Digital Future Society

Risks and opportunities of emerging tech in the climate decade

A programme of

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VICEPRESIDENCIA TERCERA DEL GOBIERNO
MINISTERIO DE ASUNTOS ECONÓMICOS Y TRANSFORMACIÓN DIGITAL
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About Digital Future Society

Digital Future Society is a non-profit transnational initiative that engages policymakers, civic society organisations, academic experts and entrepreneurs from around the world to explore, experiment and explain how technologies can be designed, used and governed in ways that create the conditions for a more inclusive and equitable society.

Our aim is to help policymakers identify, understand and prioritise key challenges and opportunities now and in the next ten years in the areas of public innovation, digital trust and equitable growth.

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Published
September 2020

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Executive Summary

The world is undergoing a profound transformation, shaped by powerful trends that are influencing our present and determining our future.

One of these trends, digitalisation, is happening at a much faster rate than any another.

Today, more than half of the global population is using the internet.[1] At the same time, almost 840 million people around the world still lack access to electricity, an average of 26.5 million people have had to migrate over the last decade due to disasters fuelled by climate change and environmental degradation, and for the first time in human history, more than 100 billion tonnes of materials (including minerals, ores, fossil fuels and biomass) entered the global economy in a single year.[2, 3]

To address these challenges, governments, corporations, research groups and other organisations are investigating how technological advances can help overcome this climate and environmental emergency. Special attention is being paid to emerging technologies, given their potential to radically change economies, societies, and the biosphere. But the widespread adoption of emerging technologies also comes at an environmental cost, contributing to climate change and pushing humanity to develop beyond planetary boundaries.

The purpose of this report is to demonstrate that, if adequately leveraged, the emerging tech industry can not only overcome most of its negative environmental and climate impacts but also become a transformative toolbox in the fight against the climate crisis and the environmental emergency. With the right conditions, emerging technologies have the potential to positively impact 103 of the 169 targets of the UN Sustainable Development Goals, significantly contribute to the global transition towards a circular economic model and reduce up to 10 times more carbon emissions than they emit in the same year.[4]

To this end, this report gathers evidence and findings from over 200 sources, including interviews with climate and tech experts, analyses of research papers, articles and industry publications, and the news media. It explores the impacts of emerging tech in terms of environmental degradation, e-waste, energy consumption and greenhouse gas emissions. The report also demonstrates the benefits of digitalisation in creating new and more resource-efficient businesses, in achieving net-zero carbon and de-materialised economies, in making material cycles more circular, and in helping to overcome critical biodiversity and conservation challenges.

The last section of the report is dedicated to formulating a number of recommendations intended for potential game-changers — policymakers and key decision-makers from the public, private, third sector organisations and academia — on how to unlock the potential of emerging tech to boost climate and environmental action at all levels.

Limiting global warming to 1.5°C, or even 2°C, requires a shift from incremental to exponential climate ambition. The digital revolution can help reorient entire industries towards this shift, and usher in net-zero, circular, regenerative economies.

To meet the needs of all within the means of our planet, we must rethink the link between the digital and the physical worlds.[5]

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[1] International Telecommunication Union 2018

[2] United Nations Economic and Social Council 2019

[3] Internal Displacement Monitoring Centre 2020

[4] Global Enabling Sustainability Initiative 2015

[5] Raworth 2017

Glossary

Carbon footprint

The total amount of greenhouse gas (GHG) emissions produced directly and indirectly by an individual, event, organisation, or product, usually expressed in equivalent tonnes of carbon dioxide (CO_2e). Carbon footprint standards usually classify GHG emissions into three types or "scopes." Scope 1 emissions come from directly owned or controlled sources, such as diesel generators or fleet vehicles. Scope 2 emissions are indirect emissions from the generation of purchased energy. Scope 3 emissions are all indirect emissions not included in Scope 2, from activities of sources that are not owned or controlled (for example, emissions associated with the use of public transport, flights or maritime shipping).

Circular economy

Unlike the "take-make-waste" linear model, a circular economy is regenerative by design and aims to gradually decouple economic activity from the consumption of finite resources while designing waste out of the system. Underpinned by a transition to renewable energy sources, the circular model builds economic, natural, and social capital. It is based on three principles: design out waste and pollution, keep products and materials in use, and regenerate natural systems.[6]

Climate crisis

A term describing global warming and climate change, and their consequences. Climate crisis is used to describe the threat of global warming to the planet, and to urge aggressive climate action. The renowned British newspaper The Guardian changed their style guidelines in October 2019 to replace "climate change" with "climate emergency" or "climate crisis" to convey the urgency of this action.[7]

Climate emergency

A situation in which urgent action is required to reduce or halt climate change and avoid the potentially irreversible environmental damage that would result. By June 2020, 1,501 jurisdictions in 30 countries declared a climate emergency, representing over 820 million citizens globally.[8]

Data centre

A building, dedicated space within a building, or group of buildings used to house computer systems and associated components, typically used by organisations for the remote storage, processing, or distribution of large amounts of data.

Emerging technologies (or emerging tech)

Technologies that are years from being fully developed but can radically change business, industry, or society.[9] In this report, emerging tech refers to ICTs in the digital domain. This includes, but is not limited to, distributed cloud and data storage, neural networks, cognitive computing (advanced analytics, machine learning, artificial intelligence), digital reality (augmented reality, virtual reality, mixed reality), modelling simulation, gaming, edge and quantum computing, the (new) internet, fixed and mobile data networks (5G), next-generation robotics, the internet of things, data processing centres, and distributed ledger technologies (blockchain).

Enablement (effect)

Any mechanism which, through its use, facilitates the avoidance of carbon emissions. An example of an enablement mechanism is mobile banking, which allows customers to avoid travelling to a bank branch.

[6] Ellen MacArthur Foundation 2020

[7] Zeldin-O'Neill 2020

[8] Climate Emergency Declaration 2020

[9] Halaweh 2013

Environmental footprint (or ecological footprint)

The effect that a person, company, activity, etc. has on the environment. It is a measure of the demand for natural resources in relation to the earth's ability to restore or replenish the resources consumed.

Environmental Kuznets curve

A hypothesis that describes the relationship between environmental degradation and income level. It has also been used to describe the relationship between ICTs and the environment. This relationship is expected to take the form of an inverted U-shape, with energy consumption and GHG emissions expected to slowly grow with low levels of ICT use but to quickly accelerate with investments in heavy ICT equipment. However, when the ICT equipment is in place, it can be used to optimise production and distribution processes and increase energy efficiency, thereby reducing energy consumption and GHG emissions.

E-waste

Informal name for electronic products discarded after the end of their "useful lives." Computers, mobile phones, televisions, stereos, copiers, and fax machines are common electronic products, many of which can be reused, refurbished, or recycled.

Frontier technologies

Forms of emerging tech. This report will mainly address this subset of technologies when referring to emerging tech. According to the OECD, frontier technologies are those "that will reshape industry and communications and provide urgently needed solutions to global challenges like climate change [...] and have the potential to displace existing processes."[10]

Hyperscale data centre (or enterprise hyperscale)

A facility owned and operated by the company it supports (for example, companies such as Amazon, Microsoft, Google, and Apple).

The term "hyperscale" refers to a computer architecture's ability to scale in response to increasing demand. This typically means increasing computing ability, memory, networking infrastructure, and storage resources.

Information and communication technology (ICT)

A diverse set of tools and resources used to transmit, store, create, share or exchange information. These include computers, servers and data centres, the internet and web technologies, live and recorded broadcasting technologies (radio, television, webcasting, podcasting, audio and video players and storage devices) and telephony (fixed or mobile, satellite, videoconferencing).

Internet of things (IoT) and Machine-to-Machine (M2M)

IoT is the interconnection via the internet of computing devices embedded in everyday objects, enabling them to send and receive data. M2M applications are part of the IoT. M2M describes any technology that enables networked devices to exchange information and perform actions without the manual assistance of humans.

Life cycle assessment (LCA)

A technique to assess the environmental impacts associated with all life stages of a product or service, from raw material extraction through to materials processing, manufacture, distribution, use, and end-of-life.

Moore's Law

The observation that the number of transistors in a dense integrated circuit doubles about every two years. Since the mid-1960s, the power of computer chips has doubled every 18 to 24 months, while the price has halved. For example, the first integrated circuits in 1960 had about 10 transistors while today's most complex silicon chips have 10 billion.

[10] Wilkinson 2019

Planned obsolescence

The calculated act of ensuring the existing version of a product will become dated or useless within a given time frame. For example, in December 2017, Apple apologised to customers for deliberately slowing the performance of older iPhone models without users' knowledge or consent.[11]

Power usage effectiveness (PUE)

A metric for the overall level of energy efficiency of a data centre. It is the ratio of the total energy consumed by the data centre divided by the energy supplied to the computing equipment alone. A PUE value of 1 is optimal, with higher values indicating worse energy performance. A typical PUE for an average data centre is about 1.8.

