Reducing Environmental Impact

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REDUCING ENVIRONMENTAL IMPACT

by NGMN Alliance

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EXECUTIVE SUMMARY

Managing the environmental impacts of mobile networks involves reducing the environmental footprint through design, material selection, manufacturing, operation and disposal of devices and network equipment, as well as reduction in energy consumption, emission, and water usage. To make this happen, the environmental impact must be understood, assessed and reported, and accordingly, strategies and collective best practices applied towards its effective reduction.

The environmental impact of the Information and Communications Technologies (ICT) sector is closely connected to the materials used for network equipment and needs to be considered in selecting strategies to address impact reduction. These considerations involve such notions as toxicity and resource depletion (e.g. in the case of gold and copper). Common metrics have been introduced such as Cumulative Energy Demand (CED) that ranks metals against each other in terms of their impact. Another metric is Global Warming Potential measured over 100 years (GWP100) as compared to CO_2. The metals of special interest include gold, silver, copper, aluminium, and lead, among others. It is noted that recycling remains an important approach, particularly for rare metals.

Beyond materials, the servers, infrastructure, and user equipment must be considered with respect to their energy consumption and the corresponding emission of Greenhouse Gases (GHG), during manufacturing and operation. The majority of the energy used is still from combustion of fossil fuels, converted to usable energy particularly electricity, and nonetheless inevitably linked to the emission of CO_2. In addition, carbon is used in the supply chain as a reducing agent when mining oxide ores, and is bound as a structural element, particularly in plastic-based structural elements, both leading to emission concerns.

Climate change has been intensifying the global water shortage. The water footprint is a measure that must be used through the lifecycle of equipment and across the supply chain to identify impact. Reports indicate major water usage during manufacturing, such as semiconductor fabrication, while highlighting the vast number of user devices of all types using significant amount of water in the process of being manufactured. Today the main parameters considered are Water Consumption and Water Usage Effectiveness (WUE). However, other aspects also to consider include water temperature and water pollution. Water consumption inevitably leads to waste water after leaving the process, which can be polluted and harmful if not treated properly. In general, multiple parameters need to be considered for water footprint.

Understanding and assessing the environmental impact are essential to be able to manage and reduce, particularly with equipment eco-design based on circularity principles. These principles, driven by design, simply and intuitively include elimination of waste and pollution through sharing, reusing, refurbishing and recycling of materials and products. Alternatively said, a circular economy redesigns materials, products, and services to be less harmful, wasteful, or resource intensive, and recaptures end-of-life as a resource, thereby extending lifecycle.

Life Cycle Assessment (LCA) is the most widely used tool to evaluate the environmental impact of products and services and show the most important parts and processes. Then the most effective strategies to improve the LCA score are established, including design for energy efficiency, longevity, and recycling. In addition, the material efficiency should also be evaluated by measuring the function(s) delivered per materials used.

To assess the freshwater use, Water Footprint is used as an indicator at both direct (operational) water use of a consumer or producer, as well as the indirect water use that form the inputs and correspond to supply chain. It is a multidimensional indicator, showing water consumption volumes by source and polluted volumes by type of pollution; all components of a total water footprint (no matter how they are sourced) are specified geographically and temporally. A company's water footprint assessment includes calculation of direct water use, indirect water use for electricity generation, and indirect water use for ICT equipment manufacturing based on Life Cycle Assessment (LCA).

Understanding the environmental impact, the corresponding assessment with clear indicators, and application of circularity principles in eco-design, will equip the companies to develop common strategies and best practices towards managing and limiting the impact. With respect to material, reduction in use, and substitution or recycling are among key strategies, particularly with respect to harmful material, the rare ones, or those with higher level of effort needed for mining. Furthermore, it is reported that much of the world's ability to mitigate the effects of climate change is linked to our ability to have an accelerated approach towards identifying new materials that can be created, consumed, and recycled with minimal environmental impact [1]. Technologies such as AI, data augmentation using traditional and quantum computing, generative models, and laboratory automation can be leveraged to accelerate the discovery of new materials.

From an equipment perspective, expanding the lifespan of antennas is one natural step towards more sustainable networks, though there are several challenges that need to be addressed. Furthermore, the extent to which one or more strategies are applied depends on particular case. A variety of approaches are considered that involve software or hardware reconfiguration, choice of sustainable material, modular design, and decoupling active and passive antennas. As an example, the latter allows extension of the passive antenna lifespan independently.

In its efforts to limit emissions, the industry takes a number of approaches that involve reduction of energy consumption, use of renewable energy, harvesting energy, and substitution for use of carbon. In addition, preserving water resources is an important priority.

A responsible water management strategy should include both an internal and external focus: reducing the amount of freshwater used within a company's operations and buildings, as well as supporting efforts to solve local water challenges by partnering with local governments, non-profit organisations, and other community stakeholders. Many organisations are approaching this by setting "context-based" water stewardship targets, such as "net positive water" or "water neutral" goals.

It is essential that everyone contributes, and it is expected and indeed promising to see that companies are assessing their ecological footprints and are developing strategies on how to reduce their carbon footprint. A number of case studies from NGMN partners give examples for practices to act on net zero targets and neutralise emitted emissions. As outlined in more details, and recommended in this document, identifying, assessing and addressing the environmental impact, in a timely, orchestrated, and transparent way, with clear common indicators and strategies, will lead the industry in its collective journey towards environmental sustainability targets.

DOCUMENT HISTORY

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CONTENTS

01 INTRODUCTION

1.1 BACKGROUND

The NGMN Green Future Network (GFN) project (Phase 2) expands on the discussion of sustainability as outlined in the NGNM GFN reports published in 2021 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 report covers the environmental impacts in terms of the footprints related to equipment design based on circularity principles, especially covering the importance of material selection, as well as the water footprint and measures to reduce the water footprint.

Fossil carbon has been stored under the soil for geologically relevant periods ranging from 20-40 Million years for lignite to almost 300 Mill. years for stone coal. Human activity now converts this fossil, previously not climate effective carbon into CO_2 and thus changes the chemical composition of the atmosphere. There is a natural generation and consumption of CO_2. The anthropogenic emission of CO_2 is superimposed onto this natural cycle and increases the atmospheric CO_2 concentration. The increase so far has been from 280ppm in 1750 to 410ppm in 2018 with recent annual increments of ca. 2ppm [2].

The planet earth is in a radiation balance which determines the average temperature on its surface. The earth receives a certain amount of radiation from the sun according to the distance (1 astronomical unit = 149.6 Mill. km) and the sun's luminosity. On the other hand, the earth radiates some of the so received energy back into space in certain regions of the electromagnetic spectrum. CO_2 (and other GHG) have the property of absorbing radiation in these regions. That in turn means that less of the received energy is radiated back into space which increases the energy level and thus the average equilibrium temperature on the earth surface. The increased energy level in the atmosphere manifests itself already in a higher abundance of extreme weather patterns, such as extreme temperatures, droughts and heavy rain floods [2]. The danger here lies in self-accelerating feedback loops as higher temperatures, for instance, lead to a reduction of Arctic ice shields which reduces the albedo. Another such effect may be the release of methane bound in perma-frost soil in Siberia when this currently still frozen soil melts.

Hence, it is extremely important to limit the climate change to avoid uncontrollable developments in the future that would severely impact the habitability of the earth in some regions. A further increase in average temperature would increase the abundance and intensity of heavy weather patterns even further. The U.N. has agreed on the Paris Climate Accord to limit the climate change to 1.5°C in average. All industries must urgently contribute to this essential target and orientate the strategic sustainability targets at this goal.

Digital technologies through the exchange of data enable organisations to improve, modernise and create efficiencies in various sectors. It is widely believed that the ICT sector can enable high impact industries, such as energy generation, manufacturing, transport and agriculture, to modernise and create efficiencies leading to reduced carbon emissions. The 'handprint' or 'enabling effect' of the ICT sector can contribute to lower the 'footprint' of high impact industries [3]. At the same time the increase of data traffic is contributing to the increase of ICT equipment, which contributes to resource depletion. Between 1995 and 2015, the material footprint of digital equipment has quadrupled [4]. Most equipment generates a lot of waste. Circularity and its goal of zero waste is a key potential to reduce the environmental impact of the ICT sector. In the transition towards a circular economy, the belief of "waste + knowledge = asset", as stated by Idriss J. Aberkane [5], highlights the importance of transparency - information and knowledge on waste to transform it into an asset and maintaining its value. Data, information and knowledge on waste that network equipment generates need to be collected and exchanged across the value chain so that the gained knowledge can be applied to keeping valuable resources in a circular economy and with that minimising the environmental impact of mobile networks. To maintain the value of equipment and its materials for as long as possible, information on the design, composition and condition of equipment components and its materials is critical. With this information end-of-life equipment can be converted back into valuable resources and assets.

Information on materials as well as collaboration and information sharing across the value chain enable the transition to a circular economy to minimise the footprint of mobile networks. So the 'handprint' of the ICT sector can be leveraged while ensuring that the benefits are not offset by its environmental costs.

1.2 SCOPE

This publication builds on the 2021 NGMN GFN Project findings on eco-design principles and material footprints, gathering more information and knowledge to turn waste into assets.

In order to reduce environmental impact, the ICT ecosystem needs to continue working on topics such as material usage and waste. Furthermore, sector impact analysis and solutions should go further than carbon emissions. Therefore, identifying other footprint metrics such as the water pollution is important for the sector.

Environmental impacts of materials used for network equipment, energy usage and the water footprint of the ICT sector are analysed. Assessments of materials, that have the biggest carbon impact in the ICT sector, as well as recyclability, repairability and refurbishing are presented. High level Key Performance Indicators (KPIs) to measure and report the networks' water footprint are suggested. Different strategies and best practices for mobile operators to reduce the environmental impacts from network equipment and servers are elaborated later in the report, covering aspects from the best ways to limit emissions, select environmentally preferable materials and components, design of antennas, leverage technology to accelerate material discovery, reduce water footprints and leverage carbon offsetting. Finally, a conclusion and recommendations are given which highlight towards the telecommunication sector how to reduce the environmental impact of mobile networks.

02 ANALYSIS OF ENVIRONMENTAL IMPACT

2.1 ENVIRONMENTAL IMPACT OF MATERIALS USED FOR NETWORK EQUIPMENT

The environmental impact of the ICT sector is closely connected to the materials used for network equipment. As outlined in the NGMN GFN report on Eco-design [6] based on the toxicity and resource depletion aspects, gold and copper are found to be two of the key metals used by the ICT and Entertainment and Media (E&M) sectors. Other materials of special interest are zinc, lead and silver (often mined together) from both a toxicity and resource depletion potential perspective and from a resource depletion potential perspective, antimony, indium, and germanium.

The metric Cumulative Energy Demand (CED) ranks metals against each other in terms of their impact (detailed ranking in Annex A). Compared to each other, following a CED ranking of elements used in metal alloys, gold has the highest impact, followed by germanium, silver, indium and magnesium [7]. Aluminium ranks on position 8, copper on position 12 and lead on position 17.

For the metric Global Warming Potential measured over 100 years (GWP100), the likely ranking of materials compared to each other per mass shows that gold, palladium, silver, aluminium, stainless steel, lead, glass and copper are the most important from a GWP100 viewpoint. For GWP100 in 2020, gold and aluminium top the preliminary ranking of the materials as totally used in the ICT network infrastructure sector.

Material selection in the design of equipment influences the environmental impact of the network and needs to be considered in selection strategies. However, the most important measure is to recycle metals, especially rare ones such as gold and copper.

2.2 ENVIRONMENTAL IMPACT OF ENERGY USAGE OF NETWORK EQUIPMENT

One of the key environmental impacts of servers and network infrastructure and at the same time one of their biggest environmental problems is the energy usage and the correlated emission of Greenhouse Gases (GHG) during manufacturing and use. **For network equipment the use phase emits ten times more CO_{2e} compared to the production phase.**

The GHG emission occurs in various chemical and physical processes associated with manufacturing and use:

1. Manufacturing and use require energy. The majority of this energy is still obtained by combustion of fossil fuels, such as oil, petroleum gas, lignite and stone coal. The chemical energy contained in these fuels is converted into usable forms of energy, such as electricity, but which is inevitably associated with the emission of CO_2.

2. Use of carbon as a reducing agent in the supply chain: many materials are mined in the form of their oxidic ores. The release of the materials requires a high temperature process where coal is used to generate the process temperature but also part of it serves to reduce the oxidic ores (mostly in the form of intermediary CO). This also emits CO_2. The reactions of carbon with SiO_2 to Si and CO_2 and with Fe_3O_4 to Fe and CO_2 are examples relevant for our industry.

