment, contained in ES 202 336 series “Monitoring and Control Interface for Infrastructure Equipment (Power, Cooling and Building Environment Systems used in Telecommunication Networks)”, and standards dedicated to innovative and green powering solutions for 5G ES 203 700 “Sustainable power feeding solutions for 5G network”. The WG EEPS has published a series of standards dedicated to energy efficiency metric definition and measurement methods of equipment, wireless equipment, broadband network equipment, routers/switches, transport network equipment, core equipment, Network Function Virtualization (NFV), and servers. In particular, ES 203 228 is a standard dedicated to the energy efficiency of mobile networks. EEPS has also published a Methodology for environmental Life Cycle Assessment (LCA) of Information and Communication Technology (ICT) goods, networks and services (ES 203 199 which is technically the same standard as L.1410) [3] and some standards on circular economy definitions.

**International Telecommunication Union standardization sector (ITU-T)** with its Study Group 5 "Environment, climate change and circular economy" (SG5) is working on items related to network protection, human exposure to electromagnetic field and environment. Working Party 2 (WP2/5) is dedicated to energy efficiency, waste management, circular economy, and environmental impact. ITU-T SG5 collaborates with ETSI TC EE to write common technical standards as the standard for 5G powering. ITU-T SG5 has also published standards for the measurement metrics of radio sites, innovative powering of telecommunication room, circular economy scoring of ICT goods, and the aforementioned standards regarding the ICT sector's carbon reduction trajectory. ITU-T has also produced a standard on methods to derive the ICT sector carbon footprint, in addition to recommendations such as L.1410 33 on the question of life cycle assessment of ICT goods, networks and services. The circular economy question has also been a key topic with recommendations such as the L.1023 [4] which proposes a scoring method related to several circular economy aspects (durability, reparability, recycled content, etc.).

**Alliance for Telecommunications Industry Solutions (ATIS)**, with its committee "Sustainability in Telecom: Energy and Protection" (STEP), and its subgroup "Telecommunications Energy Efficiency" (TEE) is active in energy efficiency standardization. It has published standards for energy efficiency measurement and reporting of server, transport and optical access, router and switch, data centre power plant component, wireline access small network equipment and base station (ATIS-0600015.09).

The **3rd Generation Partnership Project** (3GPP) has been working for many years on standards for the energy efficiency of mobile networks by following a two-step approach:
1) Defining Energy Efficiency (EE) KPIs and methods to measure them.
2) Defining use cases and solutions for Energy Saving (ES).
3GPP / SA5 (Telecom Management) is historically involved in these activities. With the advent of 5G, their scope of work has moved from RAN only, as for previous technologies, to now also include Core Network and Network Slicing. The 3GPP RAN has been primarily focused on power saving for the UE and the implicit mechanism for energy saving at the base station with, e.g. advanced sleep mode. In release 18 definition, there has been a (new) strong interest to enhance future mobile systems energy efficiency based on the proposals from a number of vendors.

# 3 DECARBONIZATION STRATEGIES AND INITIATIVES

When a company engages to decarbonize, it needs to first set a baseline which account the GHG emissions from its direct activities (Scope 1) and indirect activities (Scopes 2 and 3), as presented in Figure 2. These definitions are standardized at GHG Protocol, ISO 14064 and ITU L.1420 [9][18][19]. Direct emissions under Scope 1 are related to the energy obtained by combustion of gasoline and diesel for cars, gensets, heating for buildings, etc. Indirect emissions under Scope 2 are those related to the electricity consumed by IT, networks, and tertiary buildings, the ones for which the company is consuming electricity and paying the bill.

Finally, Scope 3 accounts for the emissions of suppliers and customers (energy for manufacturers to build their components and products (networks equipment, smartphones, etc.), electricity used by customer to power home gateways, set-top-boxes, smartphones charging, etc. Therefore, a part of the Scope 3 of a company is composed by the Scopes 1 and 2 of other companies in the ecosystem. Consequently, the only solution to achieve the carbon neutrality requires that all players work together to reduce their carbon emissions [11].

