INTERNET WASTE

A thought paper for International E-Waste Day 2020

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Abbreviations

EEE	Electrical and electronic equipment
ICT	Information and communication technology
IMT	International Mobile Telecommunications
IoT	Internet of Things
ITU	International Telecommunication Union
ITU-D	Telecommunication Development Sector
ITU-T	Telecommunication Standardization Sector
StEP Initiative	Solving the E-waste Problem Initiative
WEEE	Waste electrical and electronic equipment

International E-Waste Day
Powered by the WEEE Forum

About ITU:

The International Telecommunication Union (ITU) is the specialized United Nations agency for information and communication technologies (ICTs), driving innovation in ICTs together with 193 Member States and a membership of over 900 companies, universities, and international and regional organizations. Established over 150 years ago in 1865, ITU is the intergovernmental body responsible for coordinating the shared global use of the radio spectrum, promoting international cooperation in assigning satellite orbits, improving communication infrastructure in the developing world, and establishing the worldwide standards that foster seamless interconnection of a vast range of communications systems. From broadband networks to cutting-edge wireless technologies, aeronautical and maritime navigation, radio astronomy, oceanographic and satellite-based earth monitoring as well as converging fixed-mobile phone, Internet and broadcasting technologies, ITU is committed to connecting the world. For more information, visit **www.itu.int.**

About the WEEE Forum:

The WEEE Forum a.i.s.b.l. is an international association representing forty producer responsibility organizations across the globe. Together with its members, it is at the forefront of turning the extended producer responsibility principle into an effective electronic waste management policy approach through combined knowledge of the technical, business and operational aspects of the collection, logistics, de-pollution, processing, preparing for reuse and reporting of e-waste. Its mission is to be the world's foremost e-waste competence centre, excelling in the implementation of the circularity principle. For more information, visit **www.weee-forum.org.**

About International E-Waste Day:

International E-Waste Day (IEWD) was introduced in 2018 by the WEEE Forum with the support of its members. It serves to raise the public profile of WEEE recycling and encourage consumers to return their end-of-life gear for responsible recycling or to consider reuse or repair. In 2019, ITU collaborated with the WEEE Forum on IEWD to help promote the importance of responsible recycling of WEEE. Strong partnerships are key to achieving this. The WEEE Forum and ITU have continued to partner for IEWD 2020, which takes place on 14 October, specifically by preparing this thought paper on Internet waste, as public knowledge about waste derived from connectivity infrastructure is limited. The full impact of materials and components critical to the digital economy is difficult to assess, as the infrastructure and end-of-life management are less visible, especially to individual consumers who use personal ICT devices supported by data centres and telecommunication networks. In addition, members of the WEEE Forum selected education as the theme for IEWD 2020. It is important to make young people aware of WEEE issues and encourage a new generation of responsible consumers. For more information, visit **www.internationalewasteday.com.**

1. Introduction

ICT infrastructure plays an important role in spurring economic growth and promoting Internet and mobile telecommunication access and services. It includes digital networks, mobile phones, Internet servers and fixed broadband.[1] Digital devices such as mobile phones, tablets and computers support the movement of data, which in turn expands global connectivity, and economic activity. Increasing use of, and dependence on, the Internet has contributed to growing demand for ICT devices. The COVID-19 pandemic has also highlighted the dependence on ICT infrastructure and connectivity, with demand and use increasing. A variety of environmental impacts are linked to infrastructure equipment, such as energy consumption from production and use, carbon emissions from power supply, water consumption for cooling practices, WEEE and raw material scarcity.

The StEP Initiative describes WEEE as all forms of electrical and electronic equipment discarded by the owner as waste without the intention of reuse.[2] According to The Global E-waste Monitor 2020, the world generated 53.6 million metric tonnes of WEEE in 2019, 21 per cent more than in 2014 owing to higher EEE consumption rates (which are increasing by 3 per cent annually), shorter lifecycles and limited repair options.[3] EEE from the commercial sector accounts for a large proportion of the total volume of EEE produced globally.[4] The growth in WEEE presents a global challenge: hazardous substances can have adverse impacts on human health and the environment, call for stringent technical recycling requirements, and incur high costs associated with environmentally sound management.[5] Business-to-business equipment originates from commercial and professional applications such as infrastructure network equipment, whereas end-user devices can be either business-to-business or business-to-consumer.

The growth in data traffic, storage and processing driven by demand for online services requires a vast digital infrastructure and supporting network connectivity.[6] Data centres house computers, data storage devices, networking equipment and communication links that allow computing to be performed at scale more efficiently. With the popularity of the Internet, the number of data centres globally has grown to 8.6 million.[7] Cloud storage is also on the rise, with a more than threefold increase between 2016 and 2021 driven by big data and the IoT.[8] As people consume digital services on individual EEE devices, data centres make the services work behind the scenes. Connecting consumer services and devices with data centres requires Internet access links and an infrastructure networking component – the less visible Internet element of connectivity. Reliance on, and demand for, data centres will increase as more people, smart products and services become connected. This sector will continue to grow in order to manage the increasing volume of data, with a forecasted growth of 500 per cent by 2030.[9]

Billions of IoT devices now collect data for analysis and storage, with everything from alarm clocks to washing machines and wearable technologies connected through often mobile-based machine-to-machine communications.[10] The IoT can add sensors to products that traditionally may not have included an electronic component or have been connected, adding to the growing category of products entering the WEEE stream. Some IoT products, such as smart clothing, represent a fusion of fashion and technology, and may become obsolete much faster. Another question – where such products sit in the traditional WEEE product categories – also impacts end-of-life management. The ability to see and therefore know the full scale of the WEEE impact of the digital economy is more challenging.[11] Digitization may reduce future product use with virtual services[12] – streaming, cloud computing and purchasing services as a substitute for products – that spell fewer devices for the end consumer, but as user numbers are expected to increase, total use of products and demand for data centres will increase. This could impact future WEEE quantities in different ways – there may be a reduction if demand for hardware decreases, the shift to a service-based model may balance out waste generation, or the amount of WEEE could continue to rise.

The full impact of materials and components critical to the digital economy is difficult to assess, as the supply chain and network infrastructure are less visible to the individual or household consumer. This will make it even more challenging to change the mindset of consumers, as they see only the individual devices they use and not the potential waste generated by the infrastructure that supports their connectivity. According to their position in the waste management hierarchy, reuse and repair are more desirable than recycling. It is important to identify differences in the way waste is discarded by business-to-consumer and business-to-business sources.

The data on collection and treatment are often limited, so more research is needed regarding what happens to business-to-business equipment. Although not a focus of this paper, improving the energy efficiency of infrastructure equipment has become an important priority in the business-to-business value chain.

This thought paper focuses on WEEE derived from wireless infrastructure for mobile Internet connectivity, connected devices and data storage, with examples from mobile networks, the IoT and data centres. It aims to raise awareness about waste from infrastructure that supports connectivity and the need for sustainable WEEE management practices in data centres and the telecommunication industries, in view of the growth forecast in both connectivity and WEEE. The paper also highlights the role of international standards in facilitating the responsible management of WEEE and provides examples of how these standards have been helping countries and the ICT sector minimize WEEE impacts.

2. Drivers of growing connectivity and WEEE

The demand for data and digital services has risen over the past decade as the global economy becomes more digitalized and the Internet, mobile and sensor networks lead to socio-technical transformations and lifestyle changes.[13] A variety of societal, technological, economic and market changes are driving connectivity growth, which in turn affects WEEE (Figure 1). The number of Internet users has doubled since 2010, while Internet traffic has grown at a rate of approximately 30 per cent annually.[14] By 2023, the number of Internet users is predicted to reach 5.3 billion (66 per cent of the world's population).[15] The physical infrastructure that supports Internet connectivity will eventually become WEEE.

Although the global digital economy is evolving at a rapid pace, ICT sector development varies widely across regions and countries.[16] As the digital economy continues to grow, people and businesses have become more dependent on connectivity and digital services. Between February and April 2020, global Internet traffic surged by almost 50 per cent in some regions, driven by the growth in video streaming, video conferencing, online gaming and social networking.[17] Some companies are also reporting that much of this demand for bandwidth is being met with quick upgrades of existing equipment through modular design of cards, boards and other devices.[18] In the midst of the COVID-19 pandemic, IT asset disposition companies reported decreases of up to 75 per cent in the flow of used IT equipment, but a surge is expected as lockdown measures ease.[19] There is also uncertainty whether the pandemic could lead to more WEEE, as some companies found it difficult to get equipment collected for repair, with early replacement being easier in comparison.[20]

The number of mobile Internet users is projected to increase from 3.8 billion in 2019 to 5 billion by 2025, and the number of IoT-connected devices to double from 12 billion to 25 billion during the same period.[21] These trends are driving growth in network services and data centres, especially the cloud[22]. The emergence of the cloud has driven digital expansion and transformed how companies purchase ICT equipment and services through millions of servers hidden in data centres.[23] The data centre customer base of some end-of-life management companies has trebled over the past five years,[24] and a shift has been seen in opportunities to reuse and recycle equipment from cloud infrastructure and cellular networks in terms of refresh rates and the type of asset being received.