Rebound effects (Jevons paradox)

The idea that increased energy efficiency leads to increased energy consumption. Although energy consumption at a micro-level (for an individual) goes down, overall energy consumption at the macro-level (for societies) increases due to the combined increase in use by many individuals. Rebound effects can ultimately evolve into the "Jevons Paradox", which occurs when the rebound effect is greater than 100 percent, exceeding the original efficiency gains. A clear example of Jevons Paradox can be observed with office paper. Past decades showed that, contrary to most expectations, ICT did not lead to the paperless office. In fact, actual paper consumption increased several times with the advent of desktop publishing. Paper consumption in the United States between 1960 and 1997 actually increased five-fold.[12]

Telecommunication network

Also known as an ICT network or distribution network, is a transmission system enabling information to be transmitted in analogue or digital forms between various sites through electromagnetic or optical signals. The information may consist of audio, video, or some other type of data. Telecommunication networks are based either on wired or wireless infrastructures. Examples of telecommunication networks are telephone landline networks, mobile networks, cable TV networks and the internet.

Utilisation (rate)

The overall extent to which infrastructure or a device, such as a data centre's servers or a telecommunications base station, is being used. It is usually recorded as a percentage.

[11] Greenfield 2017

[12] Plepys 2002

1

Where emerging tech meets climate

Why this topic now?

The world is transforming in an unprecedented manner, and it is accelerating at a pace and on a trajectory shaped by the confluence of incredibly powerful forces. Five megatrends are currently defining the priorities of our society according to investment firm Blackrock and consultancy PwC. The five megatrends are: rapid urbanisation, demographics and social change, emerging global wealth (or shifts in global economic power), climate change and resource scarcity, and technological breakthroughs.[13, 14] These megatrends are redefining the way the world is operating and what the future will look like.

This report explores the confluence of two of these megatrends: technological breakthroughs and emerging tech that are at the heart of resolving or accelerating each of the five megatrends, and climate change and resource scarcity that are jeopardising humanity's fate.

In spite of the uneven distribution in the access to, use of and impact of digitalisation around the world, globalisation and the ubiquity of technology have fostered the implementation of breakthrough innovations like electric vehicles, e-commerce, solar panels, robotics, blockchain, cloud computing, streaming, and smart grids. Together, they are unleashing a wave of disruption across industries and economies, while also creating vulnerabilities that are challenging our society and planet like never before.

For the first time ever, five environmental issues topped the list of long-term risks in the 15th edition of the World Economic Forum's annual Global Risks Report, with climate action failure at the epicentre of all risks.[15] This is because society is developing beyond "the safe operating space for humanity," or what's been called the "planetary boundaries."[16]

Emerging tech represent a double-edged sword when it comes to the global climate and environmental crises. They have the potential to improve energy demand and efficiency, optimise mobility and transport flows, and contribute to closing the materials cycle. They can also reduce the demand for raw materials and help communities to improve their resilience and adaptive capacity through initiatives such as designing early warning systems, adapting agri-food systems, and installing monitoring and protection systems for infrastructure.

A 2019 Global Enabling Sustainability (GeSI) and Deloitte report shows that the emerging tech can positively impact 103 of the 169 targets of the UN Sustainable Development Goals (SDGs) by 2030.[17] In 2015 GeSI also estimated that by 2030, up to 12 gigatonnes of GHG emissions could be avoided through the use of ICT solutions, an amount nearly 10 times higher than ICT's expected footprint in that year.[18] The Exponential Roadmap report claims that digital technologies could help reduce global carbon emissions by up to 15 percent through solutions in energy, manufacturing, agriculture and land use, buildings, services, transportation and traffic management.[19] And the Frontiers of Impact Tech report makes an exhaustive analysis of over 180 impact tech trends and their contribution to the 17 Sustainable Development Goals

[13] PwC 2016

[14] Blackrock 2019

[15] World Economic Forum 2020

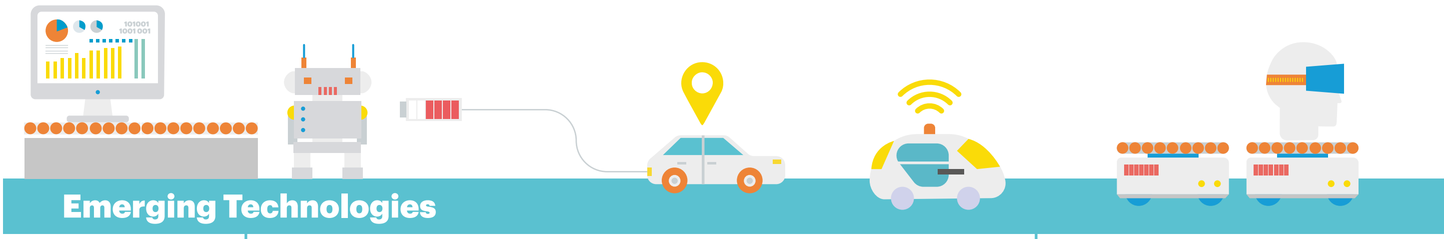
[16] Rockström et al. 2009

[17] Global Enabling Sustainability Initiative 2019

[18] Global Enabling Sustainability Initiative 2015

[19] Falk et al. 2019

How emerging tech can positively impact the SDGs



The digital economy is helping many low-income people access financial services for the first time, a pivotal step in helping people out of poverty.

ICTs help farmers improve crop yields and business productivity through better access to market information, weather forecasts, and training programmes.

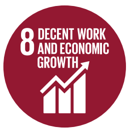
Big Data can help produce snapshots, analyse trends, and make projections about disease outbreaks, health service usage, and patient knowledge, attitudes, and practices.

Mobile devices now allow students to access learning assets anytime, anywhere, helping break down economic barriers, and gender and rural-urban divides.

Digitalisation enables women to gain a stronger voice in their communities, their government and at the global level, as well as provide new opportunities for women's economic empowerment.

ICTs are fundamental for smart water management, facilitating measurement and monitoring of water supply, and ensuring the equitable and sustainable extension of water, sanitation and hygiene services.

Smart grids, smart buildings, smart logistics and industrial processes are helping transform the world towards a more sustainable and energy efficient future.



Digital skills have already become a prerequisite for almost all forms of employment and they are transforming the way business is being done everywhere and creating new employment opportunities.

Figure 1. How emerging tech can positively impact the SDGs. Image source: Digital Future Society. Data source: ITU (2020).

9 INDUSTRY, INNOVATION AND INFRASTRUCTURE

Digital infrastructure is the backbone of our digital economy. 5G will become an essential infrastructure for the 21st-century due to its capacity to power industry and innovation.

13 CLIMATE ACTION

Satellite monitoring plays a crucial role in earth monitoring, sharing climate and weather information, forecasting, and early warning systems to better adapt to the effects of climate change.

10 REDUCED INEQUALITIES

Connectivity allows refugees and other internally displaced people to contact family members, to let them know they are safe, and to stay in touch with the situation back home.

14 LIFE BELOW WATER

Big data can be used to analyse short- and long-term trends in terms of biodiversity, pollution, ecosystem evolution, and to plan mitigation activities.

11 SUSTAINABLE CITIES AND COMMUNITIES

Emerging tech offer options to manage cities more effectively and holistically through smart buildings, smart waste management, intelligent transport, etc.

15 LIFE ON LAND

Satellite-based monitoring delivers timely and accurate data on biodversity on a global basis, while local IoT sensors can deliver on the spot terrestrial updates in real-time.

12 RESPONSIBLE CONSUMPTION AND PRODUCTION

Emerging tech contributes to increased dematerialisation and virtualisation as well as innovative applications enabling sustainable production and consumption.

16 PEACE, JUSTICE AND STRONG INSTITUTIONS

The growing use of open data by governments increases transparency, empowers citizens, and has an important role in crisis management and in humanitarian aid and peacebuilding.

17 PARTNERSHIPS FOR THE GOALS

ICTs accelerate economic growth, social inclusion and environmental sustainability, as well as provide innovative and effective means of implementation in today's interconnected world.

(SDGs) from the United Nations, showing hundreds of examples of how emerging tech can address some of the hardest global issues.[20]

However, emerging tech's environmental impact is staggering. The current energy consumption of the global ICT sector (including entertainment and media) is estimated at between five and nine percent of the world's total electricity use, with a carbon footprint (including both electricity use of running networks and equipment and also the upstream and downstream emissions of the whole sector) equivalent to around two percent of all GHG emissions.[21, 22, 23, 24] This is almost equal to the emissions associated with the fuel consumed by civil aviation transport.[25] A large part of this carbon footprint is due to data centres, cloud services and connectivity.[26] In Europe, according to several recent studies, it is estimated that the ICT sector currently consumes 10 percent of the total amount of electricity consumed in the pre-Brexit European Union (EU) and is responsible for four percent of its GHG emissions.[27]

Addressing the climate and environmental challenges facing our planet is a colossal endeavour. These challenges are complex and include measuring and minimising the climate impact of emerging tech from energy consumption, GHG emissions and e-waste generation. Making data consumption more sustainable and ensuring responsible and ethical resource extraction and technology manufacturing processes are also complex challenges. Opportunity areas include the private sector fostering carbon-neutral (or even climate positive, like recent commitments made by Microsoft[28] and Stripe[29]) and circular economy business models that embed cradle-to-cradle approaches in product and service design. In the public sector, opportunities abound for leadership in designing and adopting regulatory frameworks and incentivising sustainable practices.