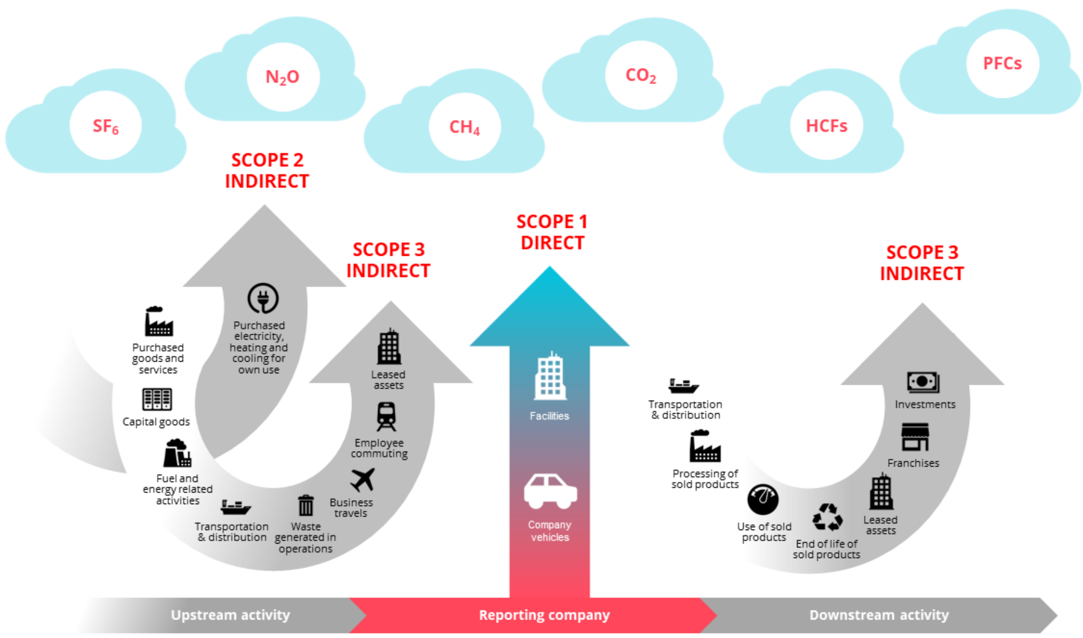


**Figure 2:** Direct and Indirect Emissions (e.g. of mobile system)

In order to decarbonize networks, there are three main axes of work, namely improving the energy efficiency, use of renewable energy and compensation through investment in carbon sinks. In what follows, a view on these axes is given.

## 3.1 Improving the Energy Efficiency

In NGMN 5G White Paper 1, published at the beginning of 2015, an improvement in energy efficiency by a factor of 2000 within 10 years is mentioned, such that a 1000 times projected increase in traffic can be carried, using half the amount of energy consumption required at the time. Others, set a target of at least 100 times improvement, compared to 4G. The 5G system is significantly more energy efficient than the previous generations, though still in an early phase on its path to achieve the required targets.

**Prospects and Challenges**

The energy efficiency in 5G systems can be attributed to multiple advancements. The enhancements in data transmission, efficiency in control messaging and signalling, and ability to use sleep mode based on traffic and load conditions, are among the capabilities by design. Furthermore, the granular architecture, and increasing disaggregation and cloud native architecture and operation, with virtualization and softwarization, increases agility and reduces footprint. This path towards intelligent and dynamic orchestration, programmability, lifecycle management, and full automation has great potential to be leveraged towards increasing energy efficiency. In addition, products, deployment and operational strategies, have already focussed on innovative ways to advance energy efficiency.

Despite these advancements in energy efficiency, some forecasts point to significant increase in consumption, and thereby in emission in the absence of active intervention, over the next several years. This is due to considerable increase in traffic across a vast range of use cases, new technologies and spectrum, great deal of connections, and densification. Some of these factors need to be evaluated and optimized, and ultimately point to the need for AI / Machine Learning based operation. For example, small cells, by nature introduce efficiency through carrying traffic at lower energy consumption. However, this can have a reverse effect with increasing densification and interference, without intelligent dynamic planning and allocation. Similarly, massive MIMO (multiple-input and multiple-output) has the potential to improve coverage area and energy efficiency, in terms of traffic per unit of energy consumption, if balanced against the complexity and consumption it introduces. Trade-offs may need to be considered to optimize and maintain design goals.

**Opportunity and Way Forward**

Advancement in energy efficiency must be considered from an end-to-end perspective. These can broadly include:

* Specifications and design, such as those related to data transmission, signalling, sleep modes, distributed architecture, cloud, and re-configurable RAN and Edge.
* Telemetry and AI-driven cognitive and autonomous architecture and operation, for energy efficient dynamic planning, deployment, resource allocation, monitoring and optimization, shutdowns, etc.
* Energy efficiency in equipment, radios, baseband, transmission, processors, devices, boards, and site or data centre cooling, etc.
* Energy efficiency in site support system, the site infrastructure equipment such as rectifiers, batteries, climate control units and diesel generators.

Mobile operators, their partners, and the entire ecosystem will not achieve the sustainability targets, without an end-to-end collaborative, committed and orchestrated effort. At its highest level, the goal involves the inter-connected pillars of achieving digital transformation with full 5G and subsequently 6G realization, sustainability, and social responsibility. With the wide and growing range of use cases, particularly for automated industries, the great impact on other sectors is well expected and articulated.

To make future networks more energy efficient and help carriers cut carbon emissions, technological innovation may focus on three levels: equipment, sites, and networks. Certain equipment has implemented intelligent energy consumption of a base station by automatic wake-up/sleep including shutdown on symbol, channel or carrier basis. In cases where free cooling is not possible, liquid cooling further improves the power system efficiency and reduces the need for air conditioner. Intelligent AI-based power management allows networks to fit custom power saving strategies with configuration and traffic needs on different bands and modes at the base station level. With these strategies, mobile users can be switched to lower bands when total traffic remains low so that high bands can be switched off to realize deep sleep power saving. By leveraging AI to learn historical traffic and KPI data, it associates energy saving effects with mobile network performance to implement dynamic parameter adjustment, so that power saving can be fulfilled without sacrificing network performance.

Cooling solutions, powered by big data and AI technologies, can help data centres save energy and automatically optimize energy efficiency, reducing Power Usage Effectiveness (PUE) by 8–15%. Precise cooling eliminates hot spot risks and improves data centre stability. In addition, AI algorithms support automatic detection of air conditioner refrigerant capacity to avoid overheating caused by refrigerant leakage. The waste heat of the cooling system may be put to good use by being fed into a heating system thereby increasing the overall efficiency of both systems. A good example might be a data centre where the server park needs cooling. In winter the building needs heating and the sanitary installations need warm water all year around. Cooling and heating can be coupled in a way that the waste heat of the servers provide at least a part of the energy needed for the heating system. Liquid cooling, whether heat exchanger, immersion or hot plate systems are currently in development [20].