3. In some materials carbon is bound as a structural element. This is the case for plastic which is used frequently and in high percentages of the total weight for structural parts such as housings and stiffening frames. Plastic is made from polymers (plus some additives according to use) which in turn are synthesised from monomers. These monomers are obtained from fossil precursors isolated from crude oil or petroleum gas or synthesised from constituents thereof. At the end of use most of the plastic is still incinerated to at least recover the chemical energy or, even worse, some of it ends up in landfills. The incineration releases CO_2.

2.3 ENVIRONMENTAL IMPACT OF THE WATER FOOTPRINT OF THE ICT SECTOR

Today, according to United Nations Water, more than two billion people lack access to safe drinking water [8]. And climate change is only intensifying this water shortage. The U.N. estimates that one in four people may live in a country affected by chronic shortages of freshwater by 2050. According to the World Bank, this climate-induced reduction in freshwater availability, coupled with increased demand, could reduce water availability in cities by more than 66% by 2050. A possible solution for reduced freshwater availability are desalination plants, such as the Carlsbad Desalination Plant [9].

The water footprint shall be measured across the full life cycle or supply chain of ICT, typically manufacturing and usage. Based on The Water Footprint Assessment Manual, the major water usage comes from manufacturing with 79%, while usage is only 21%. Besides if we compare user equipment with networks and data centres, the most water consuming by far is user equipment, with 75%. One cell phone may take up to 240 gallons to manufacture according to Water Footprint [10].

Today the main parameters considered are Water Consumption and so-called Water Usage Effectiveness (WUE). For Data Centre, WUE is a ratio between annual site water consumption and ICT equipment energy. However, water consumption in terms of volumes is not the only element to consider. With climate change and drought, water scarcity is becoming an issue in many regions. Other elements to consider include water temperature and water pollution. Some data centres extract river or table water at a given temperature, use it to cool data centre equipment for instance and then dispose it back with higher temperature, sometimes 10 or more degrees, with an impact on the environment, fishes, plants etc.

Pollution is another aspect, using water in contact with heavy metal or other materials changes the pH of the water and causes pollution that may damage the rivers, land, crops, table water of the surroundings. Water consumption inevitably leads to waste water after leaving the process. The semi-conductor industry generates waste water which can be polluted and harmful if not treated properly.

Presently, silicon chips are used in nearly all microelectronic devices, including laptops, mobile phones, flat panel displays, sensors, and lighting (LEDs). They have become an inseparable part of daily life. Semiconductor fabrication requires significant water use. Water is used throughout the manufacturing process to remove impurities from silicon wafers, as well as in support systems such as scrubbers and cooling towers, and office buildings. It is imperative for semiconductor manufacturing to manage water usage efficiently.

Considering water cooling systems, to prevent scaling, corrosion and bio-film, inhibitors and biocides are dosed. This dose varies with water evaporation and adding water, which makes the quality of the disposed water vary.

Consequently, multiple parameters need to be considered for water footprint:

Parameter	
Water consumption	m^3 or gallons
Water Usage Effectiveness	WUE
Water Usage Effectiveness Source	WUE_{source}
Potable Water Volume Source	m^3
Water release Volume	m^3
Water replenishment Volume	m^3
Water temperature source/release degree difference/delta	degree
Location vs drought area – a metric for that	Index XX

03 ASSESSMENT THROUGH LIFECYCLE

3.1 ASSESSMENT OF RECYCLABILITY, REPAIRABILITY AND REFURBISHING

3.1.1 REFURBISHMENT CHALLENGES

On the network infrastructure side, refurbishment is usually approached from a different perspective than for customer equipment such as smartphones. For network equipment the focus is on adopting processes to ensure the equipment remains in good working order. For smartphones, the focus is on restoring the device to 'as good as new'.

In both cases however a unique Lifecycle Assessment (LCA) will reveal in which cases there is an environmental gain of lifetime extension with refurbishment.

The global market for refurbished smartphones has been growing and maturing in recent years, at the crossroad between consumers' demand for reliable and affordable handsets and Mobile Network Operators' (MNOs') commitment to integrate environmental sustainability KPIs in their general strategies. Although it makes much sense to look at refurbishment as a viable solution to mitigate against the creation of e-waste which is a major challenge for Telcos, a number of challenges and concerns arise for all the stakeholders involved in the process that starts with collection, then moves through with repair/refurbish decision if the device is re-usable and in-demand, or with dismantling for spare parts extraction, thus ending up with recycling processes.

There is also a big gap in the channel partnerships with the 3PL (third party logistics) capable of providing authorised repair services and these refurbishment services internationally, with more geographic coverage, partly due to what seems to be a misunderstanding between the ecosystem of brokers and authorised repair centres in some countries. In this sense, more clarity, including from the telco industry and regional regulation bodies, would be needed if stronger circular economy programs integrating refurbished mobile handsets are expected. Moreover, clarification is also necessary when it comes to license usage entitlement across different markets, as well as to the right to refurbish a dismantled equipment and to make available spare parts which are necessary for the refurbishment operations.

Refurbishment challenges are also linked with the broader spectrum circular economy scope. A close link comes in the form of eco-design, i.e., having OEMs clear specifications in terms of equipment durability, repairing and maintenance, reusable components, and spare parts availability, all of these calibrated for the type of equipment in question. If discussing about smartphones, another prominent aspect to consider regards the device's aesthetic condition, with both eco-design and refurbishment closely concerned. On the other hand, in the case of both smartphones and CPE equipment, software-friendly update support is needed to ensure that refurbished devices can be restored to their original use functionalities.

Ultimately, when refurbishment is not possible due to end of life of the equipment, its recycling needs to be facilitated in terms of collection and transportation for an appropriate waste management with full traceability. This begs a question regarding the trade-off regarding the most opportune and sustainable choice between refurbishing specific equipment and not doing so. Additional criteria to consider could be:

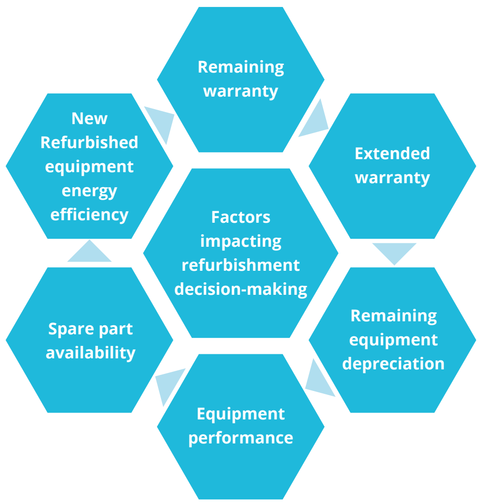

Figure 3.1: Making sustainable choices - additional criteria to consider

3.1.2 APPLY LCA TO VALIDATE MATERIAL EFFICIENCY

Life Cycle Assessment (LCA) is the most widely used tool to evaluate the environmental impacts of products and services.

LCA is essential to show the most important parts and processes for the design at hand. Then the most effective strategies to improve the LCA score are established. They commonly are:

- Design for energy efficiency
- Design for longevity with better maintainability
- Design for recycling

The material efficiency should also be evaluated by measuring the function(s) delivered per materials used.

Here follows an example for Lead Acid (LA) Batteries compared to Lithium (Li) batteries.

LA batteries have a material efficiency for electric charge of around 0.78 Ah/kg and Li Batteries 2.3 Ah/kg, i.e., better for Li.

Moreover, the energy density of LA batteries is around 37.2 kg mass/kWh delivered energy and for Lithium Batteries 4.8 to 9.1 kg/kWh delivered energy. The lifetime of LA batteries is around 8.5 years while Li Batteries may last 15 to 20 years [11].

Via LCA calculations the eco-friendliness of the materials efficiency trend can be validated.

For the Global Warming Potential during 100 years (GWP100), LA batteries cradle-to-grave (LCA) score is around 2 kg CO_2-equivalents/kWh and for Lithium Batteries, 1.1 to 1.64 kg/kWh. For resource use (minerals and metals) evaluation, the LCA score for Lead Acid batteries is around 800 mg Sb-equivalents/kWh and for Lithium Batteries as low as 48 to 88 mg Sb-equivalents/kWh [11].

This means that the higher material efficiency of Li batteries compared to LA batteries is confirmed to also reduce life cycle environmental impacts.

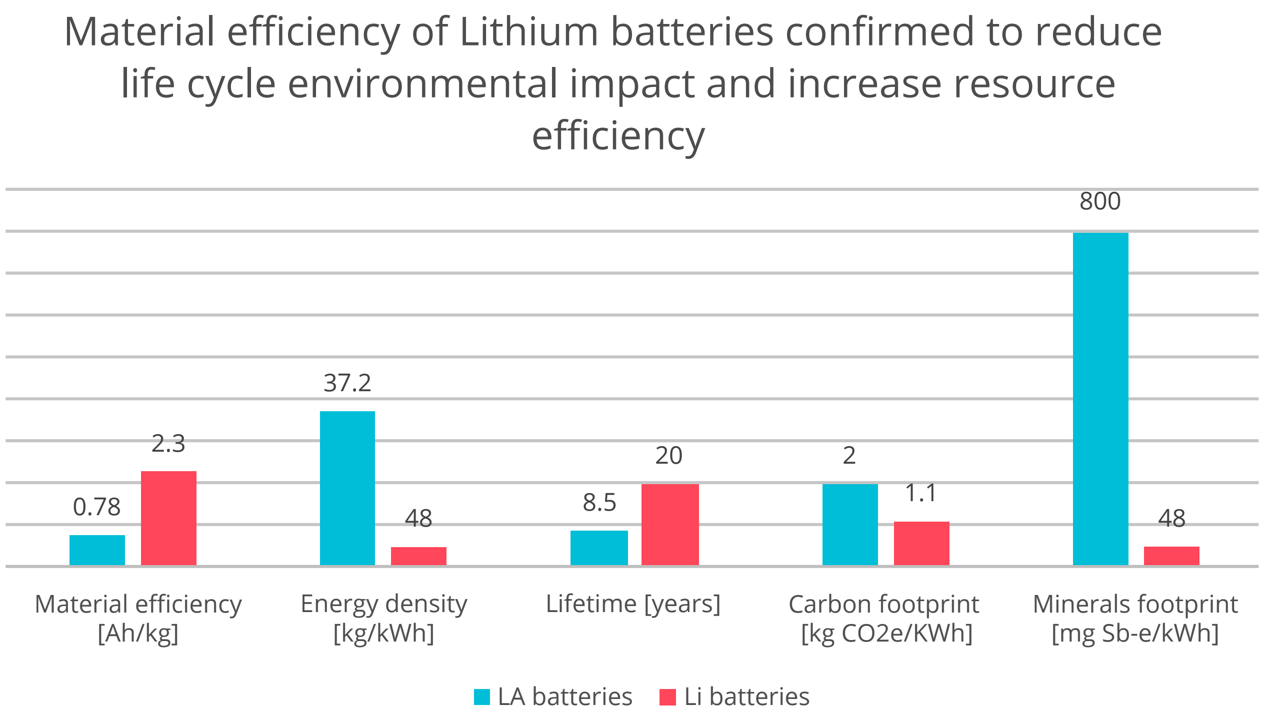

Figure 3.2: Material efficiency and environmental impact in comparison of LA and Li batteries

3.2 WATER FOOTPRINT REPORTING

3.2.1 WHAT IS A WATER FOOTPRINT?

The Water Footprint (WF) is an indicator of freshwater use that looks not only at direct water use of a consumer or producer, but also at the indirect water use. It is a multi-dimensional indicator, showing water consumption volumes by source and polluted volumes by type of pollution; all components of a total water footprint are specified geographically and temporally [10].

The water footprint has three components (Figure 2) [10]:

- **Blue Water Footprint:** refers to water that has been sourced from surface or groundwater resources along the supply chain of a product.
- **Green Water Footprint:** is water from precipitation that is stored in the root zone of the soil and evaporated, transpired or incorporated by plants.
- **Grey Water Footprint:** is the volume of fresh water required to assimilate the load of pollutants given natural background concentrations. The grey water footprint considers point-source pollution discharged to a freshwater resource directly through a pipe or indirectly through run-off or leaching from the soil, impervious surfaces, or other diffuse sources.