Video streaming, online gaming and emerging technologies (e.g. machine learning, blockchain and 5G) are also anticipated to drive demand for data centres and network services. More products compatible with these technologies and the digital economy will be placed on the market, leading to more WEEE – and suggesting that increased connectivity could also be driving WEEE generation. EEE can reach end of life owing to technological advancements that shorten product lifespan, to planned and fashion-related obsolescence, to the inability to repair and lack of repair possibilities, or to firmware and software support ending for older devices and operating systems, affecting the lifespan of hardware such as data storage devices. From a waste management standpoint, very few solutions or regulations are designed to overcome these issues. In some parts of the ICT sector, such as in consumer electronics, rapid technological advancement of EEE means new versions quickly replace existing models or become redundant, creating a consistent source of WEEE. Greater energy efficiency also encourages equipment replacement, which in turn contributes to more WEEE[25] unless the product is reused, in whole or in part. It may not always be economical and energy-efficient to recycle and reuse equipment – there may be a trade-off that makes it better to replace the equipment.[26]

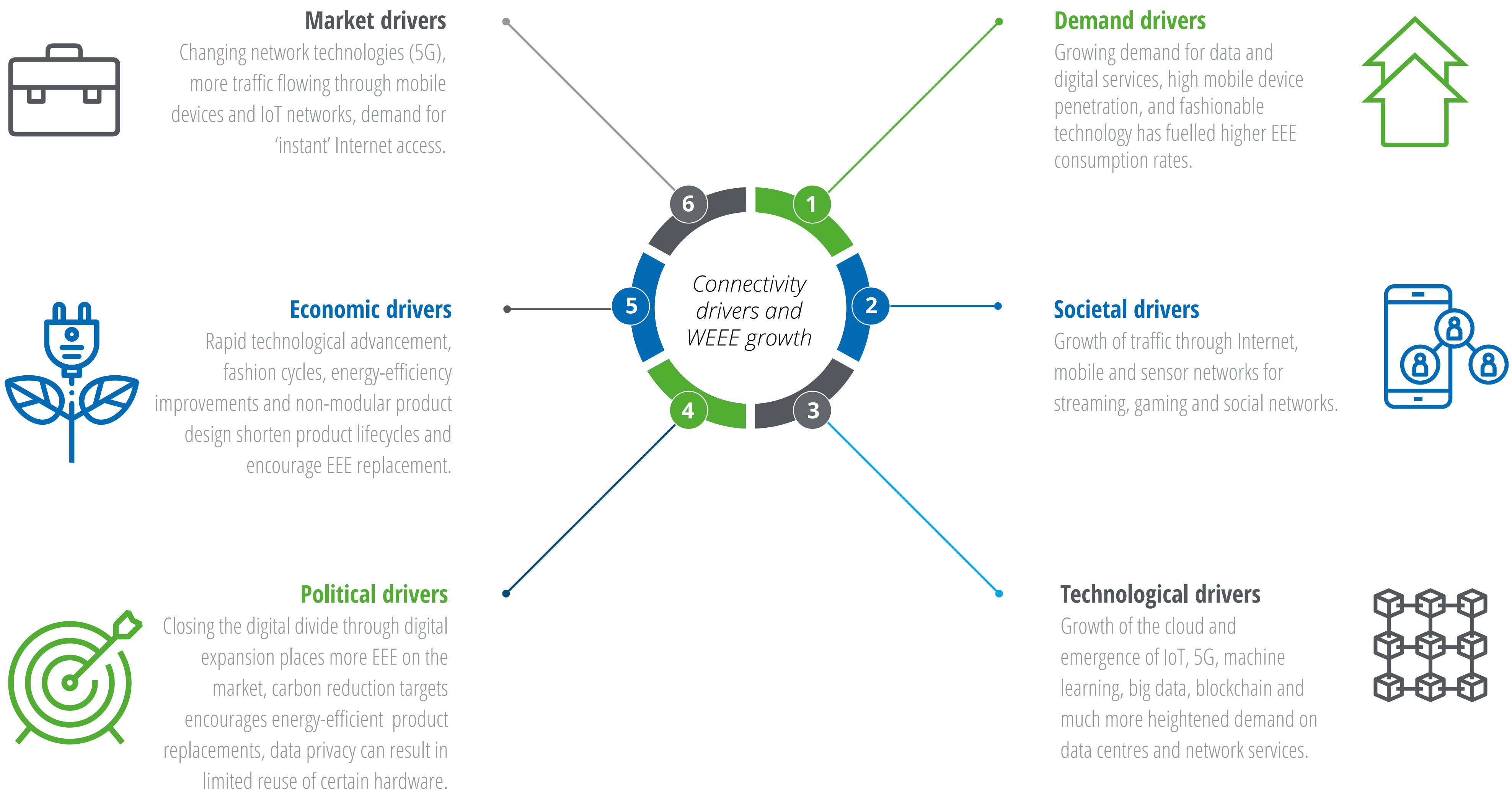
The type of data transmission is also changing as more traffic flows though mobile networks and devices, with networks rapidly moving away from older 2G and 3G technology towards 4G and 5G (which are predicted to carry 83 per cent of mobile traffic by 2022).[27] Smartphones are at the centre of data use growth: they have short operating lives (two to four years[28]) and contain numerous precious and rare metals than can be lost if not responsibly recovered. The progressive deployment of 5G will require new handsets. 5G has started to bring changes to mobility, enhancing connectivity by improving both latency and data throughput, and will be a major driver for the growth of IoT applications[29] , such as in smart cities, manufacturing and agriculture.

The role that the physical infrastructure plays in supporting and supplying the economy with Internet connectivity and digital services has mostly gone unnoticed by the individual household consumer, especially in terms of what it means for the use of resources and management of WEEE. Numerous corporate social responsibility reports provide information on circular economy goals, but most research and policy has focused largely on consumer devices.

There is very little data in the public domain on WEEE derived from infrastructure equipment for Internet connectivity; this should be a focus of future work. This type of professional equipment still accounts for less tonnage than consumer devices.[30] Improving data availability will help to evaluate developments over time, set and assess targets, and identify best practices in policies. The Global E-waste Statistics Partnership, of which ITU is a partner organization, aims to improve and collect data on WEEE in an internationally standardized way and offers capacity building to countries to help achieve this.

Sustainability efforts are becoming increasingly important across ICT supply chains, especially for energy efficiency, with the introduction of the Ecodesign Directive (Directive 2009/125/EC of the European Parliament and Council)[31], but many companies are also turning to the circular economy for material reuse, such as for the refurbishing, upgrading and recycling of infrastructure equipment.[32]

Figure 1: **Overview of connectivity drivers and WEEE growth based on literature and interviews.**



3. WEEE Impact of mobile network infrastructure

Mobile networks are moving away from older 2G and 3G technology towards more efficient 4G and 5G, which are governed by the IMT standards. 5G should deliver low latency, greater reliability, and increased network capacity and availability.[33]

The new era of 5G will help meet demands for increasingly digital lifestyles by connecting people, machines, objects and devices. It will support services that require higher bandwidths (such as virtual reality), low latency (such as remote management) and high connection density through a number of sensors, such as in smart cities and smart agriculture.[34] 5G will have a significant impact on the deployment of IoTs in smart sustainable cities (see Figure 3), as high-speed connectivity and low latency will enable data to be collected, transmitted and analysed in near real time.

The radio access network and the core network are the two main components of a mobile network. 5G will initially operate alongside existing 4G networks but will require a new network architecture that introduces radio access technologies, which can make antennas "smarter", use higher frequencies and alter or re-architect networks in the face of industry growth. The radio access network comprises a variety of facilities, including macro (using multiple input, multiple output antennas), micro and small cells, towers, masts and in-building systems that connect mobile users and wireless devices to the main core network (Figure 2). The core network is the mobile exchange and data network that manages connections. It will be redesigned for 5G to allow better integration of the Internet and cloud-based services.[35]

5G technology can operate in low, medium and high frequency bands. When mobile stations operate in millimetre wave bands (above 24 GHz), they offer higher capacity, but also much more limited coverage. The forecast, therefore, is for a significant increase in the number of small and microcells (Figure 2), which in turn increases the quantity of network equipment deployed. Optical fibre-based networks have rapidly expanded, as they can transmit data faster and over longer distances while supporting a move towards a network that reduces energy consumption and waste. Some fibre applications require fewer line cards than copper; fibre cables are of smaller diameter and weigh less than copper cables, and typically have a longer infrastructure lifespan.

To help enable device-to-device communication and be compatible with 5G wireless signals, modems in the home and workplace may need to be replaced, resulting in their obsolescence and more consumer WEEE in the future.[36] Machine-to-machine communications and wireless sensor networks are prominent features of IoT applications.[37] IoT functionality and data transmitted machine-to-machine and machine-to-people are determined by sensors, which are increasingly found in many everyday devices such as mobile phones, smart fridges and smart meters.[38] The IoT will deploy trillions of connected wireless sensor networks that in turn will generate terabytes of traffic.[39]

Product design can be very important for sustainability and a circular economy. For example, the concept of a "system on a chip" can improve IoT network design by combining sensors and processing power on chip hardware, which in turn can reduce data traffic, energy consumption and WEEE from the overall infrastructure.[40] Another effective way to mitigate IoT WEEE is to reduce the frequency of hardware updates and increase the proportion of greener materials in equipment. International standards such as Recommendation ITU-T L.1023 (Assessment method for circular scoring) can provide guidance on how to assess the circularity of an ICT product and improve product design.

The transition to 5G and related infrastructure deployment are expected to occur slowly over the next decade or longer but have already begun. For example, some small cell base stations are already available to help improve outdoor coverage.[41] Compared to the data centre industry, telecommunication infrastructure network equipment has a longer life span (5 to 15 years) and is designed for longevity, with some companies manufacturing equipment with a 10-year guarantee.[42] An increase in WEEE from 5G infrastructure is not expected immediately but is anticipated to start emerging in 5 to 15 years.[43] Base stations can be deployed in various 5G scenarios that help operators to build wide coverage, increase capacity and ensure cost-effective networks. New wireless network infrastructure equipment has been designed with projected growth in traffic in mind and so should not need to be replaced to support foreseeable growth. The number of small cells may increase the volume of total infrastructure equipment deployed.