The access elements of networks account for the majority of mobile operator's electricity use, though definitive numbers are not readily available due to the global scale of network operations. The core network, management system, billing, and data centres account for approximately 20% of energy use. Analysis by the IEA [14] and ITU [7] demonstrate that from a baseline of 2010, data centre workloads have grown by 7.5X and IP traffic by 12X, while data centre energy usage has stayed globally at 200 TWh p.a. around 1% of global electricity. Mobile networks continue to improve in terms of efficiency up to 30% in recent years. Fixed and mobile networks consume around 240 TWh p.a. with mobile networks consuming close to 60% of that. Data centre efficiency has been driven by the hyperscale and cloudification of workloads with large scale data centre deployments. Mobile operators traditionally have not had the direct benefit of such scale, with many having a high number of regionalised data centres or central office type deployments supported by grid backup with diesel generators. Consolidation of regional centres facilitated by optical transmission, with the replacement of fossil fuel standby generation with solar, batteries and fuel cell technologies, are targeted to reduce emissions [20][21].

## 3.2 Use of Renewable Energy

Renewable energy is at the heart of the reduction of network carbon emissions. The decarbonization trajectories of L.1470 [7] put forward direct investments in generation of renewable energy, purchasing of PPAs and of Renewable Energy Certificates (RECs) that respect additionality principles. Mobile operators such as Deutsche Telekom, Vodafone and Telefonica have committed to achieving 100% renewable energy consumption and have already taken steps in this direction.

Mobile operators adopt different strategies when it comes to the sourcing of renewable energy. Deutsche Telekom is sourcing more green electricity directly, acquiring corresponding guarantees of origin, or concluding special PPAs. Deutsche Telekom is also investing in its own power plants, such as cogeneration plants or photovoltaic systems. French operator Orange is positioning itself for a long-term investment in renewable energy through PPA and self-generation by using solar farms to produce renewable energy. Telecom Italia has chosen a mix between guarantee of origin and self-generation, through the installation of photovoltaic panels to reach its goal of using 100% renewable energy. By the end of 2019, Telenor had installed solar power solutions for nearly 3,000 of its base stations in Asia. The operator has announced that it wants to double the number of solar based sites over the next 3-5 years. As a reminder, the main renewable energy strategies are based on solar energy, wind energy, fuel cell and biomass. Each of these solutions have advantages and disadvantages in terms of Capex, OPEX, savings, logistics and storage.

**Renewable Energy Market and Challenges**

Renewable energy usage is an essential part of emissions reduction, but each operator must consider the local market conditions. Following are the key terms associated with the renewable energy market:

- Countries energy mix: The energy mix of a country refers to the combination of different energy sources, which it uses to fulfil its energy consumption requirements. General mix of power generation comes from lignite, nuclear, hard coal, natural gas, oil, wind onshore, wind offshore, solar, hydro power, etc.
- ESCO (Energy Service Company): An ESCO is a company which provides energy solutions for its clients including energy efficiency projects as well as renewable energy projects. Several ESCO projects are being signed to power Base Stations (BSs) and data centres.
- Power Purchase Agreement or PPA: A PPA is a long-term contract in which a company purchases electricity from a renewable energy production company. In Europe, most of the renewable energy comes from wind turbines. Two types of PPA:
    - Physical PPA: It is a contract for the purchase of power and associated Renewable Energy Certificates (RECs) from a renewable energy provider (who builds, runs and maintains renewable energy systems either on the customer property or offsite) to a purchaser of renewable electricity. It is usually an agreement for 10 or more years
    - Virtual PPA or financial PPA: Unlike a Physical PPA, a virtual PPA is purely a financial contract without any physical exchange of energy. A virtual PPA is a type of contract in which the buyer agrees to purchase a project's renewable energy for a pre-agreed price
- Solar farms: Large scale of photovoltaic panels are also referred as solar farms. They operate similar to a power plant and feed electricity to the grid. They consist of solar panels installed on the ground in large areas and can be adapted to particular situations of a given region. Solar farms can also be used to power data centres which consume large amount of electricity. In this situation, they can be built onsite as well as offsite.

Using renewable energy is an essential strategy to tackle emissions although they are not a complete solution in all markets.  Renewable energy production still presents several challenges related to the availability (in markets) and their variability. Wind and solar are intermittent sources, for example, no solar at night (diurnal) and both are weather dependant. Common storage solutions, such as pumped hydro or batteries, can supply typically in the order of hours. To facilitate significant amounts of wind and solar on the electricity grid there needs to be sources of synchronous generation that can meet demand over extended periods when required. These can be Hydroelectric, Interconnectors or less ideally, fossil fuel sources, such as natural gas. This electricity mix is also very regional in nature. Norway for example has 96% low carbon energy through usage of renewable energy sources (Hydro), France 91% through nuclear whereas some of the largest economies such as the US and China are currently in the region of 35% renewable electricity [22].

**Renewable Energy Solutions for Base Station Sites**

Different solutions account as renewable energy sources, below are few examples of commonly used solutions for mobile base stations:

- Solar on-grid: Base Stations (BSs) are not only connected to the renewable energy source but also to a power grid which acts as a backup supply to fulfil the demand when load is high. Solar energy can be stored and used later or can be utilized as it is generated.
- Solar off-grid: In off-grid mobile network areas, BS is not connected to the power grid and can be powered by solar farms enabling total renewable energy production, which can be a case scenario for most rural areas. Reducing the transmit power of the BSs where users experience better Signal to Noise Ratio (SNR) can significantly reduce the limited renewable source of energy consumption. This action will in turn increase the SNRs and hence data rates of neighbouring BSs.
- Portable solar: When a base station is needed only at a certain season of the year, solar equipment cannot be stationary. For this type of applications, a base station can be powered with portable solar panels.
- Hybrid: Powering the off-grid sites with solar and wind hybrid solution
- Fuel cell: Powering the base stations by converting the chemical energy of a fuel (often hydrogen) into electricity. Compared to diesel generators by benefiting from fuel cells, there is not any direct (Scope-1) carbon emissions at the base station and noise level decreases as well.