Direct versus indirect WF

The distinction between "direct" and "indirect" is made in case of water footprint accounting. The total water footprint of a consumer or producer refers, by definition, to both the direct and the indirect water use of this consumer or producer. This means that, without specification, the term water footprint refers to the sum of direct and indirect water use. The distinction between Scopes 2 and 3, as applied in carbon footprint accounting, is not applicable for WF accounting where there are only two 'scopes' i.e., 'direct' and 'indirect' water footprint.

The direct WF is also called operational WF which is the volume of freshwater consumed or polluted due to the business's own operations.

The indirect WF represents the supply chain WF which is the volume of freshwater consumed or polluted to produce all the goods and services that form the inputs of production of the business.

Both direct and indirect WF include the three components of WF, i.e., the blue, green and grey.

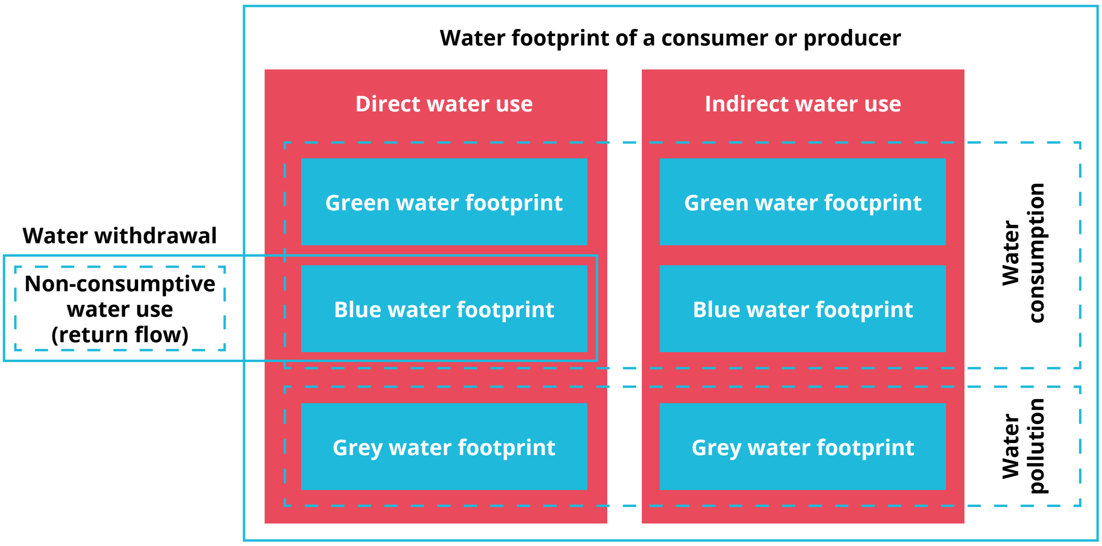

Figure 3.3: Schematic representation of the components of a water footprint [10].

3.2.2 WATER FOOTPRINT CALCULATION METHODOLOGY

A company water footprint calculation is based on the following steps (calculation formulas and examples can be found in Annex B):

1. **Water Footprint calculation of direct water use**
   Direct water consumption, e.g. connected to cleaning

2. **Water Footprint calculation of indirect water use for Electricity Generation**
   The Water Consumption of Electricity Production (WCEP) is mainly based on water consumption factors (L/kWh) of the technologies used in energy production [12].

3. **Water Footprint calculation of indirect water use for ICT equipment manufacturing based on Life Cycle Assessment (LCA)**
   Approximations of life cycle water footprint, through tools such as LCA, can help ICT companies identify where the greatest amounts of water may be consumed during the life cycle of a typical process, general product, or service. Therefore, this enables a business to make informed choices on how to reduce its impact most effectively on the environment, and to mitigate any risks posed to their value chain by climate change. Further to this, LCA can be a valuable tool to stimulate innovation by supporting sustainable choices on product design, development and manufacture. In Annex A, the LCA of a product to determine its water footprint in an ICT company is calculated as an example.

As highlighted above the water use in data centres is one of the relevant parameters to be considered for water footprint reporting in the ICT sector. The following paragraphs present a recap of water use in data centre using the Water Effectiveness Factor (WUE) that includes both direct and indirect WF.

The **direct WF** in data centres is composed by the water used for on Heating, Ventilation and Air Conditioning (HVAC) system, i.e., evaporation for humidification and cooling; plus the grey WF from thermal pollution and chemical discharge.

The **indirect WF**, focuses on data centre energy consumption. The Water Usage Effectiveness (WUESource) [13] is a metric used specifically for data centre water consumption and is defined as:

$$WUE_{Source}(L/kWh) = \frac{Annual\ Source\ Energy\ Water\ Usage(L) + Annual\ Site\ Water\ Use(L)}{ICT\ Equipment\ Energy\ (kWh)}$$

Where,

- **Annual Source Energy Water Usage:** water usage from electricity generation.
- **Annual Site Water Use:** includes water used for cooling, regulating humidity and producing electricity on-site.
- **ICT Equipment Energy:** is the energy consumed by ICT equipment including any drawn by hardware used in the day-to-day functioning of the data center.

Relation between Power Use Effectiveness (PUE) [14, 15] and WUE

$$PUE = \frac{Data\ Centre\ Total\ Energy\ Consumption}{ICT\ Equipment\ Energy\ Consumption}$$

Power Use Effectiveness (PUE) indicates how efficient is a room with ICT equipments. An ideal PUE of 1.0 would mean 100% of the energy going to power useful services running on the ICT equipment rather than wasted on cooling, lighting and power distribution. The main aim in measuring **PUE** and **WUE_{Source}** is to play with these two variables in such a way that we maintain the equilibration between them to make a good use of the resources. In other words, whenever you work with lower PUEs, you are averaging more water-based cooling systems that evaporate a lot of water (WUE_{Source} increases).

The following formula [16] can be applied to show the link between PUE and WUEs:

$$WUE_{Source}(L/kWh) = [WCF(L/kWh)\ x\ PUE] + \frac{Annual\ Site\ Water\ Usage\ (L)}{ICT\ Equipment\ Energy\ (kWh)}$$

Focus on WF of data centers cooling

The average PUE ratio for air-cooled data centers is 1.58 while in the case of liquid immersion cooling data centers the average PUE ratio is 1.03 as shown in **Table 4**.

	Data Center A Air cooling	Data Center B Immersion Cooling
Average PUE ratio	1.58	1.03

Table 4: Comparison of PUE of two Data Centers [17]

From a water consumption perspective, there is also a wide difference between both types of cooling centers. **Table 5** shows that the reduction of water consumption by up to 91% is enabled by immersion.

	Data Center A Air cooling	Data Center B Immersion Cooling
Daily site water usage (L)	507 300	43 750
Energy source water per year (Million L)	94.07	57
Site Water Usage per year (Million L)	185.1	15.97
Site WUE (L/kWh)	7.59	2.48

Table 5: Comparison of the water consumption of two Data Centers [18]

04 STRATEGIES AND BEST PRACTICES TO REDUCE IMPACT

The following sections give examples and recommendations of strategies and best practices to reduce the environmental impact.

4.1 WHAT THE ICT INDUSTRY CAN DO TO LIMIT EMISSIONS

There are several options to reduce or avoid emissions:

1. **Increase the amount of renewable energy used:** As part of their net-zero strategy, firms should identify how to reduce their dependence on fossil fuels and electricity produced from fossil fuels. In particular the strategy should outline clear targets to increase the use of renewable energy and reduce the consumption of other forms. Increasing renewables may be achieved by installing photovoltaic (PV) plants on the factory, warehouse, and office roofs. The installation of wind generators may be another option. Both may be a mutual safeguard against unavailability of either wind or sunlight, in particular when combined with some form of energy storage. Wind and sunlight are free of charge helping firms to lower their energy bills; protect from sudden energy price rises; and enable continued operation even during grid power outages. The important effect for the industry is that net emissions for each produced unit of network equipment or server are reduced. The benefits will be handed down the supply chain as operators are typical customers of such equipment and also their emissions will be reduced as a consequence.

2. **Reduce the number of units being produced through componentisation:** Emissions scale with the number of units produced. Simply put, a unit not produced means that the emissions normally associated with its production are not emitted. But this dilemma disarms with the success of item 1.) above: the number of units produced is much less critical if the production is climate neutral. Also, every unit produced needs resources, some of which are scarce. Nevertheless, new network technology needs still to be incorporated into the network and its capacity adjusted according to demand. This sounds on a first sight irreconcilable, but there are ways to keep flexibility and innovation, but yet reduce the production volume. Network equipment in principle can be broken down into two classes of components: those subject to rapid evolution and those less subject to changes. The former include antennas, transmit/receive modules and memory, while the latter consist of the power supply, cooling and housing. These components can be built with spare capacity and not replaced when a new technology or capacity enhancement is due. Those components subject to more rapid innovation can be grouped into line replaceable modules and just those are swapped or added when the need arises. This avoids the need to purchase a completely new unit when new technology is desired, but just a new module with a lower emission than a completely new unit. For more aspects please read [6], chapter 2.3.

3. **Avoid the use of fossil sources for plastics:** Instead carbon already on the surface of the earth should be used for which a variety of appro ches already exists or may come into existence in the near future (more details to be found in [19])

   a. **Classical recycling of waste plastic:** The waste plastic is sorted and shredded. The resulting granulate is then used to feed mould injection. Plastics are rarely a pure polymer instead additives are added to tune it for a specific application. These additives include plasticisers, UV stabilisers, pigments, flame retardants or mechanical stiffeners. For a given type of polymer some vendors offer 60-70 different formulations to be optimum for the highest potential number of different applications. This kind of recycling leaves the additives in the polymer which causes that the formulation is not optimum anymore for the new application. Some trade-offs in quality and in the degree of freedom for industrial design are thus inevitable.

b. **Use of biological precursors:** Plant material or biological waste contains carbon which by suitable chemical conversions can be turned into monomers. This can be achieved in various ways. Polylactic Acid (PLA) and Polyhydydroxy Alkanoates (PHA) can be obtained by conversion of carbohydrates or fats. There is also a more indirect way where bio waste or pyrolysis oil obtained thereof replaces the Naphthalene fraction from crude oil in chemical processes for monomer synthesis. The advantage is that polymers obtained from these processes allow the same freedom in formulation as those obtained from crude oil.

c. **ChemCycling:** This is analogous to b.) above with the difference that no biological material is used but instead the base material is obtained from waste plastic. Waste plastic can be decomposed, and monomers synthesised from the products of such decomposition. Here the same freedom of formulation as under b.) is given, yet the material is 100% recycled.

4. **The use of secondary (recycled) metals instead of primary metals:** Circular economy means closing loops. End-of-life devices are being collected and valuable materials, mostly metals, are retrieved. But recycling alone just does not make sense, there needs to be a use for those recycled materials which means that they need to go into new equipment. There are two advantages. One of those is related to sustainability and lies in the fact that usually secondary metals have lower emissions than primary ones. The second advantage is that recycled metals can often be lower cost than primary metals. 'Economy meets ecology: increasing demand drives prices. Recycling has a clear perspective to fill the demand gap and thus has the potential to control prices. Aluminium is a particular case in point. As a primary metal it is mined as Bauxite, mainly consisting of alkaline Aluminium Oxides, from which in the Bayer process Aluminium Oxide (Al_2O_3) is obtained. To understand the energy demand to make metallic Aluminium out of it, it needs to be realised that Aluminium Oxide has one of most negative enthalpies of formation (-1676kJ/mole) known. In the reverse process that energy needs to be put in to yield Aluminium. The smelting is done by melt flow electrolysis in the cryolite process (nearly at 1000°C) which consumes 17kWh of electricity per kg of Aluminium. At the counter electrode Oxygen is formed which reacts with the Graphite of the electrode to CO_2 and which is thus another emission source. Secondary Aluminium is made by collecting Aluminium scrap which is already in its metallic form and where it is thus not necessary to invest the enthalpy of formation again. Therefore, secondary Aluminium only requires 5% of the energy input of primary Aluminium.

5. **Carbon as a reducing agent for some technical processes in the supply chain can be replaced by Hydrogen obtained from renewable sources:** Oxidic ores react with Hydrogen to yield the element and just water. Water is electrolysed by electricity from renewable energy to obtain Hydrogen again - a perfectly circular process with no CO_2 emission in the operation itself.

4.2 MATERIAL AND COMPONENT SELECTION STRATEGIES

To reduce the environmental impact optimise recyclability, it is recommended to challenge the usage of various chemical elements and to leverage material selection strategies as well as to enable and leverage recycling techniques.