[20] Tincq et al. 2019

[21] European Commission 2020

[22] Global Enabling Sustainability Initiative 2015

[23] Ferreboeuf et al. 2019

[24] Belkhir and Elmeligi 2018

[25] International Aviation Transport Association 2018

[26] European Commission 2020

[27] Fundación Patrimonio Natural de Castilla y León and Fundación San Valero and Logroño City Council 2016

[28] Smith 2020

[29] Anderson 2019

Aim and scope

The aim of this report is to identify the risks and opportunities that emerging tech can bring in the fight against climate change and in the achievement of the SDGs. To this end, the report pursues two main objectives:

- To identify and explain, with specific examples, the extent to which emerging tech and the ICT sector are causing negative environmental impacts that are currently pushing society past our planetary limits.
- To identify how emerging tech can not only overcome these negative impacts but also become a fundamental tool to address climate change and global environmental challenges.

In order to raise climate and environmental ambitions and trigger action at all levels, the report targets two types of audiences:

- **Policymakers and regulators:** Policymakers, public servants, and officials at all levels of government (local, regional, national and international), researchers and members of academia seeking to unlock the potential of emerging tech in the fight against climate and environmental emergency. The public sector is a driver in the design and adoption of regulatory frameworks, an investor in mission-oriented innovation, and a leader in creating enabling environments that incentivise sustainable consumption and production.
- **Emerging tech leaders:** C-level decision-makers from the private sector, ICT industry leaders, SMEs, civil society organisations, and other private sector actors concerned with the social impact aspects of digital transformation. The private sector is a crucial player in the development of carbon-neutral/negative ICT infrastructure and in the development of solutions that contribute to the achievement of the global commitments on climate change and the SDGs.

What emerging tech and impacts are we talking about?

The OECD created a list of the 40 most commonly-identified emerging technologies (Figure 2).[30] They are mapped into four quadrants that represent broad technological areas: biotechnologies, advanced materials, digital, and energy and environment.

Figure 2. Emerging technologies for the future and scope of this report. Image source: Digital Future Society. Data source: Adapted from OECD Science, Technology and Innovation Outlook (2016).

[30] OECD 2016

This report focuses on the digital technologies area (Figure 3). There are technologies that share frontiers with other areas and are used in combination (for example, digital sensors or satellites are commonly used with big data analytics) so some technologies classified under the "energy and environment" quadrant are also considered in this report.

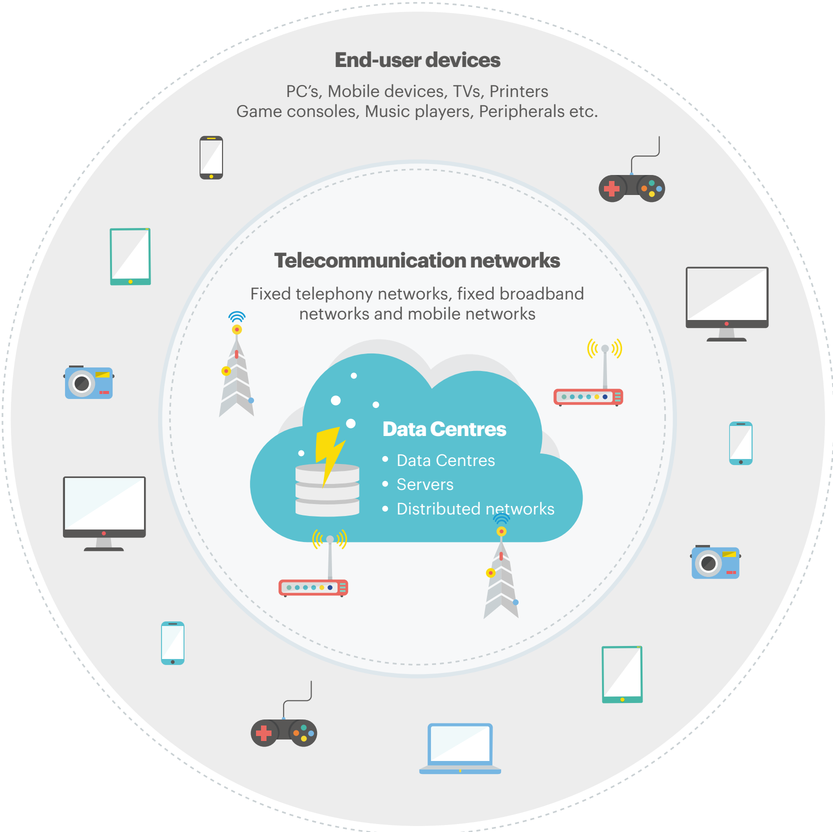


Figure 3. Scope of analysis of this report. Image source: Digital Future Society.

Within this ecosystem of emerging tech, the report analyses ICT solutions (products and services) that fall into the following broad categories:

- End-user electronic devices
- ICT/Telecommunication networks
- Data centres.

However, this is only half of the picture. The ubiquity and use of emerging tech are leading to both positive and negative environmental impacts, both of which are explored in this report. ICTs and emerging tech can generate three types of environmental effects or impacts:[31]

- **Direct effects** are exclusively negative and arise from the manufacturing, use and end-of-life disposal of ICT products (eg hardware such as computers, mobile phones, screens, printers, network cables).
- **Indirect effects** are expected to be largely positive and are related to de-materialisation (eg moving from paper-based to digital media, from compact discs to music streaming services). Indirect effects can also result from more efficient production processes (eg computer-aided design, faster production speeds, better control of production processes).
- **Structural/behavioural effects** can be positive or negative and come from structural and lifestyles changes (eg shifting from industrial to service economies, the growth of the "light industries", green consumerism), including rebound effects (eg growth of long-distance travel), often observed in the transport and energy sector.[32]

[31] Berkhout and Hertin 2004

[32] Economic and Social Research Council 2015

2

Humanity is breaking planetary boundaries

In 2009, a group of 28 scientists from around the world defined a "safe planetary operating space" restricted by nine planetary boundaries within which humanity can continue to thrive and develop: climate change, novel entities, stratospheric ozone depletion, atmospheric aerosol loading, ocean acidification, biogeochemical flows, freshwater use, land-system change, and biosphere integrity. The report examined the planetary conditions that humanity needs to respect and maintain in order to avoid catastrophic environmental changes.[33]

Transgressing one or more planetary boundaries may have fatal consequences due to the increased risk of generating large-scale abrupt or irreversible environmental changes in continental and planetary-scale systems. The report concluded that three of these planetary boundaries have already been crossed — climate change, biodiversity loss, and interference with the nitrogen cycle — and we are fast approaching the limits for freshwater use, land use changes, ocean acidification, and interference with the global phosphorus cycle.

In 2018, another report published by the same group of scientists warned that even if countries succeed in meeting their carbon targets, the world could still be on an irreversible pathway.[34] The study pointed out that reaching an average global temperature increase of 3-4°C will lead to a much higher global average temperature than any interglacial period in the past 1.2 million years and to sea levels significantly higher than at any time in the Holocene era.[35]

With the current carbon pledges, the world is already heading towards a 3°C increase by 2100. This uncontrolled climate change has the potential to collapse ecosystems, with tropical ocean ecosystems exposed to potentially catastrophic temperature rises as early as 2030, and tropical forests could also face the same situation by 2050.[36]

How emerging tech impacts the environment

Our current economic model is an accelerator of the global environmental breakdown we are experiencing. The global economy had been operating in a broadly circular manner up until two centuries ago. It was not until the First Industrial Revolution took place that the twin forces of accelerated resource extraction and consumer demand were unleashed worldwide, driving forward the new linear model of "take-make-waste." The 20th century, after the Second and Third Industrial Revolutions, gave birth to mass production, electricity and electronics, the new ICT, automation systems, and the internet. These developments consolidated the linear economic model and made it run even faster, embedding it deep within our society.

[33] Rockström et al. 2009

[34] Steffen et al.

[35] Ibid.

[36] Trisos et al.

The socio-environmental impact of global digital technology hotspots

Silicon Valley (United States)
Tech companies have admitted deliberate shortening of devices lifespan. They have lobbied against legislation to prevent easier repair of products.

Loudoun County (United States)
Home of 3,500+ technology companies, Loudoun has the largest concentration of data centers in the world. They mostly run on fossil fuels.

Presidente Figueiredo (Brazil)
The Pitinga mine, the world's largest undeveloped cassiterite deposit (Tin), is a historical case of injustice against indigenous people and the environment.

Cauchari Olaroz (Argentina)
With 46 extraction projects, Argentina ranks 4th as global producer of lithium. But claims exist on low attention to human rights and environmental issues.

Agbogbloshie (Ghana)
One of the world's largest e-waste dumps, where millions of tons of e-waste are processed each year in poor and unhealthy conditions.