Certain renewable site solutions allow to reduce energy consumption and carbon footprint by AI based integration of renewable energy sources for on-grid and off-grid sites, including solar power. One of the most effective manners in which GHG emissions can be reduced is to replace coal/oil/gas power with solar power backed up by energy storage systems (batteries/hydrogen) because the supply of renewable energy may not be as even as needed for the base station and a buffer needs to be provided for times of low renewable energy generation. A key part (≈20% of the cost) of the Photovoltaic (PV) solutions is the PV inverter.

**Carbon Impact of Renewable Energy Solutions**

If mobile operators aim to fully adopt renewable energies in order to reach their carbon neutrality objectives, it is important to note that these energies have a carbon cost which is not zero.

One of the first issues with renewable energy is the use of rare metals, which are used to produce wind turbines and solar panels (two of the four major types of renewable energy used by telecoms internationally). Indeed, these metals, in addition to being rare, are not renewable on a human scale. These resources therefore exist in limited amount. Moreover, their extraction has a high energy cost. Thus, to extract these rare metals, it is required to exploit a mine or, to refine the ores. The raw materials are then sent to production centres where they will be incorporated into a wind turbine or a solar panel [22][23]. This is certainly a smaller footprint than the combustion of fossil fuels alone, but it does not have a neutral carbon impact.

The ADEME (French Agency for the Environment and Energy Management) published an analysis of the life cycle of French wind power in 2015, which takes into account the emission of GHGs from the materials extraction to the end of life of equipment. The $CO_2$ equivalent emissions are 12.7 grams per kilowatt hour produced ($CO_2e$/kWh) for an onshore wind turbine and 14.8 g $CO_2e$/kWh for an offshore wind turbine. These values are lower compared to the French electricity mix, estimated at 79 g $CO_2e$/kWh [24]. An onshore wind turbine would produce enough energy in one year and an offshore wind turbine in 14 months, to compensate for the energy needed to manufacture it, knowing that their lifespan ranges from 20 to 30 years on average. In comparison, nuclear power generates 66 grams of $CO_2$ equivalent per kilowatt-hour produced, and natural gas 443 grams [24][25], as presented in below Table 1 [25]. According to the study, the main environmental impacts are related to the use of fossil fuels to manufacture the components. The most energy-intensive material is steel, which is used in large quantities in nacelles and masts. The next most energy-intensive material is the various plastics used in the blades and nacelles. The supply of two rare earths, neodymium and dysprosium, remains to be monitored. They are used for their magnetic properties in wind turbines with permanent magnets.

| Technology | Capacity/configuration/fuel | Estimate ($gCO_2e/KWh$) |
|---|---|---|
| Wind | 2.5 MW, offshore | 9 |
| Hydroelectric | 3.1 MW, reservoir | 10 |
| Wind | 1.5 MW, onshore | 10 |
| Biogas | Anaerobic digestion | 11 |
| Hydroelectric | 300 kW, run-of-river | 13 |
| Solar thermal | 80 MW, parabolic trough | 13 |
| Biomass | Forest wood Co-combustion with hard coal | 14 |
| Biomass | Forest wood steam turbine | 22 |
| Biomass | Short rotation forestry Co-combustion with hard coal | 23 |
| Biomass | FOREST WOOD reciprocating engine | 27 |
| Biomass | Waste wood steam turbine | 31 |
| Solar PV | Polycrystalline silicone | 32 |
| Biomass | Short rotation forestry steam turbine | 35 |
| Geothermal | 80 MW, hot dry rock | 38 |
| Biomass | Short rotation forestry reciprocating engine | 41 |
| Nuclear | Various reactor types | 66 |
| Natural gas | Various combined cycle turbines | 443 |
| Fuel cell | Hydrogen from gaz reforming | 664 |
| Diesel | Various generator and turbines types | 778 |
| Heavy oil | Various generator and turbines types | 778 |
| Coal | Various generator types with scrubbing | 960 |
| Coal | Various generator types without scrubbing | 1050 |

**Table 1** Lifecycle estimates for electricity generators

ADEME has also conducted research on the environmental impact of solar panels. A photovoltaic panel installed in France emits an average of 55 grams of $CO_2$ equivalent per kilowatt-hour produced ($gCO_2e/kWh$). This balance sheet obviously differs depending on the type of system, the module technology, and the amount of sunshine on the site. In particular, it depends to a large extent on the electricity mix of the country in which the cells and modules are produced. In the life cycle of a panel, the most energy-intensive part is the extraction and purification of silicon [26]. If this operation is carried out using coal, the balance sheet will necessarily be worse. Thus, the balance of emissions would still be much lower than the average emissions of national electricity mix: 79 $gCO_2e/kWh$ in metropolitan France, and 430 $gCO_2e/kWh$ worldwide. On average, a solar panel will produce in three years the energy required for its manufacture, according to ADEME, knowing that the life of a panel is at least 30 years when it meets European construction standards. It depends on the location and technology, but on crystalline technologies, the energy return time is already around one year [26].

The neutrality of the renewable energy deployed will also depend on the regions, and their climatic characteristics, where it is sourced. Indeed, a country's energy mix may be more or less carbon intensive, which will influence the cleanliness of the energy produced.