The following selection strategies can be applied:

1. **Improve and ramp up the substitution of harmful substances.** Equipment and its components contain harmful substances, some of which are legally regulated (e. g. RoHS - 2011/65/EU and 2015/863). There are many harmful substances which are currently not regulated. Although the potential release from completed equipment may be a minor concern (perhaps with the exception of some plasticisers) to assess the full impact requires to consider the full supply chain in a holistic manner. The raw materials are usually mined as ores or minerals from the soil. Some of these minerals are highly toxic, such as Witherite ($BaCO_3$). If not handled diligently mining can contaminate a whole swathe of land. These minerals then need to be purified and chemically processed to yield the ingredient that goes into the component. Some of the process chemicals are also harmful. During the recycling process harmful substances may be released again depending on the processes used, such as by dust escaping from shredding or by waste from acid digestion. Thus, there is a

multitude of environmental risks in the supply chain, particularly so as the environmental standards and their executionare not the same everywhere. On top, there is also a risk to corporate social responsibility if workers are not adequately protected against exposure to harmful substances. All these risks can be eliminated by not using harmful substances in the equipment in the first place. In many cases, alternatives with less harmful properties are available fulfilling the same or nearly identical physical role in the components.

2. **Reduce element diversity.** The element diversity in equipment is very large. Some of the elements are just occurring in very tiny amounts, even down to the sub-milligram range. This situation renders recovery of some of the elements difficult or makes it even uneconomic. On the other hand, some of the elements are only available from deposits in a very few countries which creates political and geo-strategic dependencies. Another supply risk may be dwindling mineable deposits world-wide. All these circumstances will impact the future price development. Secondary sources for these elements are required to fill the gap between supply and demand and to reduce supply risks.

3. **Reduce the demand of materials, that require high efforts for mining, by recycling or substitution by other elements.** Another environmental impact is that some elements contained in the equipment require high efforts for mining as their occurrence in the deposit is quite diluted (as e. g. in the case of the so-called rare earth elements) and which means that high volumes of soil need to be extracted or moved which destroys habitats not by chemical poisoning but by disturbing an extensive swathe of land. Reducing the demand by recycling or substitution by other elements will reduce this environmental impact.

   Therefore, it is strongly recommended to all companies designing or specifying equipment file a Material Composition Sheet (MCS) or do a full material declaration. The material declaration or MCS is a Bill of Material (BoM) listing the chemical composition of all components. It is grouped according to the homogeneous materials of the components and its chemical ingredients are listed. In order to allow unambiguous identification of the chemical ingredients it is advisable to list the Chemical Abstracts System (CAS) number as well which is a unique identifier.

For conflict minerals companies are obliged to report on their use and demonstrate compliance based on various regulations. Section 1502 of the Dodd-Frank Wall Street Reform and Consumer Protection Act [20] obligates U.S. publicly-traded companies to demonstrate due diligence in their supply chains and to report on their use of conflict minerals. In the EU, the Conflict Minerals Regulation [21] requires EU companies in the supply chain to ensure they import these minerals and metals from responsible and conflict-free sources only. To demonstrate compliance suppliers should have mapped their supply chain, demonstrate they have undertaken third-party assessments of smelters, refiners and downstream companies and publicly reported on their due diligence program. Third party programmes such as the Responsible Minerals Initiative (RMI) [22] provide compliance tools that enable companies to demonstrate compliance.

A route to eliminate or at least reduce harmful substances to the unavoidable minimum was already proposed in chapter 3.7.4 of the NGMN report on GFN Network Equipment Eco-Design and End to End Service Footprint [6]. Now here it is intended to share some thoughts to reduce element diversity where two examples will be picked and discussed in some detail.

1. **Capacitors:** There is a huge diversity of different capacitor types [23] with vastly different chemical compositions. For most of the many subcategories, such as ceramic or electrolytic capacitors, various alternative compositions are commercially available. Reducing the diversity of capacitor types in the equipment to the technically necessary pays into the objective of reducing the element diversity. Otherwise, a large number of different capacitor types would increase the number of elements present in just tiny amounts. The small SMT sizes in which capacitors are normally used, contain the ingredients in small milligram or even sub-milligram amounts from which it is tough to recover.

2. **Metals:** These are used for many parts. Also, here many kinds are used, which may include on a case-by-case basis stainless steel, normal steel, brass, Aluminium, Copper, Nickel Silver and even Gold. While Copper due its good specific electronic conductivity and Gold as protection against corrosion are likely irreplaceable, other metals can be more easily replaced. One way is to identify the part with

the most stringent material requirements, such as weather resistance or mechanical strength, and then to choose the best fitting material for that most demanding application and use it also for the other metal parts with lesser requirements. The advantage for a recycler is a reduced effort of sorting and a higher amount of a certain kind of metal recovered per recycled equipment as the total amount of metal in the equipment is spread over less different kinds of metal.

There are other materials and component categories inside the equipment where analogous considerations may be made.

4.3 HOW TECHNOLOGY CAN HELP TO ACCELERATE MATERIAL DISCOVERY

The ICT sector can act as an enabler of the sustainable future through enabling digitalisation and with those efficiencies in other sectors, like smart cities. At the same time the equipment powering mobile networks consumes materials including rare earth elements, harmful substances as well as materials with a high carbon footprint. As outlined in above sections companies should reduce general material usage, use materials that have low carbon and low water footprints, recycle materials, refurbish equipment, and maintain materials in the economy if possible. For most ICT network infrastructure goods, the environmental gains of refurbishing an old model must be balanced towards the increasing energy efficiency of new models. For the scenarios where harmful substances and materials with high carbon and water footprints cannot be replaced with currently available more sustainable materials, the ICT sector needs to work on discovering more sustainable materials.

The process of material design and discovery is traditionally long and complex because the space of potential chemical element combinations is incredibly vast. It takes roughly 10 years and upwards of $10-100 million on average to discover one new material with specific properties. This process needs to be speeded up and it can be through the application of technologies such as Artificial Intelligence (AI) and quantum computing. Radically accelerating the process of material discovery will enable our sustainable future.

Much of the world's ability to mitigate the effects of climate change will come down to our ability to quickly identify new materials that can be created, consumed, and recycled with minimal environmental impact [1].

Technologies like AI, data augmentation using traditional and quantum computing, generative models, and laboratory automation accessible through the open, hybrid cloud, can be leveraged to accelerate the discovery of new materials. The convergence of these computing technologies allows us to address the material discovery process in a fundamentally new way. The use of AI consolidates all of humanity's knowledge on a specific topic. Traditional and quantum simulations cover the knowledge gaps. The corresponding data can be used to create inference models to generate a hypothesis on materials and automate their making and testing, with the help of hybrid cloud technologies.

In the course of this process chemical conditions are considered. Some of the element combinations possible in theory may be unstable under certain conditions or their synthesis requires excessive conditions. Here the knowledge of theoretical chemistry is required to predict feasible element combinations and their properties. Thus, any AI solution on material discovery needs to include chemical knowledge.

AI: Researchers are more frequently relying on AI to screen novel materials and to create models to predict properties of unknown ones. AI-guided autonomous labs enable anyone, anywhere to run the chemical reactions to make a new material.

Quantum computers: Once labelled promising but distant, quantum computers are developing steadily and show potential to simulate complex molecules on the fly, accurately and rapidly predicting the outcome of chemical reactions and helping us discover entirely new classes of materials.

AI and quantum will increasingly combine with rapidly advancing, traditional high-performance classical computers as a platform for scientific discovery [24, 25].

As an example, IBM Research is applying technology like AI and quantum computing to accelerate the discovery of more environmentally preferable materials for semiconductors. The accelerated discovery cycle allows scientists to aggregate and analyse known information about photoresist chemicals and materials from patents and the public literature. The use of this knowledge drives modelling on traditional, high-performance computing systems and, in the future, on quantum computers. The combined results are used to build AI models that automatically suggest new classes of compounds that meet specific efficiency and environmental targets. The most promising of these can then be tested experimentally with robotic systems, which can synthesise these molecular candidates with little human intervention [24, 1, 25].

Like the ICT sector is enabling other sectors to create efficiencies and reducing environmental impacts, applied digital technologies can enable the ICT sector to reducing environmental impacts and becoming more sustainable.

4.4 SUSTAINABLE ANTENNA DESIGN: INCREASE LIFESPAN OF ANTENNAS IN NETWORKS, THROUGH INCLUDING NETWORK EVOLUTION FEATURES

4.4.1 KEY CHALLENGES AND POTENTIAL APPROACHES

Network evolution includes spectrum evolution (e.g., supporting the 700 MHz spectrum), RAT upgrade (e.g., LTE to NR), networking mode evolution (e.g. single-beam cells to multi-beam cells), and multiantenna evolution (e.g. 4T4R to 8T8R). Conventionally, new antennas need to be added or existing ones need to be replaced to meet new network capability requirements for spectrum and multiantenna evolution. This requires many resources and a long construction period. The capabilities of a conventional antenna are usually fixed after the design is complete and cannot be evolved throughout its service life.

Below is the general scheme of how antenna systems have been replaced across the RAN technology evolution. Within a given RAN technology period (roughly a decade), antennas have been replaced twice on average, thus leading to a waste of thousands of well performing antennas.

Expanding the lifespan of antennas is therefore a natural step towards more sustainable networks. However, there are several challenges to be addressed:

- The antenna technology is continuously evolving, which adds complexity to the coexistence of elements from different generations.
- The antenna evolution needs to align with the RAN network evolution, which in general cannot be accurately predicted beyond the short term (1-2 years).
- The benefits of the increased lifespan or future readiness must be properly justified technically and economically (the expected additional technical complexity in the antenna design may translate into higher costs).

Reusing components in the antenna industry has not been a practice so far. It is indeed quite unusual and disruptive for this industry to consider hardware reuse or upgradability for the sake of expanding the lifespan of antennas.

Within the parameters outlined above, several ideas have been considered to minimise antenna swaps in mobile networks. The extent to which MNOs may decide to adopt one or several of these alternatives depends on their specific situation and strategy. As an example, an operator with a clear long term network evolution plan including spectrum, radio configurations and features may be able to anticipate antenna investments accordingly.

On the other hand, operators with a shorter-term focus could still deploy certain antenna solutions that may still be useful in specific applications.

Some use cases are introduced in which new approaches to antenna design can help extend the lifespan of antennas on sites (either the complete antenna or certain modules remain on-site). They are expected to address:

- How to evolve FDD mid bands from 4T4R to 8T8R
- How to decouple the evolution of active and passive antennas
- How to support new frequency bands
- How to evolve from single sector to multisector configurations

4.4.2 SOFTWARE RECONFIGURATION

Digital sectorisation can be one of the approaches to software reconfiguration. It might also be an opportunity for classic FDD systems to be split between a 3 and 6-sector configurations. This would also require "Calibration readiness" for the FDD system for future radio upgrade scenarios with integrated features.

With software reconfigurable antennas, the antenna pattern properties can be modified by the RAN by selecting the appropriate weights (amplitude and phase) for the signals in the different RF ports. For example, TDD or FDD reconfigurable antennas, which have been widely deployed in many networks, may support 2T2R 12-sector, 4T4R 6-sector as well as 8T8R 3-sector configurations by simply changing the appropriate weight parameterisation in the RAN.

The beam shape and configuration of the traditional passive antenna is determined by the array design. The beam parameters of the traditional antenna are fixed and cannot be changed. For example, the horizontal beam width of a single beam antenna is fixed at 65°, and the horizontal beam width of a dual-beam antenna is fixed at 33°. If the wireless solution needs to be changed (for example, the 3-sector solution is changed to the split solution or split solution should evolve to NR with higher order MIMO supported), the antenna must be replaced.

The software reconfigurable antenna has a power sharing and calibration network. The software reconfigurable antenna beam shape is determined by the BBU's control with antenna beamforming. The BBU can accurately control the antenna waveform to flexibly change the antenna beam configuration based on the requirements of the solution. When changing the wireless solution, the antenna does not need to be replaced; although multivendor RAN-antenna interworking has already been proven, in many commercial networks, the specific weight file interpretation/handling in the RAN still remains a challenge, which can be tackled through cooperation of all involved parties or standardisation.

Power sharing between two beams can be also supported to improve the uneven distribution of UEs (i.e. users' smartphones) in the hard split solution.