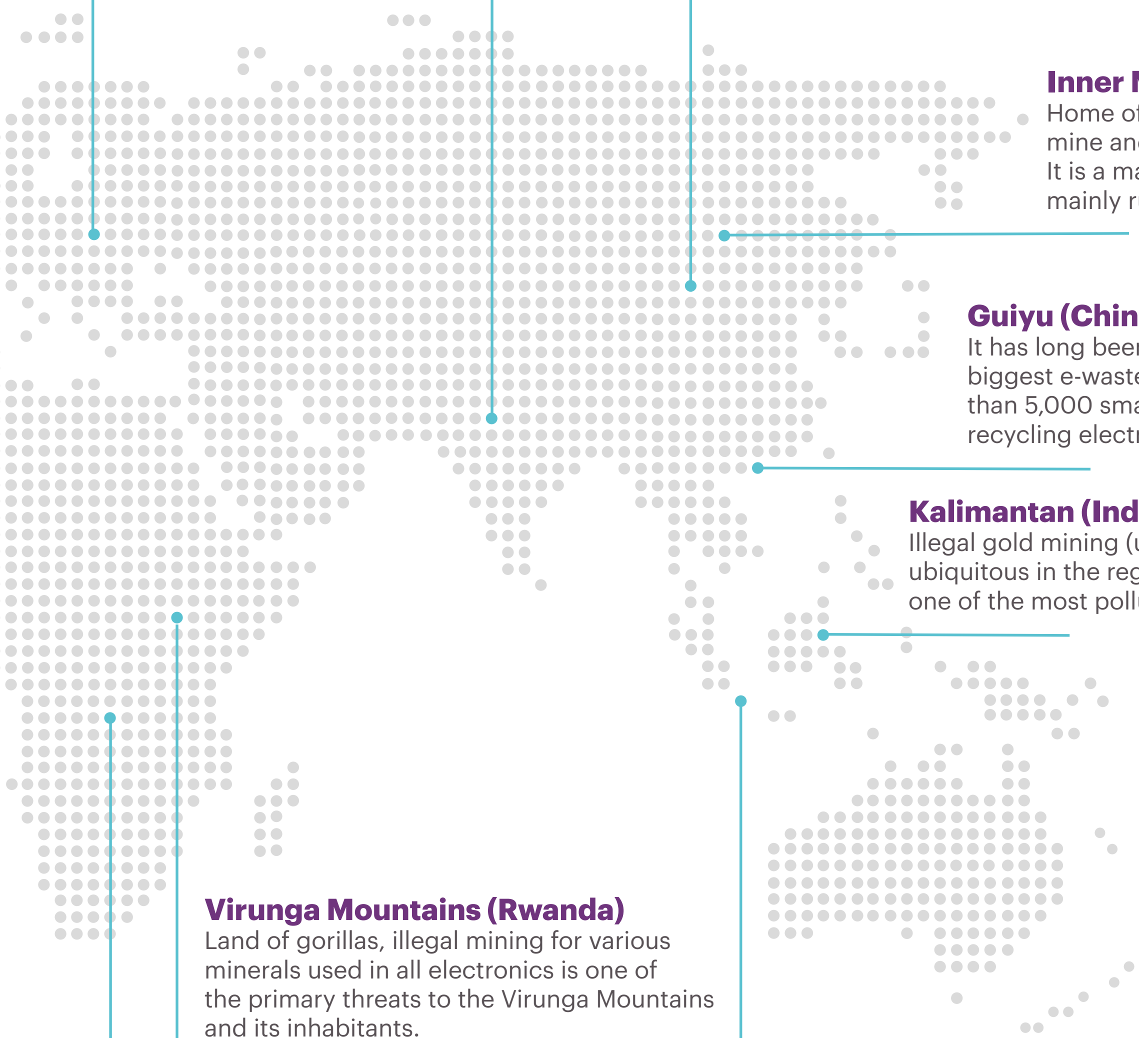
Lagos (Nigeria)
500 containers of e-waste are estimated to arrive to Nigeria each month. They are dumped in three locations in Lagos: Olusosun, Igodun and Ikorodu.

Figure 4. World's socio-environmental impact hotspots of digital technology. Image source: Digital Future Society

European Union (EU)
The EU is the second largest producer of e-waste in the world. Formally, almost 40% is recycled, but illegal exports to developing countries occur.

Seelampur (India)
50,000 people make a living in India's largest e-waste dismantling market. For as little as $4 a day, workers process dangerous, toxic waste by hand.

Taiyuan (China)
Local residents are exposed to toxic gases emitted by the Foxconn factory, a global manufacturer for brands such as Apple, Intel, Amazon and Sony.



Inner Mongolia (China)
Home of China's largest open-pit coal mine and the world's largest data center. It is a major region for bitcoin mining, mainly run on coal.

Guiyu (China)
It has long been considered the world's biggest e-waste recycling site, with more than 5,000 small family-run businesses recycling electronics.

Kalimantan (Indonesia)
Illegal gold mining (used in electronics) is ubiquitous in the region of Kalimantan, considered one of the most polluted places on Earth.

Virunga Mountains (Rwanda)
Land of gorillas, illegal mining for various minerals used in all electronics is one of the primary threats to the Virunga Mountains and its inhabitants.

Kolwezi (Democratic Republic of the Congo)
Tantalum, Tungsten, and Tin (a.k.a. 3TGs), widely used in electronics, are still reported to be produced with forced and child labor in the DRC.

Bangka Belitung (Indonesia)
Bangka Belitung accounts for a third of the global tin supply. Mining is expanding into protected forests and marine ecosystems and residential areas.

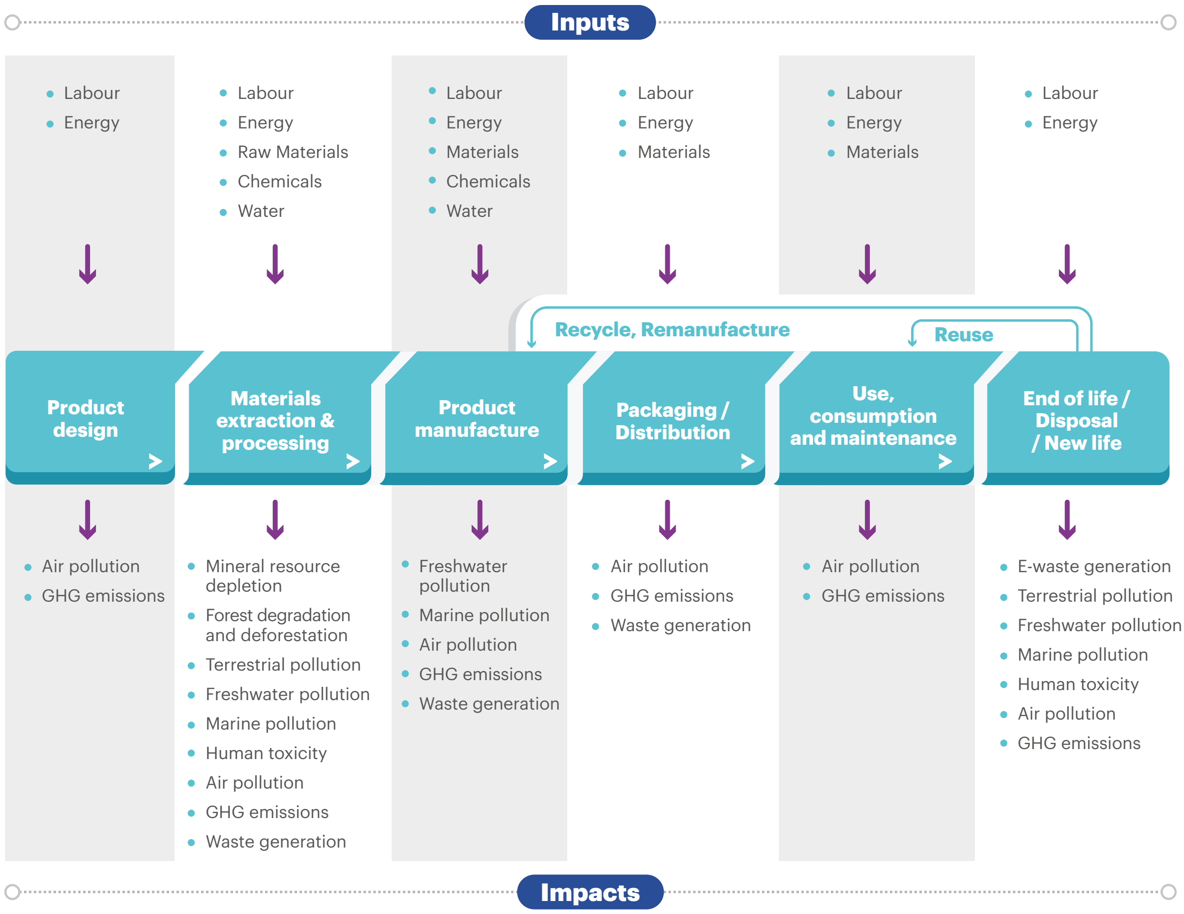


Figure 5. Environmental impacts of ICT solutions during their lifespan. Image source: Digital Future Society.