## 3.3 Compensation through Investment in Carbon sinks

A carbon sink is a natural reservoir (soils, oceans, forests, mangroves…) that absorbs carbon circulating in the biosphere, then traps it in living matter and sequesters it in a sustainable way. Forests are typically carbon sinks, places that absorb more carbon than they release. They continually take carbon out of the atmosphere through the process of photosynthesis [27]. Mangrove is also a typical example of a carbon sink. In an old mangrove, dead wood with very slow decomposition caused by a humid and oxygen-poor soil forms impressive reserves of carbon. Some mangroves in Indonesia, for example, store more than 1000 tons of carbon per hectare in their soil [28]. Creation of carbon sinks might play a determinant role in the regulation of climate conditions, by helping to reduce $CO_2$ in the atmosphere. They would also help to improve local living conditions, notably by filtering polluted air, by helping to lower temperatures, and by rebuilding a healthier ecosystem for the populations, promoting soil fertility for agriculture, and the development of fauna and flora.

Companies are using carbon sinks in the compensation of their unavoidable emissions. To do so, they invest in this solution over the long term (several decades). The carbon sink market is currently a tight one, due to a rapidly growing demand that is coming up against a limited supply. In some areas, this tension on the market is causing a sharp rise in the price of carbon credits. Certified Emission Reductions (CERs) are tradable emission credits that demonstrate the achievement of Green House Gas (GHG) emission reductions. They can be used for compliance purposes by either industrialized countries or companies and can be traded [28][29]. It is estimated that even if sequestration projects will multiply in the coming years, the growing demand from companies wishing to offset their emissions will keep a strong tension on this market. It is important to note that carbon credits can be obtained in different ways and some are more virtuous than others. Carbon credits obtained thanks to stand-alone projects or via investment funds are much more virtuous than resorting to the purchase of emission quotas, a remarkable controversial market.

However, in order for carbon offsets to have a real impact on the environment, it is recommended to meet several conditions such as:

- Compensate for the $CO_2$ at the place where it is emitted, in order to have an optimal impact.
- Adapt the type of compensation to the specific needs of each country (reforestation, agroforestry, mangroves…).
- Ensure that the investment is done in reliable projects, with transparent carbon accounting (i.e. the latter must take into account the different levels of $CO_2$ sequestration: a tree does not sequester the same amount of carbon when it has just been planted and several years later).
- Invest in a mix of projects to limit the risks related to natural disasters (fire, hurricane…), for example, use both projects via investment funds and stand-alone projects in various locations.

## 3.4 Mobile Operator and Vendor Initiatives

Particularly for the mobile operators, GSMA has announced an ambitious commitment to move the entire mobile industry to carbon neutral emissions by 2050. Many operators are announcing their carbon neutrality strategies: Some have positioned themselves on a goal of neutrality in the coming decade as Telefonica, Telia Company or Telecom Italia, which have all announced become carbon neutral in 2030. Others have announced to reach this goal in 2035 like Verizon or in 2040 like Deutsche Telekom, Orange or Vodafone. Finally, BT Group announced to become carbon neutral in 2045 while Telenor and China Mobile are positioned for the year 2050. This objective of neutrality is built on a strategy that is more or less depending on the operator, but which most often responds to the same pattern: cutting carbon emissions (increasing energy efficiency through innovation, using renewable energy, saving energy on energy-intensive items), and creating a circular economy (by recycling, refurbishing, remanufacturing or reusing the equipment, improving eco-design, carbon offsetting).

Vendors are promoting environmental protection by setting up clear goals for sustainability. This involves taking actions in the ICT technology innovation, product recycling, and operation management to reduce the impact on nature. First, reducing the carbon emissions, including those caused by its own production and operations, as well as the carbon emissions caused by customers using the products, and the carbon emissions caused by suppliers manufacturing for the vendors; second, promoting renewable energy; and thirdly, by contributing to a circular economy, including the use of the material with low environmental impact, reducing product weight and volume, reducing consumables for product packaging, etc.

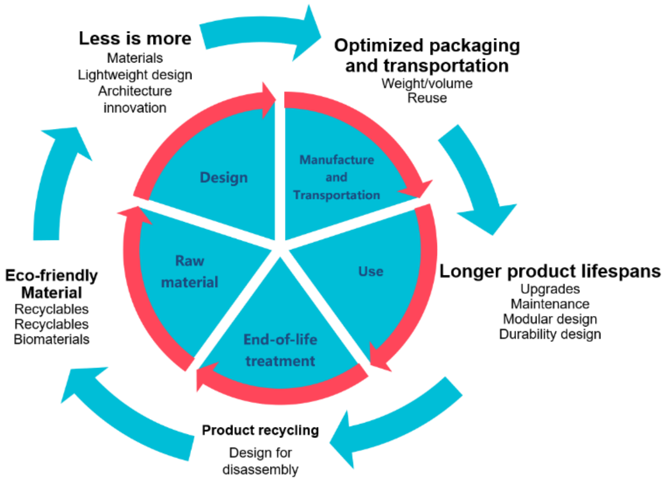


**Figure 3:** Integrate the Circular Economy Concept into the Entire Lifecycle of Products

Life Cycle Analysis (LCA) is one of the methods used to evaluate impacts across the whole product lifecycle from resource extraction, component manufacture, systems assembly, transport, installation, operation to retirement and disposal. These lifecycle impacts need to be considered across a range of environmental categories including, air acidification, water use, land use, resource usage, toxicity, and not least driving climate change through GHG emissions. The LCA results are mainly used within the framework of an eco-design strategy to identify which are the hotspots (in terms of environmental impact) at an equipment, network or service level. At equipment level the LCA can, for instance, show that a significant portion of the environmental footprint is related to semiconductors (e.g., integrated circuits, transistors) or electricity consumption during the use phase.