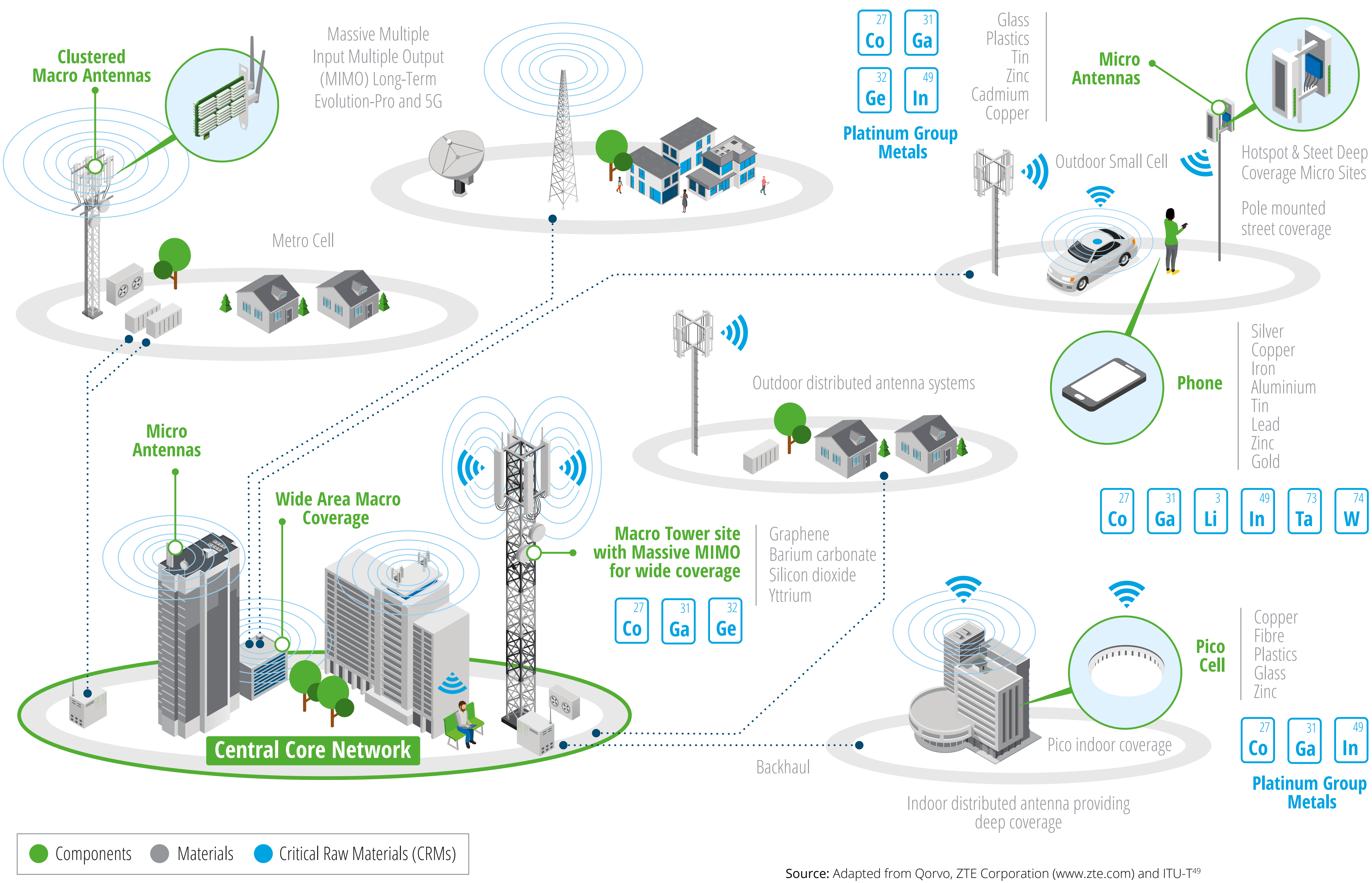
Typically, mobile network infrastructure equipment includes radio access network equipment, routers, antennas, servers, wireless base stations, optical/microwave transmission equipment and network management equipment.[44] Most of the wireless base station equipment (Figure 2) and antennas contain large amounts of metal such as aluminium. Other prevalent materials include plastics and glass fibres.[45] Materials like gold, silver, tin and copper will likely be present in significant quantities in 5G network equipment. One study found that new materials such as gallium (a critical raw material) are expected to replace silicon in transistors to improve energy efficiency,[46] and that the radiofrequency components used for 5G are based on silicon, gallium, gallium arsenide, silicon-germanium alloy, gallium nitride or indium phosphide. The same study found the following four critical raw materials in indoor and outdoor radio equipment: cobalt, gallium, germanium and platinum group metals.

The roll-out of 5G infrastructure will vary across regions, but it is not anticipated to alter the lifespans of current infrastructure equipment or add much to the amount of WEEE generated, as the shift will be gradual (volumes will increase slowly over time, as was the case with the 3G-to-4G transition). Greater future waste generation is expected from new equipment targeting industrial applications through private wireless networks, such as industry campuses.[47]

Although new equipment will lead to an increase in WEEE, it is often the preferred choice for reasons of energy efficiency. Introducing new-generation radio access network equipment means less energy consumption most of the time, but also a trade-off between new technology and investment costs. Decommissioning old and unused network equipment that is still plugged is also key to reducing energy consumption but may increase WEEE volume. Older assets that have reached end of life can be switched off and removed, and telecommunication operators have strategies to adapt, ensure the energy efficiency of and retire old infrastructure equipment. However, most 4G and 3G network hardware will continue to operate for many years, with some infrastructure equipment and devices expected to be redeployed and reused in countries where older networks are still in use or can be used as disaster fall-backs. Since 2015, many regions have been rolling out products that are 5G-ready and can be upgraded by remote software updates; in these cases, 5G enablement will not generate additional WEEE. This also means more control over resource usage, for example, some hardware can be switched off when there is no traffic, reducing energy consumption.

A key barrier to equipment reuse is the premature classification of used infrastructure EEE as waste.[48] Many companies have robust systems to take back and reuse equipment either as a whole or in part. However, it can be difficult to reuse and recustomize telecommunication equipment for other customers owing to the specific frequency band used (radio and random-access memory) and the platform requirements. This is especially the case for 5G, which requires new antennas. Reuse is more common for station equipment, servers and cabinets. Reuse is further limited if the equipment is already five to eight years old, as the preferred and most cost-effective option is often to buy new.

Figure 2: **Overview of 5G network infrastructure, including macro and micro base stations for wider coverage and indoor small cells for deep coverage**[†]



Source: Adapted from Qorvo, ZTE Corporation (www.zte.com) and ITU-T[49]

4. WEEE Impact of connected devices

The introduction of 5G could result in an increase in WEEE related to connected devices. The fact that existing devices lack a 5G radio to connect to the new networks will accelerate their obsolescence, especially as the trend is to upgrade to the newest technologies. By 2025, 5G is predicted to have 2.6 billion subscriptions covering up to 65 per cent of the world's population and generating 45 per cent of the world's total mobile data traffic.[50] The number of fixed wireless devices is expected to rise as 5G-connected households are enabled, with 5G-capable device volumes projected to reach 160 million units by the end of 2020.[51]

Industry 4.0 constitutes the fourth revolution in manufacturing, involving digitization, data exchange and automation. The IoT is a key component and is characterized by connected devices.[52] It encompasses a range of technologies, such as mobile and wireless connectivity, radio-frequency identification and smart sensors.[53] In its Annual Internet Report (2018-2023), Cisco forecasts that networked devices will total 29.3 billion worldwide in 2023, thus outnumbering humans by more than three to one.[54] The enormous scale of IoT devices will need to be managed in terms of both connectivity and their eventual end of life. WEEE from households and individual consumers is growing faster than infrastructure equipment waste, likely because of the growing number of individual devices with short lifespans and large amount of small hardware equipment used for the IoT.[55] Billions of new IoT devices will be incorporated into everyday appliances and sophisticated embedded systems connected over the Internet and mobile networks (Figure 3).

To enable these cellular IoTs and their different segments, device battery life must be sufficient and not add to the battery waste stream. IoT-enabled devices are expected to operate at low powers, with battery life of up to 10 years in some applications[56], therefore reducing WEEE in the short term. Gartner reports that there will be about 25 billion connected things by 2021.[57] During the transition, traditional analog equipment gas started to contain additional EEE components, a trend observed in household equipment such as coffee makers, USB and Wi-Fi compatible showers and refrigerators, and wearable electronics like smart watches.[58] Such products add complexity to the waste stream, as many did not contain IoT sensors for their original purpose. Many of these products remain low cost, and consumers are more likely to dispose of inexpensive products than resort to waste prevention approaches such as reuse, highlighting the need to build equipment that lasts longer.[59] Many of these new e-products do not store data like smartphones do, making disposal more practical. It may not always be economical and energy-efficient to recycle and reuse IoT devices, especially as devices are becoming smaller and smaller.

It is estimated that by 2023, 20 per cent of mobile data traffic worldwide will be carried by 5G networks: 1.5 times more than the combined 4G/3G/2G traffic in 2018.[60] The tendency to refurbish and redistribute mobile phones to countries where 2G, 3G and 4G networks are still dominant will likely increase as 5G devices are introduced. Renewing or improving this process – for example, in a waste-free or closed loop way through offsetting[61] – will benefit the countries to which the devices are being shipped, as they often lack WEEE management systems and capacity. There are also circular business models and sustainable purchasing for electronics that fund e-waste collection, especially in countries that lack formalized e-waste structures.[62] ITU also delivers national WEEE assessments in countries that do not have any basic policy and helps build long-lasting capacity. The WEEE Forum, together with its members, is turning the extended producer responsibility principle into an effective electronic waste management policy approach through combined knowledge of the technical, business and operational aspects of the collection, logistics, de-pollution, processing, preparing for reuse and reporting of e-waste.