Linearity is also predominant in the electronics industry, which means that emerging tech are also pushing humanity beyond planetary boundaries. Producing a digital device (eg an AI-powered device) causes environmental impacts all along its value chain, from inception to disposal (Figure 5). Moreover, a number of studies and research papers analysing the environmental effects of ICTs stress the significant increase in energy use and the large carbon footprint associated with the development and use of emerging tech. ICT solutions and emerging tech can cause up to 13 different types of direct environmental impacts throughout their life cycle, from raw materials extraction and processing to the end-of-life and disposal of devices, as shown in Figure 5 and unpacked in the following sections.[37]

Resources in, waste out

In 2017, for the first time in history, more than 100 billion tonnes of materials (including minerals, ores, fossil fuels and biomass) entered the global economy in a single year.[38] Of these, 5.6 billion tonnes were used in the communications sector alone (from mobile devices to data centres).

The raw materials used by electronic brands in their products are not always sourced responsibly. Despite recent efforts made by the industry, mining of these raw materials (usually minerals) often goes hand-in-hand with severe human rights and labour rights violations, as well as environmental abuses (Figure 4).[39, 40, 41]

32.6 billion tonnes of materials were collected as waste in 2017. Only 8.65 billion tonnes of this waste, 8.6 percent of the total material used, were recycled.[42] The difference between the amount of waste that has been lost, (landfilled, incinerated, wasted at mining operations and estimated unregistered waste) and the waste that has been recycled is called the circularity gap.

The ICT sector is no exception to this gap. By 2016, the world had generated 44.7 million tonnes of e-waste, an equivalent of 6.1 kgs per person, with only 20 percent recycled through appropriate channels. The amount of e-waste is expected to increase to 52.2 million metric tonnes, or 6.8 kgs per person, by 2021.[43]

The 1.7 kg microchip

Microchips have a macro impact on the environment. Although the results are now outdated, a popular 2002 study carried out by the IT and Environment Initiative of the United Nations University's Environment and Sustainable Development Programme, found that in that year it took 1.2 kgs of fossil fuels and 72 grams of chemicals to make a 32MB memory chip that weighs only two grams.[44] Additionally, 400 grams of fossil fuels were needed to generate the electricity consumed during the use phase, bringing the total amount closer to 1.7 kgs of fossil fuels and chemicals. This calculation does not include the 32 kgs of water required to make each chip.

[37] Arushanyan 2016

[38] Circle Economy 2020

[39] European Commission 2017

[40] Temper and Martinez-Alier 2020

[41] Good Electronics 2020

[42] Circle Economy 2020

[43] Baldé et al. 2017

[44] Williams et al. 2002. The study was corroborated in 2010 by Duque, Gutowski, and Garetti.

Energy in, emissions out

The digital sector is quickly becoming one of the most power-hungry industries in the global economy. According to various sources, the ICT sector is estimated to consume between five and nine percent of the world's total electricity and to have an associated carbon footprint of 1.4 to four percent of global GHG emissions, with most studies citing two percent as the likeliest figure.[45, 46, 47, 48]

In 2010, 33 percent of the global ICT energy consumption took place in data centres, 28 percent in communication networks and 39 percent in end-user devices (desktops, displays, notebooks and smartphones).[49] By 2020, these figures were expected to be 45 percent, 24 percent and 31 percent respectively.

With the rise of cloud computing, AI, 5G, and the IoT, most estimates of ICT-related energy consumption and carbon footprint predict steady future growth. But this exercise is not free from controversy, as forecasts point to two opposing trends.

Some reports predict that by 2030, data centre electricity use is likely to increase about 15-fold to eight percent of projected global electricity demand.[50] Along these lines, studies suggest that by 2040 the ICT carbon footprint could account for as much as 14 percent of the total global footprint at the 2016 level.[51] However, these predictions may prove obsolete in the coming years, as ICT and telecommunication companies make bolder climate commitments. For example, in February 2020, mobile network operators announced an agreement on setting a science-based pathway to reduce carbon emissions by at least 45 percent by 2030 and to become net-zero by 2050.[52]

On the other hand, institutions such as the International Energy Agency (IEA) estimate that, although data centre workloads will triple their 2014 activity levels by 2020, efficiency gains will cause electricity demand to rise by only three percent.[53] Following this thinking, some studies claim that ICT's carbon footprint might even drift downwards by 2020, as smartphones replace larger devices.[54] In fact, some argue that ICT's carbon footprint stopped growing and entertainment and media's (E&M's) carbon footprints have actually decreased over the period of 2010 to 2015 with electronic device footprints decreasing, while those of networks continue to grow slowly.[55]

[45] European Commission 2020

[46] Global Enabling Sustainability Initiative 2015

[47] Ferreboeuf et al. 2019

[48] Belkhir and Elmeligi 2018

[49] Ibid.

[50] Andrae and Edler 2015

[51] Belkhir and Elmeligi 2018

[52] GSMA 2020

[53] IEA 2017

[54] Ibid.

[55] Malmodin and Lundén 2018

When and where do impacts happen?

Manufacturing and usage are found to be the most environmentally-impactful life cycle stages of ICT products, especially when it comes to the carbon footprint.[56] However, transportation and end-of-life treatment should not be neglected as potential opportunity areas. There is plenty of evidence that environmental impacts happen over the whole lifetime of ICT products (Figure 5), although these vary depending on the product and the stage of the life cycle.[57]

With billions of end-user devices in daily use around the world, this is by far the segment that accounts for the largest share of the total carbon footprint of ICT. Altogether, the carbon footprint from end-user devices (395 million tonnes of GHG emissions) is higher than the GHG emissions of Spain.[58, 59] Typically, half of the GHG emissions associated with end-user devices are related to their usage and the other half to the rest of the life cycle.[60] Desktop computer usage and smartphone manufacturing represent the most substantial carbon impacts within this segment, followed by customer premises equipment, laptops and monitors.

As with telecommunication networks and data centres that are the second and third largest contributors to ICT's global carbon footprint respectively, the GHG emissions associated with the operation of end-user devices account for their largest carbon impact.[61]

Transportation has a rather low impact on the life cycle environmental impacts of many ICT products except for products with low weight (such as mobile phones), given that their components are sourced from hundreds of suppliers located in different parts of the planet.[62, 63] The end-of-life phase of ICT products is also difficult to assess as the well-functioning waste treatment process normally assumed in assessments differs significantly from possible informal recycling processes in reality. Still, waste which is usually associated with the end-of-life of a product, also occurs (in the form of solid discards or gas emissions) in all stages of product development: from mining, to manufacturing, to product use, to the final product disposal.[64]

[56] Arushanyan 2013

[57] Arushanyan 2016

[58] Malmodin and Lundén 2018

[59] Ministerio para la Transición Ecológica y el Reto Demográfico 2020

[60] Malmodin and Lundén 2018

[61] Ibid.

[62] Ibid.

[63] Barboza 2016

[64] Lepawsky 2018

Decoupling: The battle between Moore's Law and the Jevons paradox

Unlinking economic growth from environmental degradation, also known as decoupling, is a battle on two fronts. On one side, there are those who usually cite Moore's Law and maintain that the huge expected increase in activity in the ICT sector triggered by AI, big data, blockchain, and other emerging tech will not necessarily lead to a surge in energy demand thanks to efficiency gains.

On the other side, those who argue against Moore's Law point out two things. First, Moore's Law is gradually declining, as acknowledged by several prominent computer scientists and industry leaders.[65] Second, the risk of rebound effects may supersede any efficiency improvement.

Until recently, most studies have estimated a growing energy and carbon footprint for the ICT sector. But in 2016, a study from Sweden demonstrated that decoupling in the ICT sector is possible.[66] The report showed that the energy and carbon footprint of the ICT and entertainment and media (E&M) sectors had peaked in around 2010 and then started to decrease, despite growing data traffic.[67]

Similar decreasing energy consumption trends have also been reported in Germany and the US. Why? The report argues that the introduction of the smartphone and similar terminal platforms, that replaced older, energy-inefficient hardware and solutions, and the consolidation of various products with different functionalities into one single device are the main reason.[68] The authors believe that the same trends could be seen on a global scale. In the meantime, the decoupling battle rages on.

[65] Blank 2018 and Rotman 2020

[66] Malmodin and Lundén 2018

[67] Ibid.

[68] Ibid.

3

The explosion of digital devices

Digitalisation is currently one of the main levers of economic development and it is happening at a much faster speed than other global trends such as urbanisation. In January 2020, 55 percent of the world's population lived in urban areas, 67 percent had a mobile phone, 59 percent had access to the internet, and 49 percent were active social media users.[69] The average internet user now spends six hours and 43 minutes online each day. This equates to more than 100 days of connected time per internet user, per year.