While suppliers work on reducing their own global manufacturing climate footprint, it will also take actions with others to collectively expand the technology "handprint". Further measures in this regard could be to:

- Help define new metrics for energy use and carbon reduction.
- Standardization of the handprint calculation method.
- Collaborate with industry and policymakers to apply digital technologies to reduce emissions across high-impact sectors such as manufacturing, buildings, and transportation/travel.

# 4 EMISSIONS AND NETWORKS

## 4.1 Emissions Generated by Networks

The connection between data traffic and energy consumption of the Information and Communication (ICT) sector has been debated over the years. Several projections have been published. In retrospect, many projections have turned out to overestimate the future energy consumption and carbon footprint of ICT. Detailed assessments are needed based on the different contributions and understanding of this sector's development. At this point, ITU, GSMA and, GESI have established a 2015 baseline for their 1.5°C decarbonization scenario equalling 730 Mt $CO_2e$ for 2015 based on measured data and detailed sector knowledge.

Rapid digitalization and increased data traffic might raise questions about how the electricity consumption and carbon footprint of ICT could change in the future, particularly with the building of larger data centres and the launch of new communications networks. During 2020, reflecting the pandemic, GSMA members have seen a significant increase in data traffic without a corresponding increase in energy consumption, showing that it is possible to decouple growth in traffic and increase in energy consumption.

User devices, networks and data centres are the three main parts of the ICT sector. In addition, the ICT sector footprint includes ICT-related emissions of services like gaming, social media and online advertising. Currently, user devices including phones, tablets, and computers account for the largest part of the sector's overall carbon footprint (consumer devices not being in scope of this project yet).

New green technologies such as DNA storage are 95% less carbon intensive than HDD storage [20][30]. This example shows that more energy efficient technologies are on the way in the ICT Sector which will help lower the emissions. Another example is Adiabatic Reversible Logic (ARL) which defines a way to solve the energy consumption issue of computers by adopting an alternate approach to CPU and GPU design [31].

Looking at the total carbon footprint, carbon emissions are divided between operation and embodied emissions, including raw material acquisition, production, assembly, transportation, and end-of-life treatment. Operation includes electricity consumption for the use of products, and emissions for operation and maintenance activities.

A large part of the sector's carbon footprint can be linked back to electricity consumption, but many ICT players invest in renewable energy, such as solar and wind power, to lower their carbon emissions. The emissions during use emerge almost entirely from electricity consumption, but the other life cycle stages consume electricity too, for instance in manufacturing. If the ICT industry and its users only consumed electricity produced by renewable energy sources, more than 80 percent of ICT's carbon footprint could be reduced [32].

Electricity consumption of networks and data centres should be based on large measures of data from real networks as opposed to from individual applications or devices to make estimations more accurate. Research shows that e.g. streaming a video on a tablet or phone requires considerably less electricity than an older solution, such as local video storage on DVDs, Blu-ray discs and large TV displays [33]. Another comparison shows the estimated average carbon footprint of a half-hour Netflix video is equivalent to driving around 100 meters in a conventional car.

## 4.2 Emissions Avoided by Networks

While networks cause emissions (footprints) they also impact the emissions of other sectors. When the impact is reduction of emissions, this can be referred to as the handprint or enabling effect.

Many examples have been presented in which ICT solutions are used in other sectors resulting in a GHG handprint bigger than the GHG solution footprint. Various sources put forward different balances between those, but the handprint of ICT solutions could easily outnumber their footprint, and factors around 4 - 10 times the footprint [15][16].

In combination with virtualization, edge computing, AI-enabled analytics and cloud, 5G can help industries to implement new processes as an integral part of energy efficiency programs, by supporting the most efficient and flexible allocation of resources.

Using the manufacturing sector as an example, 5G enables many new services in the factories of the future that can either directly or indirectly result in a reduction of GHG emissions. The reasons for the increasing use of wireless technologies in industrial use cases are the growing need for mobility and flexibility in production, savings in cabling costs, and faster retrofitting of existing machines. Following this, 5G can be an enabler in reducing the carbon footprint of factories of the future. In addition, wireless connectivity based on certain cellular technologies allows bidirectional, secure and trustworthy communication between all main actors in the transportation ecosystem and creates solutions to reduce the carbon footprint of road transport as well.

Concrete examples exist that derive the potential of individual services, for example gas-pipe inspection and face-to-face healthcare consultation. In the first case, 5G Unmanned Aerial Vehicles (UAV) cause a handprint (difference between the footprint of the baseline solution 71kg $CO_2e$ and the modified practice 43kg $CO_2e$ per inspection) of 65% mainly by reducing the fuel usage in the transport sector. In the second case, advanced 5G video-based healthcare consultation cause a handprint of around 247 times (baseline solution 1237kg $CO_2e$ and the modified practice 5kg $CO_2e$ per consultation) mainly in the air and road travel sector [34].

Although, there are many indications of the positive effect of ICT solutions, research also indicate that the methodologies used to derive such potentials need further development [35][36].

# 5 CONCLUSION

Mobile operators, their partners, and the entire telecom ecosystem will not achieve their sustainability targets without an end-to-end collaborative, committed and orchestrated effort. At its highest level, the goal involves the inter-connected pillars of achieving digital transformation with full 5G and subsequently 6G realization, sustainability, and social responsibility. With the wide and growing range of use cases, particularly for automated industries, the great impact on other sectors is well expected and articulated.