Electronics recycling and IT asset disposition companies have an opportunity to embrace component harvesting from IoT and 5G devices, with a view to ensuring their environmentally sound management. Connecting devices via wireless access will enable a high percentage of the population to become connected using cellular technologies and mobile networks. This involves exploiting markets where there are virtually no existing fixed broadband alternatives and where the dominant way of accessing the Internet is through mobile networks on a smartphone. Mobile network operators would do well to think about waste management options in the face of continued growth in smartphone use, as consumers – even those without access to fixed broadband services – will eventually want to enjoy the benefits of high-speed connectivity.

WEEE treatment is also important for mobile network operators in carbon assessment processes (greenhouse gas accounting), because most have carbon dioxide reduction commitments. WEEE management may not weigh the heaviest in terms of carbon dioxide emissions when compared with electricity consumption, but it is part of Scope 3 emissions downstream activities.[63]

Smartphones continue to be at the centre of data use growth, as they generate most of the mobile data traffic (95 per cent projected in 2025).[64] Traffic growth is driven both by the rising number of smartphone subscriptions and increasing average data volume per subscription, fuelled primarily by higher-resolution video content viewing. Fast mobile phone development has led to a market dependency on rapid replacement of older devices.[65] Mobile devices affect the environment in many ways over their lifetimes, but the impact can be reduced and spread over a longer period by applying circular economy principles, including production control, device reuse, remanufacture and recycling, and improved circular design involving component material selection, standardization and modularization for easier disassembly.

The average lifespan of smartphones is estimated at two to four years,[66] with differences often related to device usage or availability of newer products, accelerating wider consumption and resource use. Old equipment is constantly being phased out, as was the case with 3G, the phase-of which out is expected to peak in three to five years. With continued growth in Internet connectivity, 5G already being introduced and 3G devices not yet reaching peak phase-out, pressure will continue to build on WEEE end-of-life management. The application of responsible reuse, recovery and recycling practices can help divert materials and components from landfill. Numerous responsible ICT companies are already prioritizing this, but there is enormous untapped potential for EEE reuse and reclaiming of materials.

Developments in semiconductor technology during the past 50 years have made electronic devices smaller, faster and more reliable. Smartphones contain many precious and rare metals that can be lost if not disposed of responsibly. As products continue to miniaturize and become more sophisticated, they rely on materials such as metals, alloys and polymers to implement their different functionalities. For example, a smartphone can contain at least 70 stable elements and up to 62 different metals and metalloids from the periodic table.[67] To produce an individual smartphone, 34 kg of ore need to be mined[68]; in the context of the 1.4 billion smartphones shipped worldwide in 2018,[69] that amounts to billions of kilograms of ore mined[70]. Certain rare earth elements are often not recovered because they are used in low concentrations and their recovery is therefore less economical. Low-cost solutions and inexpensive disposal options result in products being incinerated or disposed of in landfills, where valuable materials are not likely to be recovered and recycled into new products. Smartphones also contain complex chips that connect devices to 5G networks; most countries have no WEEE regulations, however, resulting in uncertainty over where end-of-life responsibility lies for chip manufacturers.

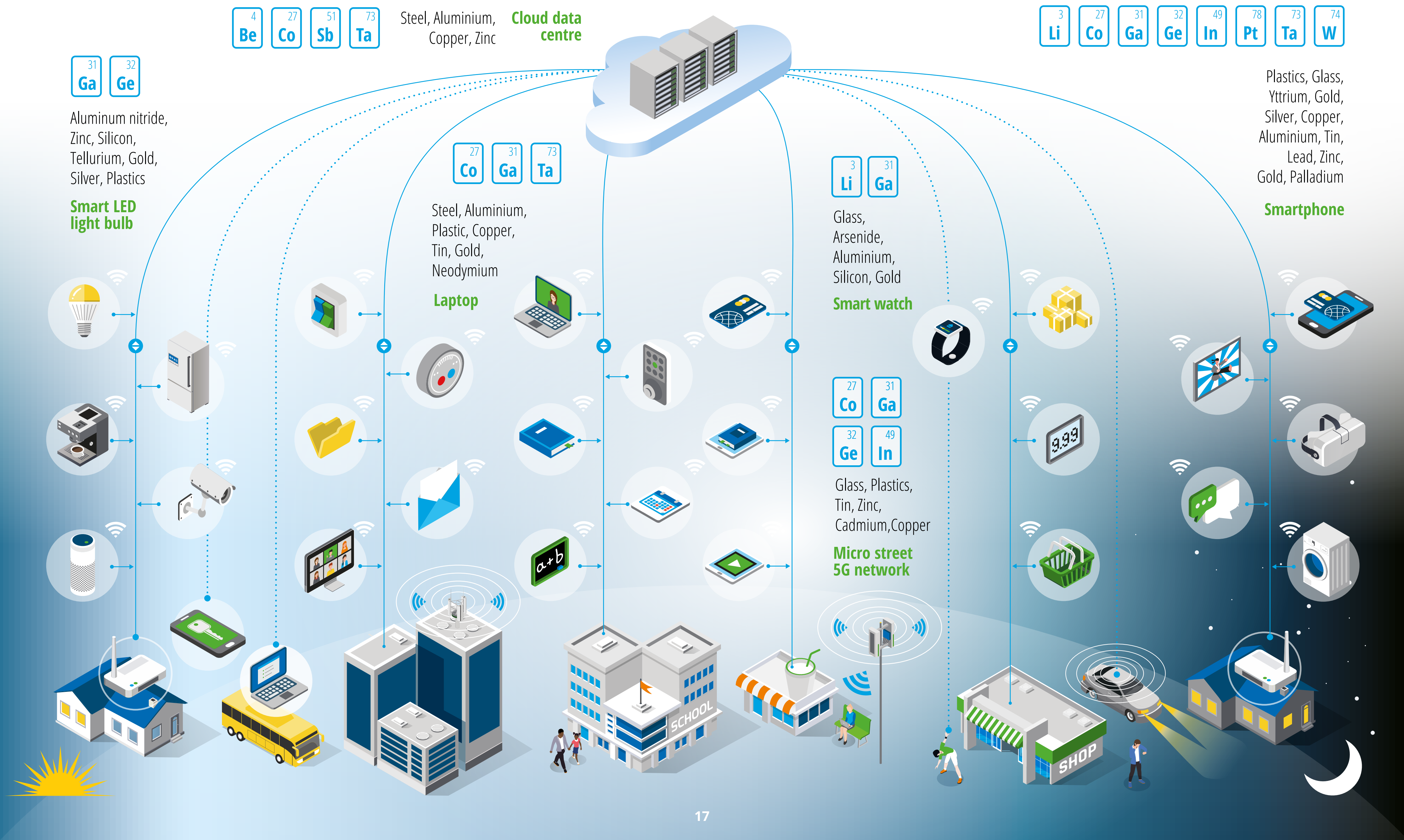
Many companies are focusing their efforts on circular design (disassembly, reuse and reassembly, more sustainable materials). For example, the circular design principles outlined in Cisco's Corporate Social Responsibility report[71] can help avoid product obsolescence at a time of 5G innovation. Circular design involves a commitment to use fewer raw materials, designing for upgrades and longevity by ensuring component standardization and modularity, opt-out options for unneeded product accessories (e.g. cables) and designing for disassembly, repair and reuse. It is still less common, except for recycled plastics, for companies to close the loop in supply chains and recycle more of the materials and rare earth elements in products.[72] Companies need to work more closely with organizations that can help create a closed-loop process, such as recyclers, smelters, producer responsibility organizations and waste collectors. Sustainability certification of IT products can also ensure that products are manufactured, used and recycled with regard to environmental and social responsibility, with initiatives such as TCO Certified Edge, E-waste Compensated[73] providing additional incentives for industry to get involved in WEEE collection.

Mobile trade-in programmes, for example, allow devices to be repurposed and reused, thereby extending their lifecycles. Consumer premises equipment, such as routers and residential gateways, are typically leased and can be refurbished and redeployed on return. Technological innovations, such as artificial intelligence and blockchain, also have the potential to help recycle more EEE and prevent products from becoming waste.