Globally, with 10 percent annual growth, devices and connections are growing faster than both the population (one percent annual growth) and the number of internet users (six percent annual growth).[70] New devices, with improved capabilities and intelligence, are introduced every year into the market and accelerate the increase in the average number of devices and connections per household and per person.

In 2023, almost 30 billion digital devices are expected to enter in the market globally, roughly three and a half times the forecasted population of that year. Of these, M2M connections will be the fastest-growing category, followed by smartphones, connected TVs (including flat-panel TVs, set-top boxes, digital media adapters, Blu-ray disc players, and gaming consoles), PCs, and tablets.

Tsunamis of e-waste and energy use

As the number of digital devices grows, so does electronic waste. Approximately 50 million tonnes of e-waste are produced yearly, despite two-thirds of the world's population being covered by e-waste legislation. Only 20 percent is formally recycled, the equivalent in weight to all commercial aircraft ever built.[71] If nothing is done, the amount of waste will more than double by 2050, to 120 million tonnes every year.

This is due to the combination of increasing global consumption of electrical and electronic equipment, unsustainable product design, planned obsolescence, lack of reparability options, low recycling rates, illegal exports, and lack of enough efforts to enforce, implement, and encourage more countries to develop effective e-waste policies.

Manufacturing digital devices is a wasteful exercise. Some studies report less than two percent of the material used to produce a PC becomes part of the product, the rest is manufacturing waste.[72] Without recycling, 12 kg of useful material for making a computer can result in 500 kg of mining waste. With adequate recycling practices, the amount of waste could be reduced to 93 kg.[73]

[69] DataReportal 2020

[70] Cisco 2020

[71] Baldé et al. 2017

[72] Hilty and Ruddy 2000

[73] Vereecken et al. 2010

De-materialisation or re-materialisation?

One of the positive indirect impacts of ICTs on production processes, products and distribution systems is de-materialisation. Digitalisation de-materialises by substituting material goods for information, and travel for communication. Some experts see the environmental effects of ICTs as mainly positive because they consider information to be different from materials and energy, and to be acting as a substitute for the use of material resources.

For others with more pessimistic views, ICTs are emblematic of unsustainable production and consumption practices. This is evidenced by the wide-ranging negative environmental impacts of computers and other hardware, especially the expanding waste stream of electrical and electronic equipment.

Today, many countries still have inadequate management systems and legal frameworks to deal with e-waste. Even those with robust legislative and policy frameworks, like the European Union (EU), are experiencing difficulties in enforcing them. Official figures show that almost 40 percent of e-waste in the EU was formally recycled in 2017, one of the highest rates in the world.[74] But, after tracking hundreds of electronic devices sent to recycling facilities across 10 European countries, the 2018 Basel Action Network (BAN) report proved that illegal export of e-waste from Europe to developing countries like Nigeria, Ghana, Hong Kong, Pakistan, Tanzania and Thailand is also happening. BAN has called for these countries to follow China and ban the import of e-waste.[75]

Illegal export of e-waste to developing countries, where inefficient techniques are used to extract materials from it, poses a serious threat to people and to the environment. Inadequate final disposal, incorrect processing and illegal recycling performed by unskilled workers can release toxic substances into the air, soil, and groundwater, causing serious health and environmental problems.

Blockchain for a circular future?

E-waste is worth more than a gold mine. In fact, there is 100 times more gold in a tonne of mobile phones than in a tonne of gold ore.[76] Globally, e-waste material alone is worth 55 billion EUR, three times more than the annual output of the world's silver mines and more than the GDP of most countries.[77]

Conscious of this value, the Platform for Accelerating the Circular Economy (PACE), a public-private collaboration mechanism and project accelerator dedicated to bringing about the circular economy at speed and scale, proposes a system upgrade and change to the circular economy. For this to happen, they recommend several measures such as urban mining

[74] Eurostat 2020

[75] The ASEAN Post Team 2018

[76] Platform for Accelerating the Circular Economy 2019

[77] Ibid.

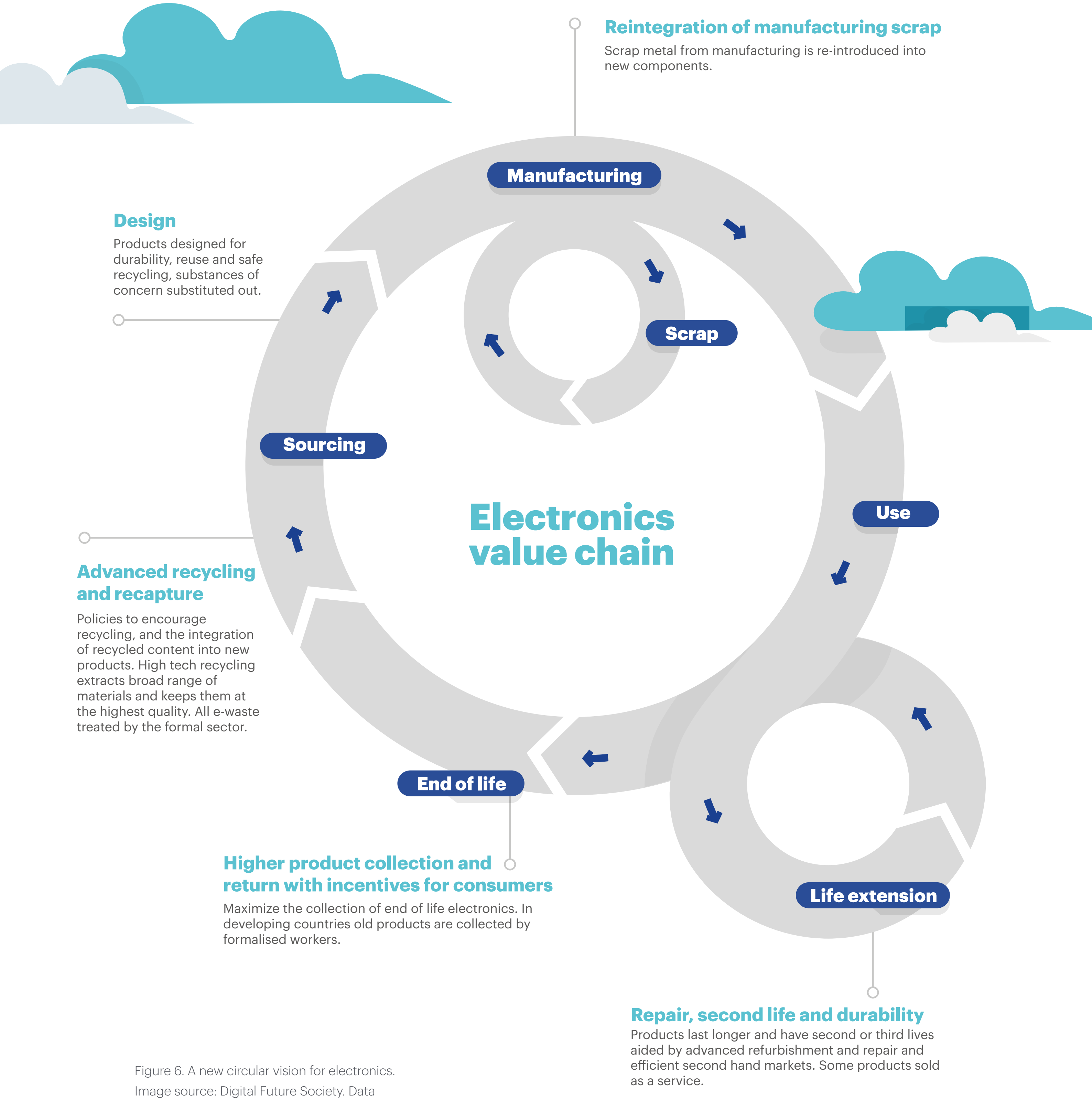


Figure 6. A new circular vision for electronics. Image source: Digital Future Society. Data source: PACE 2019.

(extracting metals and minerals from e-waste), designing long-living products, and reverse supply chain (reintegrating no longer used materials into production), as shown in Figure 6.[78]

Addressing these measures is not as easy as it sounds. Luckily, emerging tech can give a hand. With a blockchain network, producers could more easily respond to offers from consumers looking to recycle their products, accessing minerals more efficiently than gathering them from their original source. For example, in Rwanda, blockchain technology is currently used to certify e-waste components at each stage of use to enable manufacturers to track their products and collect them from end-users.[79] Materials like copper and aluminium are extracted for reuse, and components are used to build new devices.[80]

Blockchain can also add much-needed transparency to ensure accountability and prevent illegal export, with more accurate recycling data and improved tracking. For example, by assigning an encrypted reference to every single item picked up for recycling it would be possible to know what item is being picked up, from where, and which recycling centre it is set to be delivered to. Using a public and decentralised blockchain, organisations would not be able to edit their numbers to meet targets, ensuring transparency.

The Barcelona-based Electronic Reuse Association, through their eReuse project, is using blockchain to expand the life of electronic devices. They ensure a 95 percent recycling rate and transform a cost for municipalities into revenue that stays in the community and creates one job for every 300 items reused.[81] Due to its success, the open-source eReuse project is being replicated in more than 10 other cities in eight countries.