In order to decarbonize the ICT sector, main focus should be on improving the energy efficiency, using renewable energy and compensating through investment in carbon sinks. In addition to this, the ICT sector also needs to take eco-design principles into account for the hardware part. The concepts of refurbishing, lean packaging, proper usage of critical raw material, etc. cannot be ignored.

To make the mobile networks more energy efficient and help operators cut carbon emissions, technological innovation may focus on three levels: Equipment, sites, and networks. Many operators are announcing their strategies. Some have positioned themselves on a goal of carbon neutrality in the coming decade. This objective is built on a strategy which most often follows the same pattern: Minimizing carbon emissions (increasing energy efficiency, using renewable energy, saving energy on energy-intensive items), and creating a circular economy (recycling, improving eco-design, carbon offsetting). In combination with virtualization, edge computing, AI-enabled analytics and cloud, 5G can help industries to implement new processes as an integral part of energy efficiency programs, by supporting the most efficient and flexible allocation of resources.

Renewable energy is at the heart of the reduction of network carbon emissions. Emission reduction can be achieved by using renewable energy in combination with efficiency outstripping business growth. Using renewable energy is an essential strategy to tackle emissions although they are not a complete solution in all markets.

In pursuit of carbon neutrality, companies are using carbon sinks in the compensation of their unavoidable emissions which requires a long-term investment. The carbon sink market is currently a tight one, due to a rapidly growing demand that is coming up against a limited supply. In order for offsets to have a real impact on the environment, it is recommended to compensate for the $CO_2$ at the place where it is emitted. In addition, it is recommended to adapt the type of compensation for the specific needs of each country (reforestation, agroforestry, mangroves…) to have an optimal impact, and ensure that investment is done in reliable projects, with transparent carbon accounting.

As indicated, data has grown exponentially while footprints have kept quite stable. It is possible to combine data growth and reduction of the environmental footprint.
Nevertheless, data is similar to any other goods and concepts of responsible usage apply to it too. To mention some examples, the application of good practices to reduce unnecessary stored and sent data are highly recommended for service providers and clients. Also, the appropriate choice of the most adequate application or digital service, as well as its parameters to reduce the unnecessary transmitted data is important. An end-to-end approach includes the following:

- Promotion of data-driven assessments and further research of the environmental footprint of digital goods and services,
- Adoption of clear, fact-based, and data-driven objectives for the environmental footprint of digital goods and services, including incentives for economic actors to reduce their own footprint,

- Encouraging requirements for environmentally friendly digital products and services in public procurement,
- Systematic monitoring and reporting of the environmental footprint of actors of the digital ecosystem,
- A better assessment of the benefits of digitization on reducing the environmental footprint of other sectors,
- Promotion of digital and environmental literacy of citizens, providing clear information towards users on the environmental impact of their use of digital goods and services, and promoting responsible consumer decisions for a circular economy.

The goals of sustainability and carbon reduction targets can be achieved with end-to-end measures of identification and mitigation, involving all actors and players. The 5G roadmap and the journey towards 6G should include these as key drivers, as well as design, development and operation goals in a circular economy.

# 6 REFERENCES


[1] NGNM 5G White Paper 2. July 2020, https://www.ngmn.org/work-programme/5g-white-paper-2.html
[2] UN SDG's, https://www.un.org/sustainabledevelopment/sustainable-development-goals/" \o "https://www.un.org/sustainabledevelopment/sustainable-development-goals/
[3] ITU-T Recommendation L.1410, https://www.itu.int/rec/T-REC-L.1410-201412-I/en
[4] ITU-T Recommendation L.1023, https://www.itu.int/rec/T-REC-L.1023
[5] Our World In Data, Other GHG emissions, https://ourworldindata.org/co2-and-other-greenhouse-gas-emissions
[6] IPCC, https://www.ipcc.ch/sr15/
[7] ITU-T Recommendation L.1470, https://www.itu.int/rec/T-REC-L.1470-202001-I/en
[8] Malmodin, Jens & Lundén, Dag. (2018), The Energy and Carbon Footprint of the Global ICT and E&M Sectors 2010–2015. Sustainability. 10.3390/su10093027.
[9] GHG Protocol, https://ghgprotocol.org
[10] Guidance for ICT Companies setting Science Based Targets, https://sciencebasedtargets.org/resources/legacy/2020/04/GSMA_IP_SBT-report_WEB-SINGLE.pdf
[11] SBT Science based Target Settings Manual V4.0, https://sciencebasedtargets.org/wp-content/uploads/2017/04/SBTi-manual.pdf
[12] ITU-T Supplement L.37, https://www.itu.int/rec/dologin_pub.asp?lang=e&id=T-REC-L.Sup37-202005-I!!PDF-E&type=items
[13] ITU-T Supplement L.38, https://www.itu.int/rec/dologin_pub.asp?lang=e&id=T-REC-L.Sup38-202010-I!!PDF-E&type=items
[14] IEA https://www.iea.org/reports/data-centres-and-data-transmission-networks
[15] Andrae, A. S. G. (2021). Internet's handprint. Engineering and Applied Science Letters, 4, 80-97. DOI: 10.30538/psrp-easl2021.0065, https://pisrt.org/psr-press/journals/easl-vol-4-issue-1-2021/internets-handprint/
[16] GSMA: The enablement Effect, https://www.gsma.com/betterfuture/wp-content/uploads/2019/12/GSMA_Enablement_Effect.pdf
[17] ITU Area of Action, Environmental and Climate Change, https://www.itu.int/en/action/environment-and-climate-change/Pages/energy_efficiency-BAK.aspx
[18] ITU L1420, https://www.itu.int/rec/T-REC-L.1420
[19] ISO 14064, https://www.iso.org/standard/38381.html
[20] ETSI TS 103 586 Liquid Cooling Solutions for ICT, https://portal.etsi.org/webapp/WorkProgram/Report_WorkItem.asp?WKI_ID=58017&curItemNr=11&totalNrItems=29&optDisplay=10&qSORT=HIGHVERSION&qETSI_ALL=&SearchPage=TRUE&qINCLUDE_SUB_TB=True&qINCLUDE_MOVED_ON=True&qMILESTONE=1&qSTOP_FLG=&qKEYWORD_BOOLEAN=&qCLUSTER_BOOLEAN=&qFREQUENCIES_BOO