4.4.3 HARDWARE RECONFIGURATION

With hardware switch capability, an antenna can change the beam form by adjusting the RF signals on feeding networks based on the coordination of feeding networks and arrays.

Traditional passive antennas are an existing example of HW-reconfigurability: Remote Electrical Tilt technology provides option to adjust the tilt of the antenna beam with adjustment of internal phase shifter state.

Similar with Software-reconfigurable antennas, hardware-reconfigurability is another option to extend the lifespan of antenna.

With HW-reconfigurable antenna, there is no dependency on BBU/RRU features used to control the state of antenna beam configuration.

Instead of this, an internal or external hardware switch is used to change the array feed network configuration (e.g., in case of evolution from 4T4R to 8T8R to change the port configuration).

4.4.4 PROMOTE SUSTAINABLE MATERIAL CHOICES

Aluminium is a material commonly used in antennas for different purposes. Aluminium can be obtained through primary (i.e., mining) or secondary (recycling) methods with significant differences in the environmental impact between them. There are also significant regional differences in the proportion of primary and secondary aluminium used in industries worldwide.

Given the impact of aluminium on the environment, it is important to streamline its utilisation in base station antennas. Reducing the amount of aluminium in the reflector and brackets can be a useful method to reduce the overall impact of the antenna in the environment. These improvements should not affect the antenna performance and characteristics so mobile networks continue to deliver a consistent experience.

Manufacturing a product both consumes a lot of resources and produces a lot of pollution. The manufacturing process will also determine how much environmental impact the product will have. For antenna manufacturing, the materials used, energy consumed, and pollution produced are the primary concerns.

Selecting materials:
Among the materials used, plastics and various PCBs hugely impact the environment. They not only generate heavy pollution, but are also of low value in recycling, and recycling or disposing of these materials also creates severe pollution. For this reason, using as few of such materials as possible or finding substitutes must be considered early in the design phase.

As recommendations, if possible, use fewer materials and as far as possible avoid surface coating and surface treatment in the antenna design as that can lower the energy and chemicals needed for the manufacturing.

Energy-efficient manufacturing:
Over their lifecycle, antennas do not consume electricity or materials while they are in service. As such, the largest amount of power consumed is during manufacturing. Optimising the energy consumption of manufacturing antennas is critical to reduce its carbon emissions throughout the antennas' lifecycle.

Reducing pollution in manufacturing: Conventional manufacturing generates wastewater, exhaust gas, and physical pollutants, which pose a tough challenge for environmental governance. Using environmentally friendly materials can reduce pollution incurred by processing. Also, the manufacturing process must be improved to reduce pollution generated during manufacturing.

Green manufacturing should focus on two objectives:
First, minimise the use of environmentally detrimental materials in products to reduce the pollution in the material manufacturing process and the environmental impact after the product's lifecycle expires. Second, use advanced, energy-saving, and clean production processes to replace traditional high-energy-consuming and high-pollution ones to reduce energy consumption and pollutant discharge.

In terms of antennas, the key to achieve these green targets lies in architecture, process, and form innovation. These three directions of innovation are closely related to each other rather than being separate. For example, product architecture design and production process support and promote each other. Both are indispensable and need to be developed together.

Reduce the Use of fiber glass, plastics and PCBs:
The complex architecture of conventional antennas requires the use of a large number of plastic products and PCBs, such as jackets and dielectric layers of cables, PCB based power splitters, PCB based phase shifter striplines, and the supports for securing these components. For example, the total weight of the plastic parts used inside a 2L4H six band antenna is more than 3 kg. Reducing the use of these plastic materials can contribute significantly to environmental protection.

Modern architectures of antenna arrays and feeding networks noticeably reduce the use of plastic products. As mentioned above, based on the highly integrated architecture, RF signals can be transmitted without cables inside antennas. The plastic in the cables is more than 60% of the total used inside antennas. Therefore, cable-free deployment inside antennas can significantly slash the amount of plastic used.

PCB manufacturing produces various kinds of pollutants, including heavy metal ions like copper and nickel, polymer organic matter, and complexing agents. However, effectively recycling waste PCBs is a challenge around the world and discarding them may create secondary pollution. As such, the antenna architecture should be innovated with the target of reducing or even eliminating the use of PCBs. Given that metal materials have a higher recycling rate, air-type striplines made of copper, aluminium, and other metals can be used instead, alleviating the impact on the environment. Note there are regional differences on the recyclability ratio for metal materials.

Radome material is traditionally made of fiberglass – a material which is not recyclable - therefore new material level recyclable materials - e.g. GFRPP (glass fibre reinforced polypropylene) or HIP (high impact polystrene) etc. should be preferred.

Process Sustainability:
Conventional antenna production consumes a lot of power and can easily produce pollution, especially during the electroplating and soldering processes.

In addition to its high-power consumption, electroplating generates a lot of pollution, like water, air, and solid waste pollution. Among these types of pollution, water pollution (mainly containing heavy metal ions, cyanide, acid base, and organic pollutants), air pollution (mainly containing various acid mist and dust), and sludge pollution (mainly containing heavy metals and cyanide) from electroplating wastewater are major environmental problems.

During the production of antennas, soldering generates smoke pollution, which mainly contains heavy metals such as tin and lead, in addition to other harmful substances such as rosin and acid dust. Worse yet, the current soldering process in antenna production mainly involves soldering iron and is a labour-intensive, manual process, resulting in low production efficiency. For these reasons, the innovation objectives of antenna manufacturing process should focus on the elimination of electroplating and soldering, as well as the reduction of power consumption and manual labour.

It should be noted that process upgrade and architecture design innovation are complementary. A new process can be implemented only with a proper architecture and materials design, while new processes are also a necessary condition for implementing a highly integrated architecture.

Process innovation is a complex, integrated action, not just the behaviour of a single enterprise. It requires product design innovation, upgrade of manufacturing equipment, personnel training, and, more importantly, cultivation and investment in the industry chain to achieve end-to-end technology upgrade.

4.4.5 MODULAR DESIGN & PHYSICAL REPLACEMENT

Typically, antennas consist of a shroud, a mounting kit, and a radiating part. The radiating part (dipoles, reflector plane, phase shifters, distribution network, connectors...) must follow the network evolution and is therefore subject to regular replacements. Since an antenna is usually built around one single monolithic RF block, the whole antenna needs to be replaced. Thus, to avoid the full antenna swap and scrap, the idea of a modular design can be twofold:

- Enable the addition of new arrays inside existing antennas when new frequency bands are required.
- Refurbish the swapped parts.

Considering that multiband antennas often embed interleaved arrays, including active and passive with 5G, it can be tricky to replace and add new arrays. This is where a modular approach of the design can help.

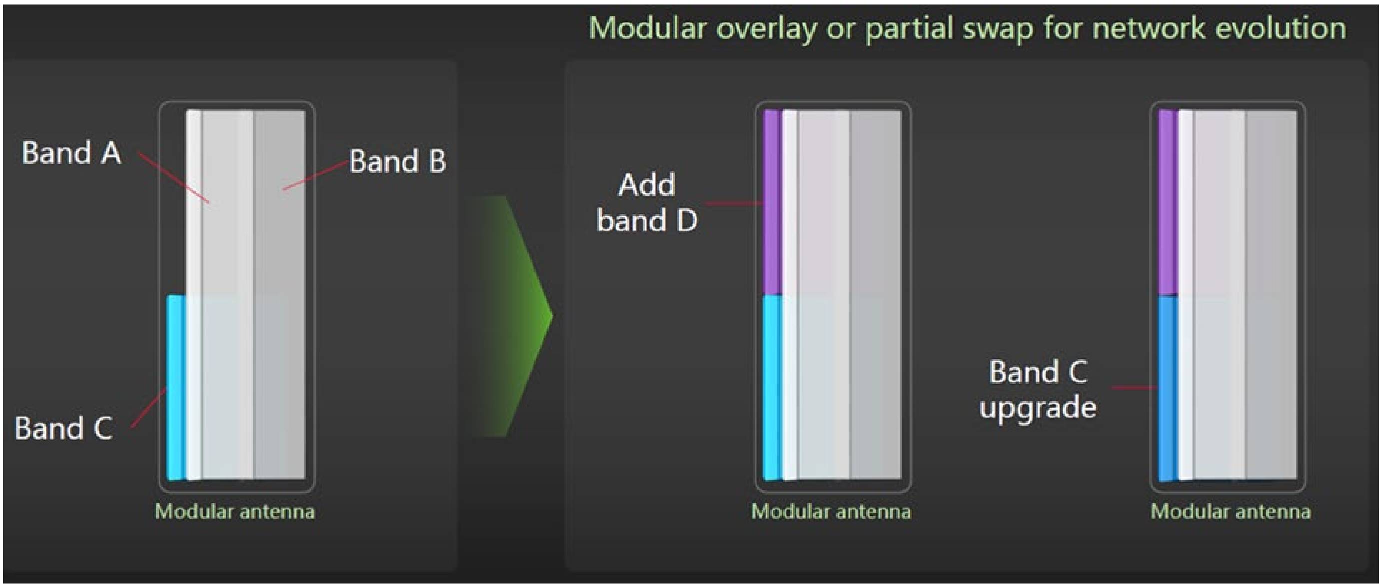

Figure 4.1: Modular overlay or partial swap for network evolution

Addition of new arrays - the concept:
Hereunder is a description of a possible approach. From the beginning, the antenna consists of several modules that can be replaced for network evolution.

In this example, the middle and right modules (Band A and B) are still needed with adding Band C and D and these modules can be kept in the field.

Here is another example of antenna upgrade (R1, R2, Y1, Y2, Y3 refer to antenna arrays. The antenna on the left is a quad-band antenna whilst the antenna on the right is a penta-band antenna):

This scenario can apply for adding a new band (1400 MHz in this instance), whereas the left and right modules are still needed.

The ability to perform this upgrade on site can simplify the logistics but would require cautious operation by the installers. The modules would be Field Replaceable Units, like the boards of radio cabinets. A minimum checking of the essential parameters of the reconfigured antenna would be desirable (e.g. S-parameters - those parameters relating to the scattering matrix). Alternatively, the antenna to upgrade could be sent to local upgrade centres.

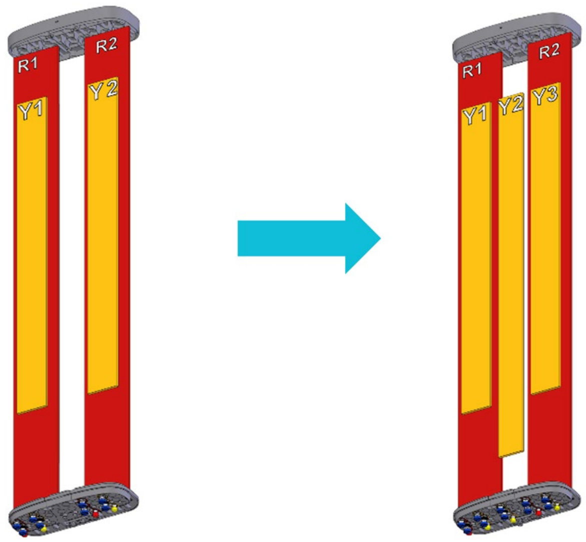

Figure 4.2: Upgrade from quad to penta-band antenna

Refurbish the swapped parts in upgrade centres:
When removing the modules from already installed antennas, a key question pops up: scrap or reuse? Indeed, refurbishing the modules is also possible. Here is a logistical flow for antenna upgrade and refurbishment:

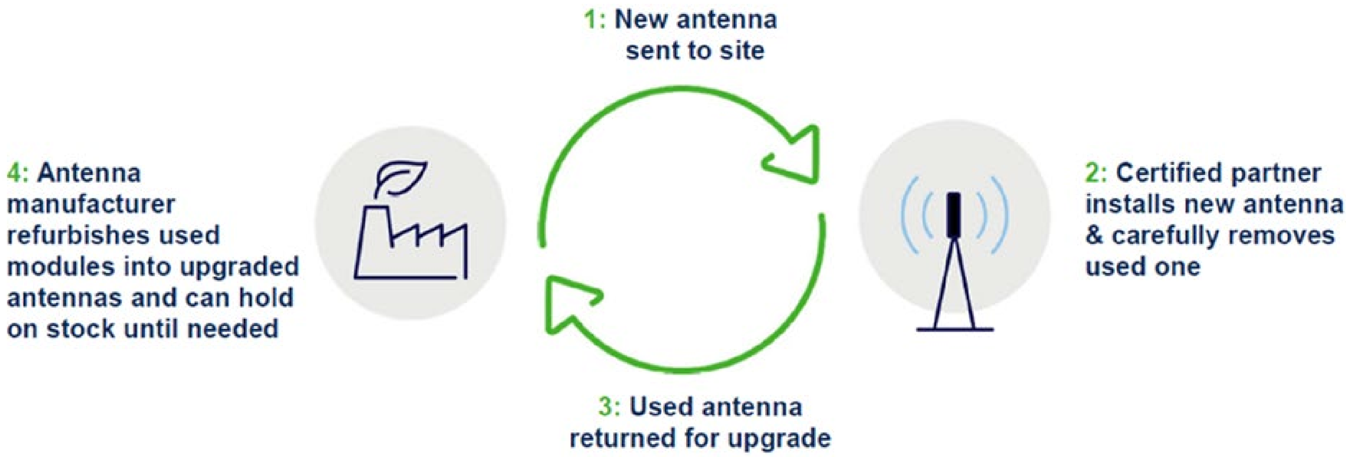

Figure 4.3: Antenna refurbishment process

A new antenna is installed while dismantling the one to replace, so that only one site visit is required. Then, the dismantled antenna is shipped to an upgrade centre where modules can be replaced to match the new antenna configurations in line with the new rollout strategy. The allocation of the modules for new antenna configurations ensures a longer lifespan, the modules having a second life once refurbished.