For example, artificial intelligence technologies are being used instead of the human eye to categorize small individual devices automatically when sorting WEEE.[74] This speeds up the recycling process and provides a safer working environment than one in which components are handled manually. Robotics is being used to separate, remove and sort components, thus also promoting smartphone reuse and recovery of non-traditional materials.[75]

Software updates can also affect hardware lifespan as software support for older devices and operating systems comes to an end. Unsupported software can lead to greater security vulnerabilities; over a period of time, it can prevent equipment from functioning properly, rendering it unusable. Customized device enrollment programmes can also make resale and end-of-life management more challenging. Such programmes are designed to limit functionality and use to a single user within a company. The device cannot be remarketed and reused without going through a un-enrollment process that can be tedious and time-consuming. It is recommended to equip devices with an easy-to-implement un-enroll option.[76]

Figure 3: **Internet of Things Connectivity**†



5. WEEE impact of data storage equipment

Data centres have undergone widespread change in the past 70 years, growing fivefold in number since 2018 to cater for the rise in data traffic.[77] They are often described as mission-critical facilities: they host a large number of servers and network communication infrastructure equipment used to handle Internet and telecommunication data, and are therefore essential for business operations.[78] More and more data centres house cloud activities, with 53 per cent of servers predicted to be cloud-hosted by 2021.[79] The core idea behind "the cloud" is on-demand access to a scalable pool of computing, storage, network and software resources involving minimal management or service provider interaction.[80] This paradigm can be more flexible than traditional "on-premises" data centres. Cloud services from a large provider can be between 22 and 93 per cent more energy-efficient than "on-premises" services, owing to the increased power usage effectiveness of data centre hosting services, computational efficiency, cooling techniques and use of renewables.[81]

At a time of such rapid development, the industry has focused on service and performance, while sustainability improvements have focused on reducing and greening energy consumption. Less attention has been paid to improving resource efficiency and circularity, with equipment lifespans typically lasting one to five years.[82] Data centre expansion has resulted in more WEEE as data centre equipment is continuously upgraded or replaced. The CEDaCI project (www.cedaci.org) is working to address some of these issues for infrastructure equipment within the data centre industry; it aims to bring together stakeholders from all lifecycle stages.

Company internal work on infrastructure asset and WEEE management is not always in the public domain.[83] For example, some companies are working to reduce the environmental footprint of hardware design, extending the lifespan of equipment. There is little transparent or clear quantitative data in the public domain regarding the composition, lifespan, volume and end-of-life management of equipment generated by data centres (and other networking equipment). This information is fundamental to the establishment of optimal end-of-life strategies and knowledge sharing is therefore encouraged, especially to improve the qualitative information already in corporate social responsibility reports. Estimated volumes of ICT infrastructure equipment are difficult to obtain because they are unevenly distributed (for example, Europe has an estimated 20 million servers, equivalent to more than half a million tonnes of materials).[84] Estimates of the amount of WEEE generated, collected and recycled at international, regional and national level are important for the implementation of environmentally sound WEEE management. The Global E-waste Statistics Partnership can help produce better WEEE statistics based on nationally comparable data. This will help minimize WEEE, prevent dumping, promote recycling, create jobs in the reuse, refurbishment and recycling sectors, and contribute to achievement of the Sustainable Development Goals, particularly Goal 12 (Ensure sustainable consumption and production patterns).

Data centre equipment is regularly refreshed as the technology develops, and the typical server has a lifespan of one to five years[85] if not given a second life through reuse and recycling. The average refresh rate for server and storage equipment varies by company size and industry but is typically one or two years in financial services, three to five years in the data centre industry, and five to ten years in some smaller companies and government agencies.[86] Equipment is not systematically changed; indeed, change is highly dependent on the company and use. In addition, the three-to-five- year average lifespan typically applies to first use; it can increase to eight to ten years thanks to secondary use. In general, equipment lifespan is difficult to estimate accurately, as data are not always available or may not account for secondary use. A high percentage of equipment can also be reused internally, i.e. redeployed in support of different business functions. The age of equipment is an important factor in determining recycling or end-of-life management options, with equipment older than 10 years having more limited reuse possibilities. Overall, the lifespan of equipment in data centres appears to be dropping substantially as a result of rapid technological innovations.

Some end-of-life management companies have only recently started to see waste from the first cycle of upgrades from hyperscale data centres – such facilities have more capacity to scale applications to meet demand – but more of this is expected in the future. There is continued debate over product life cycles, with some believing they are getting shorter as new features and applications emerge annually, while others insist that greater efforts are being made to extend product lifespan; a third group feels that infrastructure equipment lifespans have remained fairly consistent over the last five to ten years.[87]

The transition to the cloud saw some faster refresh rates but this did not contribute directly to WEEE thanks to secondary resale and extending lifespans.[88] Many hyperscale data centres with a shorter refresh cycle of services provide “feedstock” for other data centre operators who can use this secondary equipment. The equipment is apparently also fully tested and refurbished, and sometimes recertified, before resale, leading to reuse with no compromise in terms of performance. Many servers are broken down into components, providing a global supply of spare parts and a remanufacturing system. This circular model has been operational for some time.

The most critical components in data centres (such as data servers and storage equipment, network equipment and batteries from uninterruptable power supplies) have a shorter operational lifespan and therefore have to be refurbished, remanufactured or recycled more frequently (every three to eight years).[89] Figure 4 provides examples of components and materials commonly found in data centres. Storage equipment, such as hard disk drives, is used to store data and tends to be replaced every three to five years, even though it can last longer, and the typical solid disk drive has a notably shorter lifespan than a typical hard disk drive, but offers better performance.[90] Reuse or recycling are the most likely scenarios, depending on data destruction methods, the technology and the age of the device. Data centre network equipment (e.g. routers and switches that connect devices) also has a high refresh rate (three to five years).[91] Like mobile network infrastructure, data centres are increasingly migrating core backbone infrastructure to fibre-based networks that support higher performance than copper cables. In data centres, fibre installations typically require fewer line cards than copper; this could also lead to fewer racks, reducing waste.

There is often a trade-off between energy efficiency, on the one hand, and reuse and recycling of equipment, on the other.[92] Certain data centre markets, such as social media and search engines, demand hardware upgrades for specific components (for example, to keep up with energy-efficiency targets) more frequently (every two to three years) than local telecommunication exchange carriers with longer use phases. After about 18 months, the performance and energy-efficiency ratio of servers decrease, making timely replacement of hardware important. Some equipment can have a second life phase, but there is often a time (10 or more years) after which it becomes less energy-efficient and the resulting negative environmental impact and associated costs work against its reuse. Ecodesign principles will play an important role in preventing product obsolescence, allowing equipment to become more standardized and modular for easier disassembly, repair and reuse.

Virtualization technology allows software to create the appearance of separate computer or storage devices from a single physical device, enabling more efficient use of the hardware and ultimately a reduction in WEEE. This has been instrumental in cloud development, as it allows multiple users to share the resources of a smaller number of servers transparently. Before the cloud existed, service providers would have to purchase and install enough servers to handle “peak load”, e.g. when a new device is released or during a big sale. The rest of the time, many installed servers would do nothing or be underused, and eventually become waste, despite having been underused over their lifetime. Cloud customers can pay for their needs at a particular time, it being the role of the cloud provider to supply enough capacity to handle peak load. Cloud providers will be able to better manage and average out traffic across their customer base at different times of the year; this will optimize use, be more economical and have a positive environmental impact. Many companies, especially in Europe, are shifting to service-based business models, meaning more infrastructure equipment is being leased in the data centre industry.[93] Service models are expected to keep products in use for longer as the provider has more control over end-of-life options and most cloud providers are engaged in good maintenance practices for economic reasons. Higher levels of customization for specific customers (for example, radio frequencies, which are common in the telecommunication sector) make it harder to lease hardware as a service. The C-Servees project (https://c-serveesproject.eu) seeks to boost a resource-efficient circular economy in the electrical and electronic sector through the development, testing, validation and transfer of new circular economic business models based on systemic eco-innovative services that include eco-leasing of EEE, product customization, improved WEEE management and ICT services to support the other eco-services.

Data centre composition

WEEE management can be challenging, as products can be complex to disassemble (e.g. non-modular designed servers with welded or glued components and laminated circuit boards) or contain valuable materials in small quantities or materials that are hard to separate from others (valuable or not). This can result in element loss, especially if material recovery is not economically viable. As many as 50 different elements and materials can exist across different data centre products (see Figure 4), including precious metals, platinum group metals, ferrous and non-ferrous metals and rare earth elements, some of which are critical raw materials.[94] As of 2020, the European Union had defined 30 materials as critical raw materials (see Table 1) based on their economic importance and risk to supply. The CEWASTE project (https://cewaste.eu) aspires to develop and test a voluntary certification scheme with requirements enabling the recycling of valuable and critical raw materials, including components found in data centres and connectivity equipment such as printed circuit boards and hard disk drives.

Data centre equipment consists almost entirely is largely (greater than 99 per cent) composed of "common" metals (e.g. steel, copper, aluminium) and polymers (e.g. ABS, PVC, PBT), while 10 critical raw materials typically make up 0.2 per cent of components.[95] Publicly available information about such materials in data centre equipment is limited and focused on enterprise server composition.[96] More studies are needed to gauge the composition of components and equipment lifespan. Producers are aware of what materials their products contain but are not always fully aware of their exact amount and value, although some have internal tools to map and predict how to manage them.[97] Some companies measure products and parts that are reused versus ending in landfill, down to the material level, including rare earth elements. The Urban Mine Platform (www.urbanmineplatform.eu), an offshoot of the European Union-funded ProSUM project (www.prosumproject.eu), in which the WEEE Forum was involved, developed the very first European Union-wide and open-access urban mine platform providing data on primary and secondary raw materials available in Europe in a harmonized and updateable format. The recycling industry and policy-makers are thus able to make more informed investment and policy decisions to increase the supply and recycling of secondary raw materials. ORAMA (https://orama-h2020.eu) took the results of ProSUM to the next level by allowing producer responsibility organizations to better compare collection data across Europe. Although Europe-centred, close international cooperation could eventually lead to a world knowledge base on raw materials, especially as the data are compliant with international standards.