AI and the new wave of energy use

The exponential growth of digital devices is not only a headache for e-waste managers but also a growing concern for energy planners. In 2015, all the world's digital devices put together were estimated to consume more energy than data centres and ICT networks combined.[82] If not addressed properly, this figure is likely to experience a steep increase because of the recent integration of AI into digital devices.

AI is quickly becoming part of many end-user devices, bringing new features and functionalities. The International Data Corporation (IDC) predicts that 27 percent of the growth in AI by 2023 will be in hardware alone, for example with conversational AI systems such as Amazon's Alexa-powered smart speakers.[83] In fact, global spending on AI systems is expected to reach 97.9 billion USD globally in 2023, two and a half times more than the estimated expenditure in 2019.[84] Tech giants like Apple, with more than one billion AI-powered end-user devices, are in the process of building one of the biggest edge computing networks ever for AI, using computation in the cloud and personalised, data-sensitive computation locally on devices.[85]

[78] Ibid.

[79] Kidmose 2019

[80] Ibid.

[81] Zero Waste Europe 2018

[82] Malmodin and Lundén 2018

[83] Ibid.

[84] Rasay et al. 2019

[85] Panzarino 2018

Figure 7. The eReuse approach to dealing with e-waste. Image source: Digital Future Society. Data source: Zero Waste Europe (2020).

All this comes at an energy cost. The firm Applied Materials estimates that in 2020, servers running AI account for 0.1 percent of global electricity consumption.[86] In the absence of significant innovation in materials, chip manufacturing and design, data centres' AI workloads, this figure could rise more than ten-fold in the coming years.[87] In this scenario, quantum computing, that uses quantum mechanical properties instead of the classical binary bits to encode information, could use significantly less energy and lead to lower costs and decreased fossil-fuel dependency as adoption grows.[88]

Deep learning, deeply polluting

Deep learning, a subset of machine learning, is inspired by the workings of the human brain, which is remarkably energy-efficient. Ironically, deep learning appears not to be. According to a 2019 study by the Allen Institute for AI in Seattle, the computations required for deep learning research have been doubling every few months, resulting in an estimated 300,000 times increase from 2012 to 2018.[89]

A University of Massachusetts Amherst study in 2019 revealed that the training process of several common large AI models can emit up to 284 tonnes of CO_2e (based on the average energy mix in the US), nearly five times the lifetime emissions of an average car, or the equivalent of about 300 round-trip flights between New York and San Francisco.[90, 91] Testing AI models is energy-intensive because making accurate models involves processing large matrices of data. The more data that is processed, the more energy is required. To overcome this issue, the authors of the study propose making efficiency an evaluation criterion for research alongside accuracy and related measures.[92]

In response to these studies, and following the suggested approach, researchers from the Efficient and Intelligent Computing Lab at Rice University created an innovative method that could use 10.7 times less energy to train a deep neural network to the same level of accuracy, or better, than typical training.[93] The method, called Early Bird training, finds key connectivity patterns early in the training process, reducing the number of computations needed, and therefore the energy consumed and its associated carbon footprint.[94]

[86] Giles 2019

[87] Ibid.

[88] Brownell 2019

[89] Schwartz et al. 2019

[90] Hao 2019

[91] Strubell and McCallum 2019

[92] Ibid.

[93] You et al. 2020

[94] Ibid.

Future now challenge: adapting to climate change with IoT

Extreme weather events across the world, including floods, storms, droughts, and wildfires, caused more than 100 billion USD worth of damage and thousands of casualties in 2019 alone.[95] Nearly 2,000 natural disasters, many of them fuelled by climate change, triggered 24.9 million new internal displacements across 140 countries and territories, the highest figure recorded since 2012 and three times the number of displacements caused by conflict and violence.[96] If not well addressed these figures are very likely to surge in the future as global warming accelerates.

To mitigate or avoid the impact of extreme weather events, cities and territories around the globe must set up or improve early warning systems that collect timely and relevant meteorological information in a systematic way, to enable prompt reaction in case of emergency.

With increased rates of internet penetration and mobile connectivity, a growing number of initiatives in developing countries and rural areas are proliferating to address these challenges. Taking advantage of emerging low-cost technologies such as IoT technologies and big data, projects are collecting, analysing, and using data to release warnings about the risk of extreme weather events.

For example, thanks to the IoT, citizens in Santo Domingo, Dominican Republic, and farmers in Kayonza, Rwanda, receive timely warnings on their mobile phones when their national meteorological agencies forecast an extreme weather event in their areas.[97] This is also the case in Iceland whose low population nearly all own a smart device and receive updated weather forecasts.[98]

The benefits of IoT do not end there. The increasing popularity of sensors and connected devices can also foster the implementation of innovative techniques. One example is precision agriculture that limits the use of pesticides, fertilisers, and water to the very minimum, and allows farmers to adapt to gradually changing conditions.[99] With climate change's effect on the availability of drinking water, measuring water quality with sensors can also play an essential role in improving processes and reducing cost in water quality management.

Yet, IoT alone is not the solution. The successful delivery of IoT solutions must also address and overcome specific challenges and concerns such as the cost of scaling up implementation, security concerns (eg durability, maintenance and safety of sensors, electricity stability, internet connectivity), ensuring data collection complies with international standards (eg the World Meteorological Organization), and the availability of local technical IT expertise.[100]

[95] Kramer and Ware 2019

[96] International Organization for Migration 2020

[97] Climate Technology Centre & Network 2015

[98] UNDP 2018

[99] Blankers 2016

[100] Ibid.

4

ICT networks: the superhighways of data

As the number of internet users, mobile users and devices connected to the IoT grows, the amount of data generated is also growing. Cisco estimates that the number of IoT connections globally is expected to more than triple, from 7.5 billion in 2018 to 25 billion by 2025. Consequently, global internet traffic is expected to further double by 2022 — after tripling since 2015 — to 4.2 zettabytes per year (4.2 trillion gigabytes).[101] This means that more traffic will be created in 2022 than in the 32 years of the internet's existence.

The Covid-19 pandemic has jumpstarted this trend, with lockdown policies causing a surge in global data traffic. GSMA reports that the energy consumption and carbon emissions from the telecommunication networks have remained mostly unchanged despite significant increases in network traffic.[102] In any case, many countries are now realising that their existing network infrastructure is inadequate, with a growing chorus calling for upgrades.[103]

While video surveillance will drive a large share of the IoT data, the industrial and automotive sectors will see the fastest data growth rates between 2018 and 2025 according to Market intelligence firm IDC. These sectors will use devices that continuously capture data as well as advanced sensors capturing richer metrics and machine functions (audio, image, and video).[104]

But what do internet users consume? An analysis of 2.5 billion users shows that video streaming is currently the number one source of data traffic on the internet, with over 60 percent of the traffic share (for mobile internet the figure is over 65 percent).[105] This is followed by 13.1 percent for web browsing, 8 percent for gaming, and 6.1 percent for social networks.

Environmental impacts of ICT networks

ICT networks have received little attention compared to end-user devices and data centres in terms of analysing their environmental impacts. This translates into fewer studies and less research, which can also be read as an opportunity to increase exploration in this field.

A lack of research does not mean that telecommunication networks are without impact. On the contrary, networks are the second most power-hungry segment within the ICT sector. One report estimated that in 2015, ICT networks (both fixed and mobile) consumed 242 TWh of electricity globally, similar to the electricity consumption of Mexico.[106] This energy consumption is estimated to have released 169 million tonnes of CO_2e in 2015, or 0.34 percent of global GHG emissions.[107]

Although networks are becoming more energy-efficient over time, most studies point out that the predicted surge in data transmission in the coming years will result in more energy consumption.[108] The GeSI SMARTer 2020 study estimated that GHG emissions linked to the use of ICT networks will increase four percent annually for fixed networks and five percent

[101] Cisco 2020

[102] GSMA 2020

[103] ABI Research 2020

[104] IDC 2019

[105] Sandvine 2019

[106] Malmodin and Lundén 2018

[107] Ibid.

[108] Andrae and Edler 2015

annually for mobile networks between 2002 and 2020, to end up reaching around 300 million tonnes of CO_2e by 2030.[109] Other studies have concluded that the figure for 2020 might actually be 24 percent lower than the one estimated by the SMARTer 2020 report.[110]

Lowering the environmental impact of ICT networks is a bold enterprise, and a more complex challenge when compared to data centres. Unlike data centres, which are massive, centralised infrastructures, ICT networks are small, scattered and highly diverse in their characteristics and energy consumption profiles. They range from cellular base towers and stations, to switches and routers, to wired, wireless and smart grid networks. This range of devices will become more complex with the deployment of 5G and the development of edge computing.

Currently, insufficient data is available regarding the global penetration of renewable energy in this specific sector. But what is clear is that tech companies continue to dominate clean energy procurement. In 2019, the top corporate "first movers" for renewables were all tech companies, making the tech sector the largest global buyer of power purchase agreements (PPAs), and by far the largest investor in renewable electricity.[111]

Edge computing: A new opportunity for sustainability?