The above concept of modules and upgrade assumes that the carbon footprint benefit of reusing the hardware to avoid the manufacturing of brand-new parts is not penalised by transportation back and forth to the upgrade centres. This means that the upgrade centres must be located close to the operators' networks. Local facilities are required. It should also be checked with Lifecyle Analysis (LCA) if the overall environmental impact will increase, e.g. whether the refurbished antenna is less efficient than a completely new one.

Evolution axis:
The granularity of the modules can be increased to offer even more flexibility of reconfiguration. An enhanced granularity of the modules would also contribute to increase the ability to repair faulty antennas.

Another aspect of the antenna swap is the mounting hardware. Standardising the mounting hardware across the vendors (like for mobile phone chargers after EU regulation) would enable the reuse of the existing mount while changing the antenna of vendor A by vendor B. As of today, the mounting hardware is scrapped together with the swapped antenna.

4.4.6 DECOUPLING ACTIVE AND PASSIVE

The deployment of 5G networks has been a significant civil engineering challenge for mobile operators, especially in urban sites where M-MIMO radios are the preferred solution. Adding new site infrastructure or upgrading the existing one to accommodate the active antennas (i.e. adding or reinforcing existing poles or steel structures) is a costly and time consuming exercise and not always possible. Site sharing restrictions and potential increased rental fees may leave the mobile operator with limited options other than sacrificing the size of the existing passive antenna(s) and hence compromising the network performance.

To address these challenges, antenna vendors have developed new technologies and platforms, which enable active and passive antennas to share the available space at the tower top while maintaining or improving the network performance.

The first generation of these products relies on a tight integration between the active and passive elements, interleaving arrays in low (700/800/900MHz) and mid bands (i.e. 3.5GHz) into a common module. In general, these active and passive antennas form a single entity that cannot be disaggregated (i.e., either one or both cannot operate as stand-alone units).

The second generation of these products relies on a different architecture, where the passive and active antennas remain two distinct units that can operate independently. The passive antenna is designed with some unique RF properties so that the active antenna can be placed behind the passive antenna without any major impact on the overall performance. With this approach, the evolution and lifespan of the active and passive antennas are decoupled. Active and passive antennas from two different vendors can coexist and be upgraded independently and the performance of the passive antenna remains independent from the active one. This approach may benefit from a standardised methodology for the solution characterisation as well as cooperation from different vendors and/or 3rd party integrator party.

This approach can be particularly useful to protect investments in potential RAN vendor swaps as well as to enable a smooth introduction of Open RAN architectures into existing networks. Since the active and passive antennas are two separate entities, the active one can be swapped without having to replace the passive antenna offering a longer lifespan for the passive antenna.

4.5 WATER MANAGEMENT STRATEGY AND BEST PRACTICES TO IMPROVE WATER FOOTPRINTS

Section 3.2 highlighted what needs to be considered to report the ICT water footprint in terms of water consumption as well as water disposal qualities – temperature and pollution. Responsible water management and measures to improve the water footprint of the ICT sector are critical to reducing environmental impact. Climate change is intensifying water shortage. Besides reducing the carbon footprint, the water footprint of the ICT sector needs to be reduced as well.

Preserving water resources and safeguarding watersheds are important priorities. A responsible water management strategy should include both an internal and external focus: reducing the amount of freshwater used within a company's operations and buildings, as well as supporting efforts to solve local water challenges by partnering with local governments, non-profit organisations, and other community stakeholders. Many organisations are approaching this by setting "context-based" water stewardship targets, such as "net positive water" or "water neutral" goals [26, 27]. These types of goals include minimising a company's overall freshwater use while understanding and contributing to watershed improvements [26, 27, 28]. An example of how this type of goal can be implemented is Intel Corporation's goal to reach net positive water by 2030. Intel is achieving this goal through significant on-site water conservation investments, partnerships with local governments, and funding of watershed restoration projects [29, 30].

Figure 3 shows this example's (Intel's) progress toward its net positive goal, which has achieved 99% (by volume) of fresh water treated and returned to communities or the environment and restored through watershed projects [29].

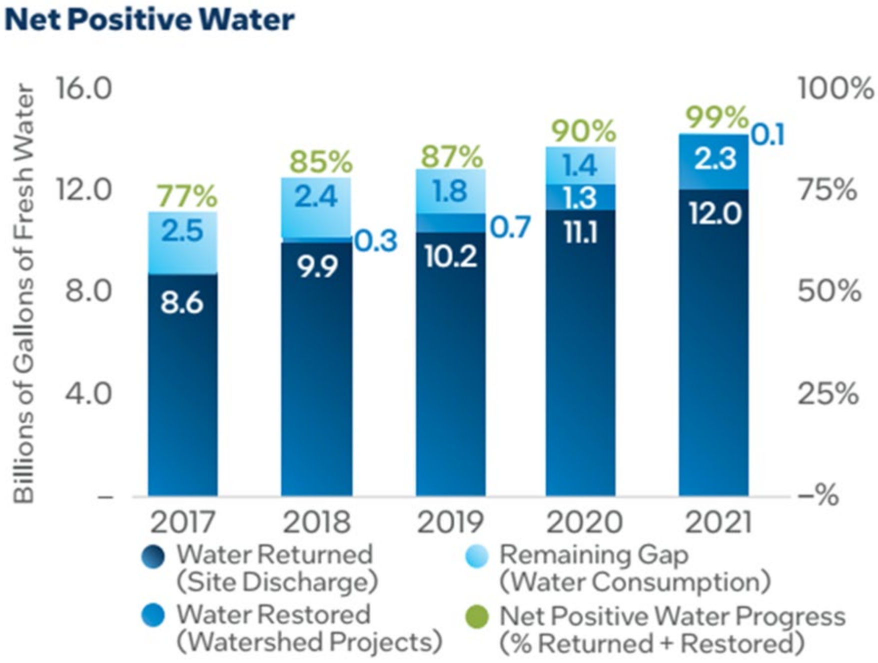

Figure 4.4: Net Positive Water (source: Intel)

Examples of water withdrawal reduction measures are: reusing or recycling water for landscape irrigation and to supplement makeup water used in cooling tower systems, installing automatic irrigation systems and decreasing overall landscape irrigation, upgrading cooling tower equipment and water storage tanks, upgrading to reverse osmosis deionised water systems to allow for reuse of reject water, ongoing maintenance of water pipes or raising awareness of the importance of efficient use of water and conservation during new employee onboarding [31].

Water conservation measures are especially critical in relation to data centre cooling. Many hyperscale data centres are located in the regions where abundant supply of carbon-free solar and wind energy are available. However, these regions also are likely to be water starved. Therefore, water consumption is a major concern for the data centre operators.

Data centres are cooled typically with water, or refrigerant, or evaporative cooling by evaporating water to cool the air. Water evaporating uses less energy at the expense of using more water. Given that in most cases, water is cheaper than electricity, data centres tend to choose the more water-intensive approach.

Water usage dependency can be reduced with the use of immersion cooling – whereby servers are submerged in a thermally conductive dielectric liquid. It further contributes to saving of water from the indirect water savings related to the generation of electricity (to power, for example, air conditioning) and as well as directly reducing the water use and requirements at the data centre.

Facilities that need to reduce water use further can retrofit to air-cooled chilling, such as compressor and condenser systems like CRAC (Computer Room Air Conditioning) units or centralised air-cooled chillers with an integrated compressor and condenser. With this technology, there is no evaporative cooling, no blowdown, no new water usage, and no release into the sewer system. Of course, the most efficient method is to design the data centre with waterless cooling from the beginning, which allows the whole cooling system to be balanced for air-cooled chilling rather than a retrofit. Moving forward, data centres should create water-free cooling and work with suppliers to optimise for air-cooled chilling.

When designing data centres for a sustainable future, the goal should be near-zero water consumption. While small amounts of water may still be used for humidification, facility maintenance, and sinks and toilets, these uses account for a fraction of the water consumed by water towers and evaporative cooling.

4.6 CARBON OFFSETTING AND THE CORPORATE PATH TO NET ZERO

4.6.1 HOW TO NAVIGATE OFFSETTING

While reducing the carbon footprint always comes first and has the highest priority in every strategy on the path to net-zero, it is obvious that every corporate has to deal with the CO_2 emissions that are impossible to abate. Enter offsetting! While offsetting often has a negative connotation because it is seen as an "easy way out" for companies to hide from their environmental responsibilities, it is worth taking a closer look at what offsetting does and does not enable, and why it is important for companies to start looking at offsetting now, even if reaching their climate targets is still years away. Corporates have to plan early on how to actually realise their respective net-zero targets or they risk of not reaching them at all. It should also be noted that by offsetting we do not refer to compensating the emission of CO_2 by some "good deed" as it was done in the past. If we want to be serious about reaching the 1.5. degree goal, we must take what we have emitted out of the atmosphere elsewhere at the same rate. In other words, offsetting means neutralisation of emitted CO_2 and ideally, the CO_2 should be removed permanently. In addition, measures should be exclusively dedicated to the emissions that are targeted to be removed.

Carbon-capture options are scarce. So far, carbon removal from the atmosphere has been limited mainly to natural solutions such as reforestation, wetland restoration, and the natural function of our oceans, which sequester about 1/3 of all CO_2 . While Earth's natural processes have worked perfectly in the past to capture enough CO_2 , the equilibrium has long been broken, thanks to broad industrialisation. Biological carbon removal at the current scale is merely a drop in the bucket and will not help us to reach the necessary climate goals. The Earth needs solutions that are able to remove CO_2 at scale and we need them fast. The IPCC report estimates that we will have to remove approx. 10-15 giga tonnes of CO_2 annually from 2030 onwards, to not go beyond the 1.5 degree-limit that might save the Earth from the worst effects of climate change [32]. On our current trajectory, however, we will most likely miss out on meeting this huge demand. Thankfully, more and more bright minds have put their genius to work and have developed impressive solutions that tackle carbon removal (and storage as well as use) at a large scale, but most of them are early stage in terms of their development and commercialisation. This is where corporates can play an important role to not only meet their own respective climate targets but also help by supporting different efforts to capture and store CO_2 permanently from the atmosphere and store it underground or develop new uses to be able to reuse it.

Corporates have to prepare for offsetting. Increasing demand and a shortage of supply could lead to steep price curves. The lack of regulation and unified standards in the voluntary carbon market cause reputational risk that relates to offsetting (green washing).

The best way to navigate through these uncertainties is to prepare and commit early. Mid- and long-term commitments can incentivise start-ups to scale faster. For some corporates, it might be interesting to invest into its own dedicated project which might offer a secure amount of carbon credits at a stable price. This, however, comes with huge up-front investments that not every CFO is willing to commit to.

Whatever path a corporate is planning to take, and no matter whether climate targets will be met in 2030, 2040 or 2050, the journey should start now. These are also new challenges for boards who will need to develop and invest in a net-zero carbon strategy ensuring sufficient management oversight to ensure goals are met on time and within budget.

4.6.2 CASE STUDIES ON NET ZERO PATHS

Below various case studies give examples for best practices to act on net zero targets and neutralise emitted emissions.