LEAN=&qSTOPPING_OUTDATED=&butSimple=Search&includeNonActiveTB=FALSE&includeSubProjectCode=&qREPORT_TYPE=SUMMARY
[21] GSMA. 2019 Mobile Industry Impact Report: Sustainable Development Goals https://www.gsma.com/betterfuture/resources/2019-mobile-industry-report
[22] Our world in data, Electricity mix, https://ourworldindata.org/electricity-mix
[23] Guillaume Pitron, « La guerre des métaux rares, The hidden face of the digital and energy transition". 2018, Les Liens qui Libèrent
[24] ADEME, "Environmental impacts of French wind power, 2015 data", published 2017
[25] ADEME, "Lifecycle estimates for electricity generators", 2017*
[26] "Métaux et Terres rares, la face cachée de la transition énergétique », Les focus Techniques de l'Ingénieur, 2018, p. 8.
[27] National Geographic, "Carbon Sources and Sinks", Resource Library, Grade 5-8.
[28] Donato, D., Kauffman, J., Murdiyarso, D. et al. "Mangroves among the most carbon-rich forests in the tropics". Nature Geosci 4, p. 293–297, 2011.
[29] Pérez Correa, S., Demenois, J., et Wemaëre, M., « Le régime des crédits carbone générés par les projets de boisement ou de reboisement dans le cadre du mécanisme pour un développement propre : un défi pour les juristes et les développeurs de projet », Revue juridique de l'environnement, 2011, pp. 345-364
[30] Koch, J., Gantenbein, S., Masania, K., Stark, W. J., Erlich, Y., & Grass, R. N. (2020). A DNA-of-things storage architecture to create materials with embedded memory. Nature biotechnology, 38(1), 39-43.
[31] Scott, A., & Lewis, T. G. (2021). Sustainable computing. Ubiquity, 2021(February), 1-10.
[32] Ericsson - A quick guide to your digital carbon footprint, https://www.ericsson.com/4907a4/assets/local/reports-papers/consumerlab/reports/2020/ericsson-true-or-false-report-screen.pdf
[33] IEA – The carbon footprint of streaming video, https://www.iea.org/commentaries/the-carbon-footprint-of-streaming-video-fact-checking-the-headlines
[34] Huawei (2020). Green 5G: Building a sustainable world. https://www-file.huawei.com/-/media/corp2020/pdf/public-policy/green_5g_building_a_sustainable_world_v1.pdf?la=en
[35] A Methodology for Assessing the Environmental Effects Induced by ICT Services: Part I: Single Services (2020, Coroamă and Bergmark et al)
[36] A Methodology for Assessing the Environmental Effects Induced by ICT Services: Part II: Multiple services and companies (2020, Bergmark and Coroamă et al)

## List of Abbreviations

| | |
|---|---|
| 3GPP | 3rd Generation Partnership Project |
| AI | Artificial Intelligence |
| ANSI | American National Standards Institute |
| ARL | Adiabatic Reversible Logic |
| ATIS | Alliance for Telecommunications Industry Solutions |
| BS | Base Station |
| Capex | Capital Expenditure |
| CEN | European Committee for Standardization |
| CER | Certified Emission Reduction |
| CPE | Customer Premise Equipment |
| CPU | Central Processing Unit |
| $CO_2e$ | $CO_2$ equivalent |
| ESCO | Energy Service Company |
| ETSI | European Telecommunications Standards Institute |
| GeSI | Global enabling Sustainability Initiative |
| GHG | Green House Gas |
| GPU | Graphics Processing Unit |
| GSMA | Global System for Mobile Communication Association |
| ICT | Information and Communication Technologies |
| IEA | International Energy Agency |
| IEC | International Electrotechnical Commission |
| IEEE | Institute of Electrical & Electronic Engineers |
| IPCC | International Panel on Climate Change |
| ISO | International Organization for Standardization |
| ITU | International Telecommunication Union |
| KPI | Key Performance Indicator |
| LCA | Life Cycle Assessment |
| M2M | Machine to Machine |
| MIMO | Multiple-Input and Multiple-Output |
| MNO | Mobile Network Operator |
| MVNO | Mobile Virtual Network Operator |
| OPEX | Operating Expenditure |
| PPA | Power Purchase Agreement |
| PV | Photovoltaic |

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| PUE | Power Usage Effectiveness |
| REC | Renewable Energy Certificates |
| SBT | Science Based Target |
| SBTi | Science Based Target initiative |
| SDG | Sustainable Development Goals |
| SDO | Standard Developing Organization |
| UAV | Unmanned Aerial Vehicles |
| UN | United Nations |
| VoIP | Voice over IP |