With technological improvements, enterprise servers may not represent hyperscale data centre equipment or the modular equipment designed by the Open Compute Project to allow component swapping.[98] A wider range of data centre equipment and its material composition needs to be analysed, with a view to promoting circular economy strategies. It is also difficult to estimate amounts of critical raw materials with publicly available information, as much equipment is customized and the literature focuses on sources and supply restrictions. Moreover, the composition of a product can change from what was received from the original manufacturer if some components are replaced and recycled, with critical raw materials in particular more likely to be lost in the recycling process. To ensure that material flows are more transparent, material passports using the cloud or blockchain technology can give materials an "identity" and include information facilitating material reuse and recovery.[99] Online resources such as the Information for Recyclers Platform (I4R) provide recyclers with information about the presence in WEEE of materials and components that require separate treatment. The platform also allows producers to comply with Article 15 of Directive 2012/19/EU of the European Parliament and Council, on WEEE, which requires EEE producers to provide information free of charge on the preparation for reuse and treatment of each type of EEE placed on the market.

Supply risk to critical raw materials is high, and their recycling rate from WEEE is estimated to be only around 1 per cent.[100] Some metals are recycled more often because of their stable properties, consistent qualities, and well-established and more economically viable recycling technologies, including a market for resale. End-of-life management companies face many challenges in recovering critical raw materials and rare earth elements from infrastructure equipment, particularly the viability of technology and economic recovery, and these are compounded by the falling value of WEEE, meaning there is less value to extract.[101] In general, data centre WEEE contains more high-grade recycling material than small IT devices such as laptops. For example, data centres use high-grade circuit boards and backplanes that have, on average, a higher precious metal content than the typical circuit boards from individual consumer or small IT devices.[102]

Like mobile network infrastructure, data centres are increasingly migrating core backbone infrastructure to fibre-based networks that support higher performance than copper cables. In data centres, fibre installations typically require fewer line cards than copper; this could also lead to fewer racks, reducing waste. Storage devices and central processing units tend to be the primary recovered components due to cost-effectiveness, with other integrated circuits being more expensive and time-consuming to recover. Recycling of base (such as copper and iron) and precious metals (such as gold and platinum) is generally well established, as these materials have been recovered for decades. However, there are challenges in dismantling, sorting and pre-processing precious metals and many other critical raw materials. Inside servers, valuable components for recycling include printed circuit boards, some of which contain >400 parts per million of gold.[103] The fact that many critical raw materials are lost in slag during the refining process should spur the development of a more economically viable recovery process.[104]

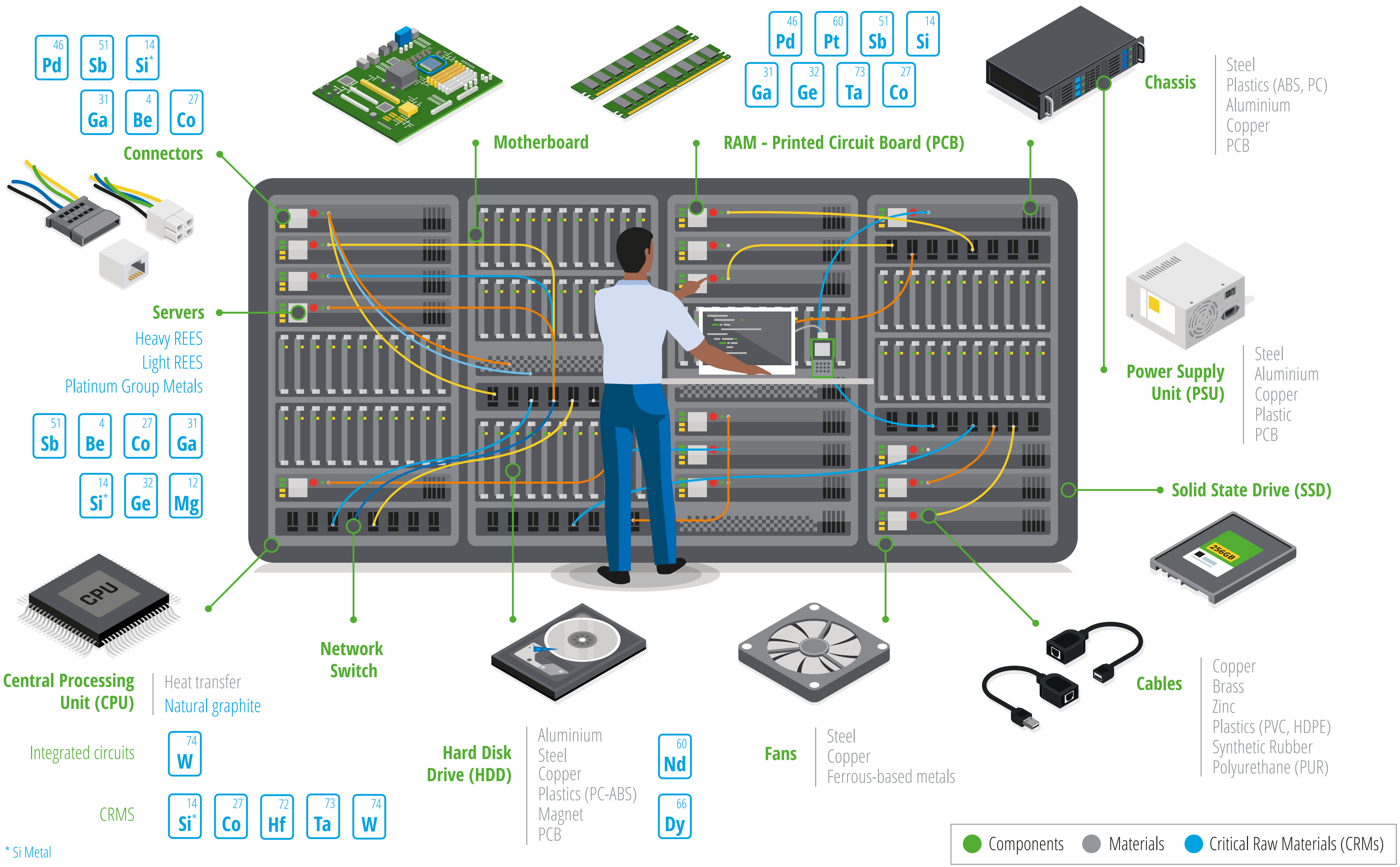
EEE is also getting smaller, which in turn reduces the quantity, and therefore the value, of base metals – more WEEE is needed to offer the same economic returns. Servers generally reach recycling facilities after potentially reusable parts have been harvested and tested for reuse in second-hand equipment. Reduced component size also impacts the ease of recycling and separation, with many original equipment manufacturers developing their own end-of-life policies to optimize component reuse and recycling – more collaboration is needed between such manufacturers and recyclers to improve the design for recyclability. Reduced component size also means the individual value is relatively low. This raises a supply chain issue, as it is then often more economical to buy virgin rather than recycled materials and components.

Table 1: List of the 30 critical raw materials identified by the European Commission (see Figure 4 for indications of where some of these materials are found in data centre components).

List of 30 critical raw materials identified by the European Commission *(new additions in 2020 compared to 2017 in italics*; **blue indicates materials identified in enterprise servers**)		
Antimony	Hafnium	Phosphorus
Baryte	**Heavy rare earth elements**	Scandium
Beryllium	**Light rare earth elements**	**Silicon metal**
Bismuth	**Indium**	Tantalum
Borate	**Magnesium**	Tungsten
Cobalt	**Natural graphite**	Vanadium
Coking coal	Natural rubber	*Bauxite*
Fluorspar	Niobium	***Lithium***
Gallium	**Platinum group metals**	*Titanium*
Germanium	Phosphate rock	*Strontium*

Source: European Commission, at https://ec.europa.eu/growth/sectors/raw-materials/specific-interest/critical_en, and (in blue) Peiró and Ardente, at https://publications.jrc.ec.europa.eu/repository/bitstream/JRC96944/lb-na-27467-en-n%20.pdf

Figure 4: **Common EEE components and materials found in data centres, including critical raw materials of high economic importance†**



Source: Based on data from Peiró & Ardente, at https://publications.jrc.ec.europa.eu/repository/bitstream/JRC96944/lb-na-27467-en-n%20.pdf

6. Maintenance and end-of-life management

The fate of WEEE is guided differently, both physically and in policy, in different parts of the world. WEEE management is more challenging in least developed countries, where greater amounts are traded, burned or end up in landfills because of the frequent lack of disposal infrastructure and waste management technologies, including limited targets and systems of collection such as producer take-back. Developing nations also face challenges with receiving exported WEEE, particularly non-working equipment, an area in which improved regulation is required. Exports for reuse become problematic when goods are repaired or treated in unregulated conditions that can have a negative impact. Guidelines for the safe collection and dismantling of WEEE, particularly in the informal sector, are also important. ITU-D offers technical assistance and capacity building for WEEE policy development aimed at achieving environmentally sound management of WEEE through collection, dismantling, refurbishing and recycling.

When servers, network equipment and storage devices reach their end-of-life phase, they are removed from service. The equipment is tested for functionality to determine if it can be directly reused. If it cannot be reused, then it is dismantled and parts are sold to spare parts providers or reused internally. Some companies donate old equipment to educational institutions or other causes. Some original equipment manufacturers also have return programmes for equipment buy-back or take-back. For example, Cisco's Takeback and Reuse Program encourages the return of hardware at end of use to maximize asset lifetime. Assets can be reused as a product or module, or unusable equipment can be recycled and recovered – 99.6 per cent of assets are reused or recycled.[105]

Specialist IT asset disposition companies operate a range of services, such as testing, data device destruction, data erasure without destruction, and repair or refurbishment. Some companies also offer warranties post product refurbishment. These services are available to all companies that are retiring IT assets.[106] Recovery work also involves dismantling and component recovery, where the components are remarketed to approved buyers or responsibly recycled.[107] Some companies take equipment back to logistics hubs, to coordinate reuse and recycling, for example, by separating materials and components, while others use global recycling companies for local handling. Operators are also working closely with suppliers to increase the reusability and recyclability of their products. Manufacturers help customers, sometimes as part of the contract, to upgrade and refresh the infrastructure they produce, including from third parties.[108] Some manufactures outsource maintenance to repair partners around the world to minimize product movement. This typically involves renewing existing products and/or services, providing spare parts or supporting software updates and maintenance, and is often linked to customers wanting better performance or improved energy efficiency.