Ericsson:
Ericsson has a long-term ambition to become Net Zero across its value chain by 2040. The first major milestone will be to cut emissions by 50% in the supply chain and portfolio in use until 2030, and to become Net Zero in their own activities at the same time. The commitment to be Net Zero across the value chain is in accordance with the ITU Net Zero standard[1] which means that emissions must be **reduced** in line with the 1.5°C ambition. This ambition requires halving emissions by 2030 and reaching Net Zero before 2050. Only emissions that are not technically possible to be reduced can be neutralized or removed with carbon offsetting. Such removals must also consider the origin of the emissions to ensure that removals follow the "like for like" principle. This means that there is a difference when removing carbon emissions of fossil origin and emissions from biogenic sources, such as biofuels.

In line with Ericsson's climate strategy, it is most likely that the remaining emissions, not possible to reduce, will be of fossil origin. To be able to remove these, the negative emissions must emerge from carbon removal projects that store carbon permanently, such as Direct Air Carbon Capture and Storage or Bio Energy Carbon Capture and Storage. Ericsson is starting to screen for potential investments in projects developing future Bio Energy Carbon Capture and Storage capacity, in order to enable future removals in line with their Net Zero ambition.

HPE:
Overview: HPE has an overall goal of achieving "net zero" greenhouse gas emissions across the value chain by year 2040. Serving that goal, HPE has set a science-based target to reduce Scope 1 and 2 emissions 70% by 2030 from a 2020 baseline. After exceeding our previous operational emissions target (achieving a 62% reduction from 2016 to 2020), we are already progressing toward our ambitious new target with an additional 16% year-over-year reduction in 2021.

HPE has defined a hierarchy of actions and investments to achieve these targets. We prioritise energy efficiency improvements and renewable energy, purchasing carbon offsets as a last approach. As of 2021, we have no carbon offsets in our energy portfolio. Our operational emissions mitigation strategies include:

- Improving transportation logistics
- Adopting electric vehicles
- Transitioning to renewable energy
- Improving building energy efficiency, acquiring at least Silver Leadership in Energy and Environmental Design (LEED) certification [33] for new builds or interior designs in Europe and Asia Pacific and Japan, and leasing green buildings where available

Improving Transportation Logistics: HPE has reduced emissions related to transportation and distribution by 20% over the last five years; however, in 2021, transportation-related emissions increased by 9.1% year-over-year. This can be attributed to the increased reliance on airfreight as the ocean logistic channels remain impacted worldwide. Throughout the pandemic, freight has continued to move with minimal disruption. It has been challenging, however, due to an approximate 50% reduction in passenger flights (a primary transport mode), global container shortages, and port congestions for the ocean industry. We have mitigated these risks by exploring various alternatives such as diversion to other ports that are fully operational, modal shifts to rail, and charter aircraft use as necessary.

Adopting Electric Vehicles: We regularly replace company vehicles to update our fleet with better fuel-efficiency and engines, including implementing hybrid and electric vehicles (EV) as choice options in mature EV-infrastructure markets. In 2021, we began integrating both fully electric and plug-in electric hybrid vehicles into our corporate fleet of more than 7,000 vehicles in 31 countries. Our goal is to transition the majority of our fleet to either EVs or plug-in hybrid electric vehicles (PHEV) by 2030 in markets where the infrastructure is mature, proven technology exists, and it is economically feasible. In addition, we will pursue other ultra-low emission solutions where EVs and PHEVs are not a viable option. Successes in our auto fleet transformation program will reduce our overall carbon footprint and optimise our total cost of ownership.

Transitioning to Renewable Energy: We have made it a priority to transition to clean energy alternatives, taking a hybrid approach that includes owned renewable assets, on-site and of-site power purchase agreements (PPAs), green tariff programs, green contracts and bundled and unbundled renewable energy certificates (RECs). In 2021, we signed a deal to build an on-site cogeneration plant in Aguadilla, Puerto Rico, which came online in spring 2022. Powered by renewable liquefied natural gas (RLNG), the plant is over 50% more efficient than using grid power and will be 100% renewable due to its bio-based feedstock.

IBM:

By 2030, **IBM** wants to achieve net zero greenhouse gas emissions (GHG) without purchasing nature-based carbon offsets to claim any reduction of IBM's emissions. IBM directs its resources toward achieving energy conservation and purchasing renewable electricity that it actually consumes – actions that avoid or reduce GHG emissions, versus merely offsetting them. IBM does not count the purchase of unbundled Renewable Energy Certificates to comprise any percent renewable if IBM cannot credibly consume the electricity those certificates represent. IBM's net zero GHG emissions goal covers Scope 1 and Scope 2 emissions, as well as Scope 3 emissions associated with IBM's electricity consumption at co-location data centers [31].

IBM anticipates relying on new carbon removal solutions such as direct air capture to meet the net zero GHG emissions goal and supports their development with research to accelerate the discovery of enabling materials [31].

In 2020, IBM Research launched a global initiative called the Future of Climate to accelerate the discovery of solutions to address climate change. Leveraging hybrid cloud and AI, researchers across IBM's labs worldwide are developing and demonstrating innovations including accelerated materials discovery for carbon capture. The initiative emphasises the use of deep search, quantum computer-based simulation, generative machine learning models, and cloud-based autonomous labs like RoboRXN to accelerate the discovery of new materials, like complex polymers and materials for carbon CO_2 capture and separation [34]. IBM RoboRXN is a cloud-based AI-driven robotic lab that efficiently automates most of the initial groundwork in materials synthesis, making it possible for scientists to synthesise materials remotely [35]. Invisible and difficult to capture, CO_2 is a great challenge in tackling climate change. Capturing it at the point of origin is thought to be one of the most effective ways to limit its release into the environment. IBM researchers identified several hundred molecular structures that could enable more efficient and cheaper alternatives to existing separation membranes for capturing CO_2 emitted in industrial processes. Researchers are now evaluating these candidate molecules [25].

05 CONCLUSION AND RECOMMENDATIONS

Identifying and assessing environmental impacts, enables companies to make informed decisions and act on their sustainability goals by implementing measures to reduce their impact. This report offers various best practices and examples of how to reduce the environmental impact of mobile networks.

In summary our recommendations are:

- **Implement Component & Material Selection Strategies**
  - **Establish a harmful substance management for all components:** For this purpose, sub-suppliers should reveal the chemical composition of all candidate components. This should be followed by a review whether harmful substances (substances with any chapter 3 or 4 GHS hazard statement) are contained therein. Wherever possible, alternatives with no or the least number of harmful substances should be chosen.
  - Plastics constitute for many types of equipment a substantial portion of the total weight. A strategy should be devised to avoid plastics from fossil sources. Considerations may include recycled (post-consumer or post-industry) plastics, plastics made from biological (renewable) precursors or plastics made from chem-cycled precursors (monomers are obtained by chemical decomposition of plastic waste).
  - Reduce element diversity in equipment.
  - File a Material Composition Sheet (MCS) or do a full material declaration.
  - Substitute metals obtained from primary sources by those from secondary sources as the latter have usually a better eco-balance.
  - Enable sustainable material choices for companies at the start of supply chains via promoting sustainable material choices as 'buyer'.
  - Information on materials as well as collaboration and information sharing across the value chain enables the transition to a circular economy to minimise the footprint of mobile networks.
  - Leverage technologies like AI, data augmentation using traditional and quantum computing, generative models, and laboratory automation accessible through the open, hybrid cloud, to accelerate the discovery of new, more environmentally preferable materials.
- **Reduce the water footprint**
  - A company's water footprint assessment should include calculation of direct water use, indirect water use for electricity generation, and indirect water use for ICT equipment manufacturing based on Life Cycle Assessment (LCA).
  - Responsible water management strategy should include both an internal and external focus: reducing the amount of freshwater used within a company's operations and buildings, as well as supporting efforts to solve local water challenges by partnering with local governments, non-profit organisations and other community stakeholders (e.g. funding of watershed restoration projects).
  - Leverage Immersion cooling to reduce water usage dependency. Moving forward, data centres should create water-free cooling and work with suppliers to optimise for air-cooled chilling. When designing data centres for a sustainable future, the goal should be near-zero water consumption.
- **Reduce CO_2 emissions**
  - Reduce emissions, offset residual emissions with a like-for-like approach. Prepare and commit early to carbon offsetting, make mid- and long-term commitments and invest into dedicated projects that neutralise emitted emissions.

06 ABBREVIATIONS

CED	primary / cumulative energy demand
E&M	Entertainment and Media
GFN	Green Future Networks
GHG	Greenhouse Gases
GWP100	Global Warming Potential averaged over 100 years
ICT	Information and Communications Technologies
IT	Information Technology
KPIs	Key Performance Indicators
LCA	Life Cycle Assessment
LA	Lead Acid
Li	Lithium
MNOs	Mobile Network Operators
OEM	Original Equipment Manufacturer
PV	photovoltaic
WUE	Water Usage Effectiveness
3PL	Third party logistics

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08 APPENDIX A – MATERIALS CUMULATIVE ENERGY DEMAND

Table 1: Ranking of elements from an upstream energy use per mass perspective [7].

Element	Cumulative Energy Demand
Au	1
Ge	2
Ag	3
In	4
Mg	5
Cr	6
Sn	7
Al	8
P	9
Ni	10
Sb	11
Cu	12
Zn	13
Mn	14
Bi	15
B	16
Pb	17
Cd	18
S	19
O	20
Ga	21
Si	22

09 APPENDIX B – WATER FOOTPRINT CALCULATION

9.1 WATER FOOTPRINT CALCULATION OF DIRECT WATER USE

One example of direct WF is presented in the following:

WF of Photovoltaic panels cleaning
Although the solar Photovoltaic (PV) technology use no water to generate power; still the maintenance of solar panels consumes a significant amount of water. Water consumption for cleaning panels depends on the location, type of solar module, technology used and manpower's efficiency.

In fact, there are three basic steps in cleaning PV panels: Soaking/cleaning, scrubbing and rinsing. The direct WF appears in the soaking and rinsing steps. When special cleaning equipment is employed, water can also be consumed in the scrubbing step.

In a comparison context, two types of water spread are considered: the water is either cast (thrown from large plastic cups/pails and/or hosed) or sprayed onto the surface of the protective glass in the soaking and rinsing steps. For example, in a water consumption test done in India [36], when both soaking and rinse water were sprayed on to the panel, only 230 mL of water/SPW (Solar Panel Wash™) mixture was used. This translates to more than 40 times more water consumed when panels are cleaned with water alone. These comparison tests measured the amount of water used in the soaking and rinsing steps using only water versus those same steps using an Water/SPW mix in a 25:1 ratio.

Water only	Water/SPW mix
10	0,230

Table 1: Water consumption in PV panel cleaning in L/Panel in India [36].

Another article [37] states that in Europe Cadmium telluride (CdTe) PV modules was estimated at 20 L/m2 over the lifetime of 30 years and modelled with the region-specific life cycle inventory of tap water supply in Europe.

9.2 WATER FOOTPRINT CALCULATION OF INDIRECT WATER USE FOR ELECTRICITY GENERATION

The Water Consumption of Electricity Production (WCEP) is mainly based on water consumption factors (L/kWh) of the technologies used in energy production [12].
The WCEP is calculated as follows:

$$WCEP\ (L) = Energy\ Production\ (kWh) * Water\ Consumption\ Faktor\ (L/kWh) \qquad (1)$$

where,

$$Water\ Consumption\ Factor\ (L/kWh) = \sum_i WCF_i\ (L/kEh) * National\ Electrical\ Mix_i\ (\%) \qquad (2)$$

i: Electricity generating technology
WCF_i: Water consumption factor of technology i

By analogy with the Carbon Footprint, the energy mix at a country-by-country level can be used for water consumption factor calculation. Table 3 shows an example of water consumption factors by electricity generation technology in France.

	Biogas	Biomass	Coal Gases	Hard Coal	Heavy Fuel Oil	Hydro
WCFi (L/kwh) [38]	1,55	2,64	2,15	1,7	0,49	12,64
National Electrical Mixi (%) [38]	0,3	0,3	0,4	1,7	0,3	12,3

	Natural Gas	Nuclear	Photo-voltaic	Waste	Wind
WCFi (L/kwh) [38]	0,6	2,42	0	6,43	0
National Electrical Mixi (%) [38]	2,3	77,6	1,1	0,7	3,1

Table 3: Detailed calculation of the water consumption factor in France.