It is very common for upstream recyclers to receive infrastructure equipment that is still functioning (B- to C-grade condition), i.e. equipment that is suitable for reuse following cleaning and the occasional minor upgrade.[109] Equipment that is beyond economical repair due to its condition or age is selected for parts and/or material recovery. Materials that are considered waste by former owners can often become mixed in others and sometimes damaged unnecessarily, but still have a reuse or harvestable potential. Many data centre customers prefer new equipment for reasons related, for example, to security, cost-efficiency and maintenance, and therefore tend not to reuse older equipment. Some service providers will not sell recycled equipment to new customers.[110]

Data sanitization, as it relates to all data-carrying devices, is a major concern for companies, especially those warehousing other people's data. The consequences of a data breach are enormous at both the reputational and the legal levels. For these reasons, many companies insist that any data-carrying devices be physically destroyed, so that there is no chance of a third party harvesting unauthorized information. This is a major barrier to the reuse and recycling of data storage infrastructure equipment, with destruction being the preferred course of action. Other methods exist for erasing data (e.g. sanitization of data by running dedicated data deletion software aligned with standards, degaussing of discs or in-house methods), but not all companies are comfortable using them for storage infrastructure.[111] This has been especially the case since the adoption of the European Union's General Data Protection Regulation, which requires compliance related to secure storage and protection of data, including data archiving and deletion. Data storage devices have limited reuse if data deletion cannot be guaranteed, as customer data are very sensitive, meaning more cloud providers are not able to reuse hard/solid disk drives.

Precious metal recovery can also be impacted if shredding is too high-grade and recyclers are likely to recover only four to five material fractions. There have been a number of cases of personal data being found in second-hand components, such as hard disk drives put on secondary markets.[112] Before enterprise servers are reused, operators need to delete personal data contained in WEEE before further treatment. Physical destruction of data storage devices can be viewed as extreme and is not specifically required by data protection authorities (which often encourage reuse of the device), leading to overcautious end-of-life practices for data storage devices.[113] In this regard, ITU is developing standards on assessment of the material efficiency of ICT network infrastructure goods (circular economy) that address firmware and security updates.

Firmware attacks have become more common in the last decade, and it is important to manage firmware to prevent vulnerabilities.[114] Firmware and software often became unsupported faster than hardware, restricting continued use of hardware such as hard and solid disk drives in data centres, which have high security requirements.[115] However, it is important to note that this is not the case for all products, and software updates arguably keep equipment in use for longer, delaying end of life. The fact that used hard disk drives from data centres are generally shredded back into raw materials has given rise to debate, and the potential exists for more product reuse with data erasure software developments. Firmware security is especially important in the growing IoT market and in home automation, and as many products are new to the market, limited numbers have reached end of life and the associated reuse and recycling treatments have not been explored. Access to firmware security updates is common in some industries (e.g. car manufacturing), but the fact that many original manufacturers of ICT products restrict access to updates (to those who have signed a maintenance agreement) acts as a deterrent to the reusability of servers and data storage products.[116] Older equipment will have more issues with software updates, which may affect usability; software updates can therefore bring on obsolescence.

Traceability is another challenge for infrastructure equipment recycling, as a shift in ownership also means a shift in liability, with a large percentage of circularity in the data centre industry relating to reuse and refurbishment. Professional IT asset disposition service providers maintain tight chain-of-custody records as the equipment is processed and resold. Their customers are then provided with a detailed chain-of-custody report, including information on the equipment's final destination. Without this professional support, transparency may fall short, as the reuse route is not always clear; there is a thin line between clear reuse and opportunistic reuse, which can occur under the radar and not be declared to compliance schemes. Companies may be unwilling to pay the contribution on equipment placed on the market or be unaware of their duties as producers.[117] To help improve traceability and monitoring along the reuse and recycling chain, equipment could be provided with a unique digital ID or passport. For example, blockchain technology could enable resource tracking, incentivize sustainable behaviour and improve resource efficiency, especially for the IoT.[118]

Regulations, legislation and compliance schemes play an important role, as they set standards and controls governing the actions of stakeholders associated with WEEE management in the public and private sectors. Least developed countries often lack the policies, legal instruments, regulations, technology and infrastructure needed for the environmentally sound management of e-waste recycling. It is important for countries to establish a legal, regulatory and policy framework that covers both the design and organization of an e-waste management system, and its enforcement based on standards. ITU-D has developed the *Handbook for the development of a policy framework on ICT/E-waste*, to help governments establish effective environmental frameworks for WEEE management.[119]

National regulations provide the basis for WEEE collection systems and ensure compliance at national level. Activities carried out by third-party organizations, or compliance schemes, also vary from country to country, depending on specific legislative requirements and the services offered. Collective compliance schemes, set up by either the private sector or government, are common in most European Union countries. Many compliance schemes and producer responsibility organizations are based on the extended producer responsibility policy approach, which assigns significant responsibility to producers, specifically post-consumer product responsibility. Producer compliance schemes are normally for-profit companies that provide services to producers and are responsible for financing, organizing collection and recycling, maintaining standards and audits, data management and reporting.

Compliance schemes usually offer producers a standardized service to apply established national practices related to proper and efficient collection and recycling of WEEE products. Greater implementation of compliance schemes, especially in least developed countries, will help enhance WEEE management, as will improved stakeholder engagement and technical capacity building, especially within national governments. More compliance schemes or producer responsibility organizations will also promote data collection on EEE products sold to businesses or consumers, improving WEEE statistics.

Moving equipment for reuse and recycling can be challenging for companies, as waste classification restrictions can vary both between and within countries. The Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal assists countries to protect human health and the environment against the adverse effects of hazardous and other wastes through the regulation of their movement. There are many controls in place to prevent illegal waste disposal or restrict movements of hazardous wastes. There are also tools to help countries understand whether the Convention applies to them and identify when used EEE becomes WEEE. Moving certain WEEE requires specific, higher-cost handling and transportation. For example, large rack systems and server units require more space in storage and transportation, and are therefore not as easy to transport. Flexible policies are needed for different types of equipment and volumes to make the recycling process more efficient. Standardizing regulations for infrastructure EEE movement through countries will make reuse and recycling more effective and cost-efficient. More assistance could be given to approved end-of-life management companies, for example, by creating "fast tracks" for the efficient movement of EEE.[120]

It can also be challenging to determine who is responsible for end-of-life management, as extended producer responsibility obligations are not always clear and can vary from country to country. Policy-makers have increasingly used extended producer responsibility as a means of enhancing the sustainability of waste and material management. It shifts responsibility upstream to the producer and incentivizes producers to incorporate environmental considerations into product design. In collection schemes, a producer responsibility organization is set up to implement extended responsibility principles on behalf of adhering companies.

It is important to define the role of all stakeholders involved in these systems, where more discussions are needed with manufacturers, operators, end-of-life management companies and local governments. ITU provides countries that do not have a basic WEEE policy with technical assistance and capacity building, including on producer registration and responsibility.

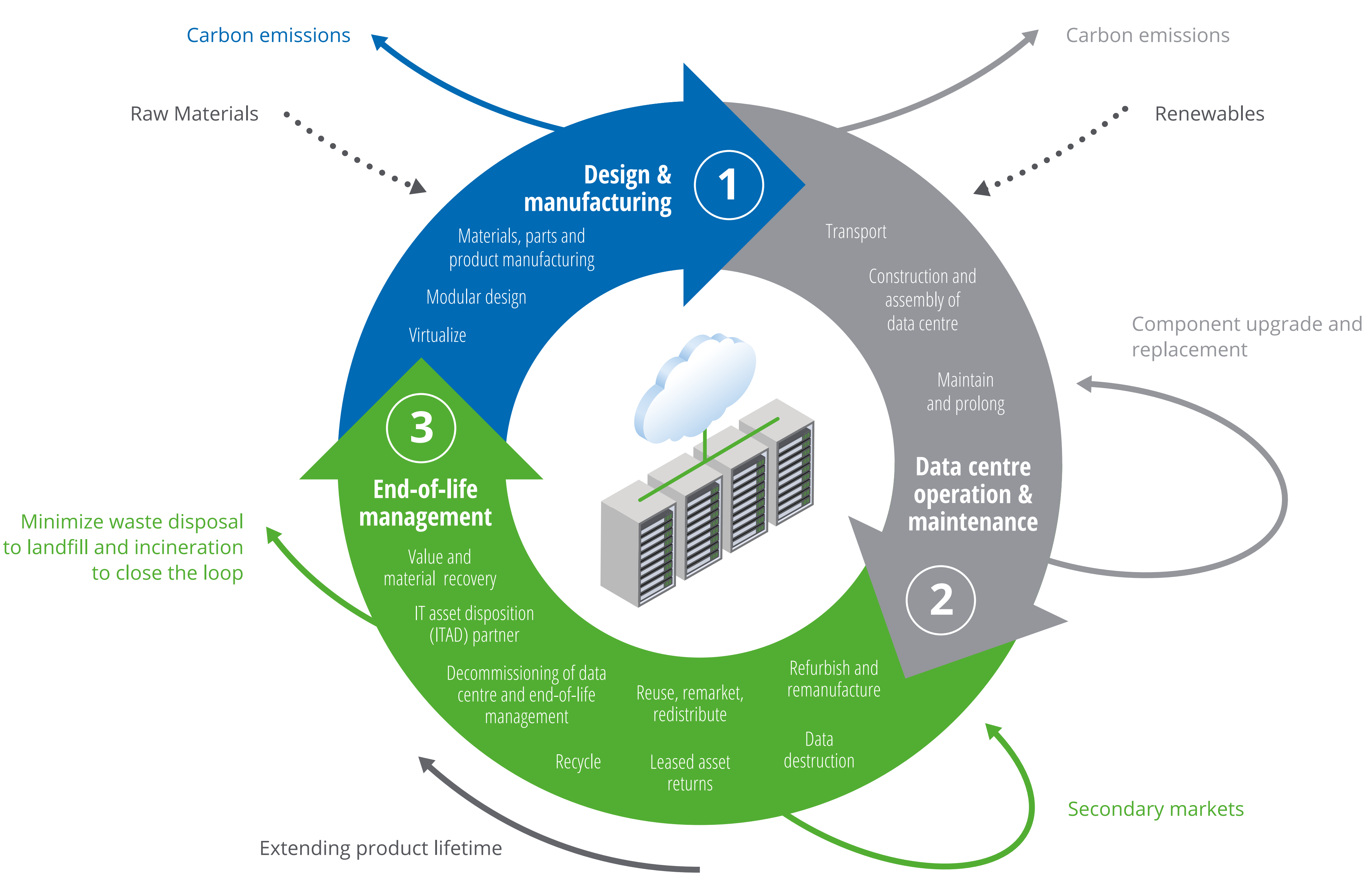
Modularity and ease of product disassembly (non-destructive taking apart) are also important for reuse and recycling but are often limited by design or the use of mixed materials.[121] In terms of manufacturing, some products are designed in-house while others are outsourced. Original equipment manufacturers are increasingly making infrastructure equipment such as servers and switches modular, to facilitate dismantling for repair or replacement of specific components that can extend product lifespan overall and reduce WEEE.