Please notice that solar PV and wind do not use water to generate power; their water use factors are zero. The same calculation methodology is applied to all the countries. Table 4 shows some examples of water consumption factors calculated for different European countries.

	France	Spain	Poland	Slovakia	Belgium
Water Consumption Factor based on Energy Mix (L/kWh)	3,54	5,96	1,70	2,90	1,56

Table 4: Examples of water consumption factors.

9.3 WATER FOOTPRINT CALCULATION OF INDIRECT WATER USE FOR ICT EQUIPMENT MANUFACTURING BASED ON LIFE CYCLE ASSESSMENT (LCA)

An LCA [39] is a tool that can help to better understand environmental impacts of products and services throughout their lifespan **(Figure 2)**– from raw material extraction, manufacture, transportation, distribution and use to end-of-life disposal, recycling or reuse.

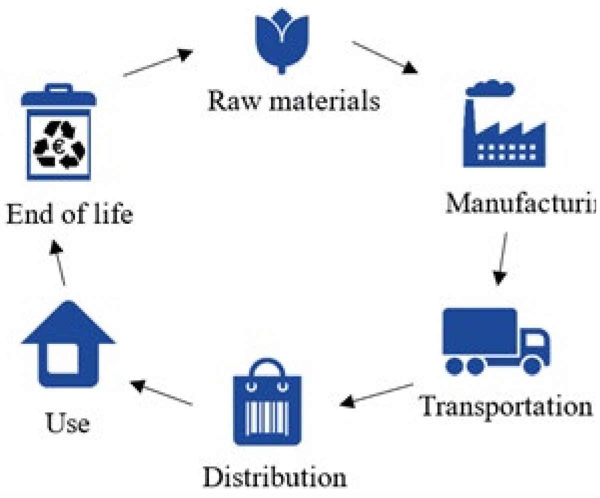

Figure 9.1: The life cycle of a product/service.

Approximations of life cycle water footprint, through tools such as LCA, can help ICT companies identify where the greatest amounts of water may be consumed during the life cycle of a typical process, general product, or service. Therefore, this enables a business to make informed choices on how to reduce its impact most effectively on the environment, and to mitigate any risks posed to their value chain by climate change. Further to this, LCA can be a valuable tool to stimulate innovation by supporting sustainable choices on product design, development and manufacture.

In the following sections, we will be particularly focusing on the LCA of a product to determine its water footprint in an ICT company.

9.3.1 THE WATER FOOTPRINT OF PRODUCT MANUFACTURING

The WF of product manufacturing is the water consumption during the extraction, production, and transport of raw materials, the manufacture and transport of product's components assembly.

The Water Footprint of raw material production
In this section, the raw material production is considered, including all activities such as harvesting, mining, lumbering, etc. To this end, the water footprint of each material needs to be considered as a function of the amount of material used in the final product. In what follows some figures are presented for glass and plastic production. Please notice that the water footprint of many other material used in ICT equipment are missing.

- **Glass production**

As shown in Table 8, the blue WF_{energy} of soda-lime float glass due to energy consumption is 2,6 L/kg. In addition, an electrical boost of 10% increases the WF up to 4 L/kg.
The grey WF is determined by the effluent of the Solvay process. Suspended solids reported by ecoinvent for the Solvay process result in a grey water footprint of **1300 L/kg of glass**. Heavy metals in the effluent come from the raw materials used in the Solvay process and from the fuel source which are cokes.

<table>
<tr><th></th><th>Blue WF of float glass production (L/Kg)</th><th colspan="4">Energy related blue WF of float glass (L/Kg)</th><th>Grey WF of float glass (L/Kg)</th></tr>
<tr><td rowspan="3">Glass[40]</td><td rowspan="3">3,2</td><td colspan="4">Fuel composition</td><td rowspan="3">1300</td></tr>
<tr><td>58% natural gas, 38% heavy fuel oil and 5% electrical power</td><td>Heavy fuel oil + 10% electric boost for melting</td><td>100% natural gas for melting</td><td>100% heavy fuel oil for melting</td></tr>
<tr><td>2,6</td><td>4</td><td>0,41</td><td>0,71</td></tr>
</table>

Table 8: Blue and grey water footprints of glass production for electronics.

- **Plastic production**

Acrylonitrile butadiene styrene [41], or **ABS plastic**, is one of the most common types of plastic used in electronics. On the other hand, for higher durability, **Polycarbonate** [42] enclosures are the apex of Polycase's high-performance electronic enclosure offerings. The WF of the production of these materials are respectively 150 L/Kg and 142 L/Kg.

- **Critical Raw Materials' (CRMs) production for servers**

Based on a case study of a Dutch Telecommunications company [43], CRMs data were gathered from their suppliers via internal interviews to understand the role of servers in telecom and ICT business. However, only CRMs that are with high mass content were considered in their WF calculations as shown in **Table 10**.

CRM	Substance	Use within the sub-assembly	Water consumption
CRMs contained in the motherboard of a rack server			
Ba	$BaTiO_3$	Multilayer capacitors	To produce 10 g of barium titanate, we need 0,0476 to 0,11 L of oxygenated water and 0,286 L of deionised water [44]
Bo	B_2O_3	Passive component glass/ceramics	No significant water consumption [45]
Si	Si_2O_3	Capacitors and resistors; diodes, transistors, crystals, Integrated circuits	No significant water consumption
CRMs contained in the HDD* of a rack server			
Dy	-	Base Motor Assembly, VCM Assembly, Magnet Circuit, Magnet Raw Material	No significant water consumption [46]
Nd	-	Base Motor Assembly, VCM Assembly, Magnet Circuit, Magnet Raw Material	No significant water consumption [47]

Table 10: The Water Footprint of the CRM's production for servers.

The Water Footprint of ICT equipment production

- **Smartphone production**

The raw materials in a smartphone include minerals such as lithium, tantalum and cobalt and rare metals such as platinum all contribute to a heavy footprint for such a small product – with the overall footprint of a generic smartphone estimated to be **12,770L** of water.   shows the distribution of water footprint according to its three components: blue, green and grey WF [48].

Manufacturing process step	Blue WF	Green WF	Grey WF
Raw materials including Mining and packaging	35%	100%	11%
Computer and electronic product manufacturing	6%	-	22%
Final manufacturing and assembly	18%	-	63%
Power generation	7%	-	-
Chemical manufacturing	11%	-	-
Metal manufacturing	19%	-	-
Other	4%	-	4%
Total (100%)	**1,460 L**	**3,720 L**	**7,590 L**

Table 11: Volumes and distribution of blue, green and grey water in the supply chain of a generic smartphone.

Analysis of the water footprint showed that manufacturing of the components and assembly account for the largest sector of overall water use (40%) with grey water, used to dilute pollutants, accounting for almost all (95%) of this. This can be attributed to the chemicals in the glues and lubricants used in the manufacturing of the component parts, stretching back through the supply chain

9.3.2 THE WATER FOOTPRINT OF PRODUCT TRANSPORTATION

Car transportation

In what follows, the water consumption levels are presented for internal combustion vehicles (ICVs), plug-in hybrid electric vehicles (PHEVs), and battery electric vehicles (BEVs). Several studies have shown that the vehicle operation phase is responsible for the highest energy consumption (76%-85% of the total life cycle energy consumption). That is why we present the WF analysis of the vehicle operation phase.

- Conventional vehicles (ICVs and HEVs)

For conventional vehicles transportation of a given number of units, the following formula [49] can be applied to calculate the WF:

$$WF\ of\ car\ transportation\ (L/unit) = \frac{\frac{Distance\ (Km)}{Fuel\ Consumption\ (Km/L)} * Energy\ density (GJ/L) * 0{,}0036 * Water\ factor\ of crude\ oil\ (L/GJ)}{Number\ of\ smartphones\ picked\ (units)}$$

Constant Factor	Value	Variable Factor	Example Value
Water factor of crude oil (L/GJ) [50]	1060	Fuel Consumption (Km/L)	10
Energy density (Diesel) (kWh/L) [51]	9,8	Distance (Km)	50 (one way)
-	-	Number of smart-phones picked-up (units)	90

Table 14: Data for car transportation WF calculation.

- **Battery Electric Vehicles (BEVs)**

The electricity consumption rate of BEVs is of 0.186 kWh per kilometre, calculated as a function of the fuel economy, as presented for a case study performed in the United States [52]. As a function of the distance travelled the energy used can be estimated and then WF can be calculated as a function of the electricity mix of the region where the vehicle has been charged as explained above.

Whereas, to calculate the WFBEV impacts by BEVs, we must multiply the fuel economy of electric mode by the impact factor electricity supply.

$$WF_{BEV} = (1/FE) * WCEP$$

Where FE is the fuel economy of BEV (km/kWh).

- **Plug-in Hybrid Electric Vehicle (PHEVs)**

Since PHEVs use gasoline and electricity, their total impacts are the accumulation of impacts from both of these fuel supply sources. Therefore, the formula has two parts, the first part representing electric mode impacts and the second part representing gasoline mode impacts.

$$WF_{PHEV} = UF * (1/FE_{\text{on electic mode}}) * WCEP + (1-UF)*[(1/EF_{\text{on gasoline mode}}) * WCF_{gasoline}$$

Where,
$FE_{\text{on electric mode}}$ is the fuel economy of electric mode (km/kWh),
$WCF_{gasoline}$ the amount of water required to produce one Liter of gasoline (L/L)
UF * [53]: is the utility factor, which shows the fraction of the vehicle miles travelled (VMT) driven in electric mode

- **Cargo plane transportation**

The following formula [49] allows to calculate the WF from cargo plane transportation fora given number of units.

$$WF\ of\ airplane\ transportation\ (L/Unit) = Kerosene\ usage\ (GJ) * \frac{Water\ factor\ of\ crude\ oil\ (L/GJ)}{Number\ of units}$$

Where,

$$Kerosene\ usage\ (GJ) = \frac{Fuel\ consumption\ (L/Km) * Distance\ (Km) * 5{,}86125\ (GJ)}{Quantity\ of\ Kerosene\ used\ (L)}$$

$$Number\ of\ units = \frac{Airplane\ capacity\ (m3)}{Package\ measures\ (m3)}$$

- Useful water footprints of different means of transport based on biofuel [54]

Transport mode	Energy source	Green & Blue water footprint of freight transport (L per 1000 kg of freight per km)
Airplane	Biodiesel from rapeseed	576 - 1023
	Bioethanol from sugar beet	169 - 471
Bus/lorry	Biodiesel from rapeseed	142 - 330
Train	Biodiesel from rapeseed	15 - 40
Ship (inland)	Biodiesel from rapeseed	36 - 68
Ship (sea, bulk)	Biodiesel from rapeseed	8 -11
Electric train	Bioelectricity from maize	2 - 7

Table 18: The water footprint of different modes of freight transport when based on first generation biofuel produced in the European Union

9.3.3 THE WATER FOOTPRINT OF PRODUCT USE

The WF of product use is mainly the water use associated with the electricity consumption of the expected use of the product over its lifetime. Calculated electricity consumption is then used in combination with average water consumption factors for the designated country of use to calculate emissions. Therefore, the same formula [12] used for the WCEP calculation is also applied in this section:

$$WCEP\ (L) = Energy\ Consumption\ (kWh) * Water\ Consumption\ factor\ (L/kWh)$$

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NGMN, established in 2006, is a global, operator-led alliance of over 80 companies and organisation spanning operators, manufacturers, consultancies and academia.

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The vision of the NGMN Alliance is to provide impactful guidance to achieve innovative and affordable mobile telecommunication services for the end user with a particular focus on supporting 5G's full implementation, Mastering the Route to Disaggregation, Sustainability and Green Networks, as well as 6G.

MISSION

The mission of the NGMN Alliance is

- To evaluate and drive technology evolution towards 5G's full implementation and the three major priorities for 2021 and beyond:

  Route to Disaggregation: Leading in the development of open, disaggregated, virtualised and cloud native solutions with a focus on the end to end operating model.

  Green Future Networks: Building sustainable and environmentally conscious solutions.

  6G: Emergence of 6G highlighting key trends across technology and societal requirements plus use cases to address.

- to establish clear functional and non-functional requirements for mobile networks of the next generation.
- to provide guidance to equipment developers, standardisation bodies and cooperation partners, leading to the implementation of a cost-effective network evolution
- to provide an information exchange forum for the industry on critical and immediate concerns and to share experiences and lessons learnt for addressing technology challenges
- to identify and remove barriers for enabling successful implementations of attractive mobile services