The industry has also shifted to more open-source products, especially in the cloud.[122] For example, the Open Compute Project (www.opencompute.org) has reimaged hardware to make it more flexible and scalable, which in turn optimizes repurposing and recyclability. The Ecodesign Directive requires product manufacturers to improve environmental performance by meeting energy efficiency requirements, but also covers aspects of material efficiency such as reparability, reusability, recyclability and the ability to disassemble components. In addition, the European Committee for Electrotechnical Standardization standards series EN 45550 to EN 45559 (Material Efficiency Aspects for Ecodesign) also cover these aspects.

Enterprise servers and data storage products were included in the 2012–2014 Ecodesign working plan. Barriers to disassembly can occur in household products (e.g. tablets and smartphones) containing glued or welded components, using different fastening techniques or incorporating proprietary systems. They have also been observed in enterprise servers, especially if disassembled by independent reuse operators who are less aware of the architecture and required disassembly procedures.[123] Ease of disassembly is especially important in servers, whose data storage components (e.g. hard and solid disc drives) have to be removed for data privacy. The European Commission has developed the Green Public Procurement criteria for data centres, server rooms and cloud services, to encourage public bodies to purchase products that have a reduced environmental impact and producers to align with lifecycle impact requirements.[124]

Companies acquire equipment in different ways, including buying new (with or without customization), buying second-hand, leasing, and paying for use via the cloud or as a service.[125] Sometimes customization can make recycling more difficult, but this is compensated by the high global demand for second-hand equipment and there is no difference in sales price between standardized and customized equipment. Moreover, many companies feel that customized equipment does not restrict reuse, with many offering take-back programmes to recover and recycle used equipment.[126] In addition, openings exist for organizations that customize equipment to partner with end-of-life management companies for input on reuse in design, which could result in longer-lasting equipment, facilitate repair and refurbishment, and provide an opportunity to incorporate recyclable materials instead of those more likely to end up in landfill.

Figure 5: **Life cycle of a data centre with circular principles applied**†



Source: adapted from A. Laurent and M. Dal Maso, Environmental sustainability of data centres: A need for a multi-impact and life cycle approach, Brief 1, Data Centre Brief Series, Copenhagen Centre on Energy Efficiency, February 2020.

7. The role of international standards in minimizing the impacts of WEEE

International standards provide a strong basis for the development of national and international regulations. They can help save time in the development process, reduce barriers to international trade and help countries protect the environment and achieve the Sustainable Development Goals.

ITU is at the forefront when it comes to supporting the sustainable management of WEEE and assisting countries and the ICT sector to transition to a circular economy. ITU-T Study Group 5, on environment, climate change and circular economy, has been developing international standards that support the sustainable deployment of ICTs and management of WEEE.

The standards provide energy-efficiency solutions for telecommunication networks, infrastructure and mobile devices, methodologies for evaluating their environmental performance, and guidance on transitioning to a circular economy and the environmental requirements of 5G. They also provide guidance on implementing extended producer responsibility systems,[127] safely recycling and extracting valuable metals in WEEE[128] and defining the circular economy in the context of ICT[129].

ITU-T Study Group 5 is currently developing a series of standards on the assessment of material efficiency of ICT network infrastructure goods (circular economy), which focuses on server and data storage equipment in relation to secure data deletion, availability of firmware and security updates, critical raw materials and disassembly instructions. ITU has also developed a toolkit on environmental sustainability for the ICT sector,[130] which provides organizations with a checklist of sustainability requirements, including on sustainable products and services and end-of-life management for ICT equipment.

For many years, the WEEE Forum – usually in a coalition with organizations representative of the producer and recycler community – has expressed the view that it is of critical importance that facilities be legally required to collect, handle and treat WEEE in strict conformity with all normative requirements of EN 50625 and EN 50614, the suite of European Committee for Electrotechnical Standardization standards covering the collection, transport, preparation for reuse and treatment of WEEE. This approach presents a unique opportunity to create a level playing field.

8. Conclusions

Connectivity infrastructure for mobile networks, the IoT and data centres provides essential services to billions of people and the global economy. Digitization and connectivity will continue to grow in the face of market demands and increased user traffic. There are many questions about what will happen to the infrastructure and devices that have enabled connectivity, and how best to deal with the end of life of new and miniaturized IoT technologies.

The current regulatory environment helps make it uneconomical to recycle and reuse obsolete IoT devices. To help reduce the amount of WEEE generated by the IoT, products need to be designed in such a way that they contain more greener materials and have longer lifespans.

Tackling connectivity infrastructure-related WEEE and reducing its environmental impact are key aspects of a sustainable and circular economy. There is a great deal of knowledge to be shared about this waste stream, with many companies having their own end-of-life guidelines and working internally to reduce their waste footprints, while also working with customers to refresh, reuse and recycle infrastructure equipment.[131]

Unless concerted joint efforts are made to proactively educate, make information more accessible, adopt more closed loop-models of infrastructure equipment management and put in place systems to facilitate their application, WEEE will continue to be generated.

There are many challenges to infrastructure equipment reuse and upgrading: security, limited software support, energy efficiency, newer technology availability, design and recycling limitations, to name but a few. Serious barriers to reuse include the following:

Energy efficiency is a partial driver of equipment becoming waste before end of life is reached, as it affects reuse and leads to faster equipment turnover, especially if replacement is more economical. It will be important to improve the energy efficiency of future products so as to enable longer lifespans and improve equipment consumption rates. Modular design already helps with this, as it requires fewer unique components in each product and makes it easier to swap components.

EEE should not be prematurely identified as waste. Products that are not clearly identified as waste should be made available for possible reuse. The definition of WEEE should be discussed with manufactures, operators, end-of-life management companies and local governments to increase awareness of the issue. It will also be important to have controls in place to ensure that equipment being exported for “reuse” is actually in the condition it is labelled as and is not a “waste” product. A change in public policy or legislation could help encourage extended life usage, promote circularity and counter linear model thinking.

Reuse options for infrastructure equipment are limited by security concerns that data-bearing devices or software support will become outdated and incompatible, and that ageing equipment can no longer be maintained. If equipment becomes incompatible with the latest technological developments while still operational, users are forced to replace it before it reaches its end of life.

The digital economy is vital, and multidisciplinary action from industry and policy-makers is needed to encourage sound environmental management of the wireless infrastructure, data centres and IoT devices that enable connectivity. This is an even bigger problem in least developed countries, where recycling and recovery options are more limited and which face additional pressures in the form of exported WEEE.

Circular economy initiatives within these sectors will be important, especially in terms of design to reduce the volume of materials and equipment for disposal, which can be then better regulated through policy. Increased collaboration and standardization among stakeholders all along the supply chain will help achieve this, especially as technology continues to change. Knowledge sharing across sectors will also help identify challenges and opportunities, and improve understanding of circularity and thus business practices. Improving data availability will also help to evaluate developments over time, set and assess targets, and identify best practices in policies. Reuse will be encouraged by reducing material use per product (size and/or mass), improving data destruction options for storage devices, and continuing to apply and improve ecodesign methods for material efficiency and the ability to disassemble components so as to facilitate component upgrade and refurbishment in order to extend product life.

Modularization and standardization of components will continue to play a key role in making refurbishment and recycling more feasible, including reducing the use of critical raw materials and hazardous substances (more research and development in recycling is needed, especially to make this more economically viable). Modular and circular design principles enable flexible equipment and material repurposing and reuse that could reduce WEEE overall. The development and implementation of international standards is key for the sustainable management of WEEE and to help the ICT sector become more circular throughout the value chain. The "as-a-service" business model is also becoming more common, with infrastructure equipment being rented or leased instead of owned, leading to greater control over maintenance and lifespan.

9. Endnotes

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