Edge computing is a new, distributed cloud computing paradigm where computing and storage capabilities are decentralised and pushed to the topological edge of a network. Edge computing brings computation and data storage closer to the devices where it is being gathered, rather than relying on a central location (typically, data centres) that can be thousands of kilometres away. This brings several advantages, such as increased data security and privacy, better, more responsive and robust application performance, reduced operational costs, improved efficiency and reliability, unlimited scalability, and reduced latency.

Edge computing can also bring some energy-related advantages. For example, it can alleviate some overloaded data centres by moving certain operations and processes to more energy-efficient edge devices (that are smaller in size and require less energy for cooling). Base stations or routers are moved closer to the data source, minimising energy consumption due to data transmission. With the ongoing trend of sourcing renewable energy in a distributed manner, one of the benefits of edge computing is that it can consume energy close to where it is generated. It thereby reduces energy supply problems and distribution losses at centralised data centres. Finally, edge computing can play a key role in supporting smart grid applications such as energy demand management and electricity grid optimisation with the adequate use of tracking and monitoring sensors and IoT devices.

The negative side of edge computing, according to a recent report that surveyed 75 edge computing initiatives, is that sustainable developments generally receive too little attention within the framework of edge computing.[112] Therefore, reinforced efforts for the development of roadmaps for sustainable edge computing are needed.

[109] Global Enabling Sustainability Initiative 2015

[110] Malmodin and Lundén 2018

[111] IEA 2020

[112] Hamm et al. 2020

5G: The (mobile) network of networks

5G is considered by many to be the "network of networks" in the mobile industry. Previous generations of wireless technology (2G, 3G and 4G) connected billions of people, where 5G will be able to connect hundreds of billions of people and devices. Compared to 4G, which can simultaneously support up to 60,000 devices per square kilometre, 5G will be able to simultaneously carry more than a million devices per square kilometre, deliver up to 1,000 times as much data, and reach speeds 13 times higher than the average of today's networks. The possibility of using more connected devices will enable cities to become smart cities, workplaces to become IoT workstations, and houses to become smart homes.

The technological rollout of 5G is unprecedented in its magnitude, scale and possibilities. Despite this, it has raised many concerns about energy consumption, which is a hot topic as the climate emergency rises on government agendas. Currently, there are opposing schools of thought on network energy consumption in 5G. On one side, some experts believe that the combination of massive Multiple-input and Multiple-output (MIMO) antennas, legacy networks in multiple bands, and the massive proliferation of small cells will result in a steep overall energy increase.[113] On the other side, other experts point to no overall net increase in energy consumption thanks to more efficient equipment.[114]

Debates aside, with the deployment of 5G networks, devices and services are expected to follow the requirements set in the International Mobile Telecommunications-2020 Standard (IMT-2020), issued in 2015 by the ITU Radiocommunication Sector (ITU-R) of the International Telecommunication Union (ITU). These requirements include specific provisions related to energy efficiency, that expect networks to have the same level of energy intensity as 4G networks and to include sleep modes in the absence of traffic at the base stations.

How AI is making 5G networks more energy-efficient

One of the key characteristics of 5G networks is that they rely on network virtualisation — the process of consolidating hardware and software resources into a software-based, virtual network. Virtualisation brings the possibility of managing the network infrastructure remotely, and therefore saves on travel and its associated carbon emissions.

Taking advantage of virtualisation, equipment vendors have started to offer AI-driven energy-saving solutions, to existing network management platforms. Solutions such as Nokia's AVA and Ericsson's Operations Engine can make energy savings of five to 15 percent on the Radio Access Network (the part of the telecommunications systems that connects individual devices with other parts of a network through radio connections).[115]

[113] Clark 2019

[114] Malmodin and Lundén 2018

[115] GSMA 2019

Whether IMT-2020 requirements will lead to an overall decrease in energy consumption or not remains to be seen. In the meantime, warnings of more data and power consumption are coming from South Korean and Chinese operators, who have been leading the world in 5G deployments since 2019.[116, 117, 118, 119]

Several 5G industry experts share the view that energy consumption will follow an inverted U-shape, with a steep increase in energy use in the short run that will decline in the long term, but is still likely to remain above the initial level. In environmental economics, this is known as the environmental Kuznets curve. Following this line of thought, Ericsson proposes to "break the energy curve" with an ambitious plan for mobile network operators (MNOs) to lower the energy consumption of their 5G networks. The plan, however, like most initiatives in the sector, considers the supply-side only. As explained in the next section, taking full advantage of the indirect and structural effects of emerging tech requires not only developing more sustainable production systems (eg using renewable energy) but also encouraging end-users to adopt more sustainable consumption patterns.

In fact, breaking the energy curve is in the best interest of MNOs. Energy consumption constitutes between 20 to 40 percent of an MNO's network operating costs, and represents one of the highest operating costs, alongside employee remuneration.[120] Therefore, although climate change and sustainability considerations are on the rise, it is in the interest of MNOs to become as energy-efficient as possible, even only for purely economic reasons.

MNOs are not always best positioned to drive energy efficiency because they usually lack specific in-house technical expertise.[121] With some exceptions, energy is usually seen as an expense line item that is out of their control management, and most of their efforts are put in ensuring the quality of their networks and their reliability. This is when energy as a service (EaaS) comes in. Instead of developing in-house energy capacity and expertise, EaaS offers a new business model that promotes MNOs partnering with outside experts, usually known as energy service companies (ESCOs), for the purpose of regaining control over energy spending. Industry giants like Telefonica, Deutsche Telekom and AT&T are already taking advantage of it.[122]

There is an ongoing trend across the world of MNOs that are in the process of selling off their tower assets, including the energy infrastructure, to ESCOs.[123] This trend is expected to intensify in the 5G era bringing a high degree of customisation across multiple tower sites, specific technical expertise, and improved energy management. Nevertheless, 5G is a complex regulatory field and authorities are not always in favour of outsourcing towers and other equipment as it may lead to reduced competition.

Lastly, but not least important, is the growing public concern about the potential adverse effects of wireless networks on human health and the environment. Since 2011, the World Health Organization (WHO) and the International Agency for Research on Cancer (IARC) have classified radiofrequency electromagnetic fields (EMFs) as "possibly carcinogenic" to

[116] Clark 2019
[117] Hardesty 2020
[118] Waring 2019
[119] ZTE 2020
[120] GSMA 2019
[121] Ibid.
[122] GSMA 2020
[123] Ibid.

humans.[124] In the same group are other "possibly carcinogenic" agents such as aloe vera, carpentry and joinery, and oxazepam.

Some of the most recent research findings on EMFs were published by the WHO in February 2020. In relation to 5G, the WHO stated that "to date, and after much research performed, no adverse health effect has been causally linked with exposure to wireless technologies." Nonetheless, the WHO acknowledges that, due to its novelty, only a few studies have been carried out on the frequencies used by 5G.[125]

To improve the knowledge base, the WHO is currently conducting a health risk assessment for exposure to radio frequencies to be published in 2022.[126] In addition, the EMF-Portal, a project of the University Hospital RWTH Aachen in Germany, is compiling an extensive database with over 31,400 publications and 6,700 summaries of individual scientific studies on the effects of electromagnetic fields.[127] Among these, over 430 studies are specifically related to 5G.

The European Commission has not yet conducted studies on the potential health risks of 5G technology, but the European Parliament has reviewed existing research and concluded that "whereas researchers generally consider such radio waves not to constitute a threat to the population, research to date has not addressed the constant exposure that 5G would introduce."[128]

While more research in EMFs is underway, precautionary and proportionate actions are being proposed and taken by various public administrations (including the European Environment Agency) to avoid plausible and potentially serious threats to health resulting from EMFs.[129]

Future now challenge: video streaming and gaming

Video streaming, along with virtual reality (VR), augmented reality (AR), and gaming are challenging sectors to watch for two main reasons. The first reason is that altogether they represent around three-quarters of the global data traffic and they are expected to exceed 80 percent of the global share soon with 4K, 8K, AR and VR going mainstream.[130]

The second reason is that video devices can have a multiplier effect on traffic. A single 4K video is three to five times larger than an HD video, and an 8K video grows another three to five times from a 4K video. This means that an Internet-enabled HD television that displays two to three hours of content per day from the internet would generate as much traffic as an entire household today, on average.[131] And this is even worse for gaming. A single download of the game, Call of Duty: Black Ops, is equivalent to 14 hours of 4K viewing.[132]

[124] International Agency for Research on Cancer 2011

[125] World Health Organization 2020

[126] Flores 2020

[127] Research Center for Bioelectromagnetic Interaction 2020

[128] European Parliament 2020

[129] Ibid.

[130] Cisco 2020

[131] Sandvine 2019

[132] Ibid

These trends are driving exponential growth in demand for data centre and network services. For this reason, organisations like the Paris-based Shift Project are calling for a shift towards digital sobriety. Digital sobriety proposes prioritising allocations of resources for digital uses to conform to physical constraints while still preserving the most important societal contributions of digital technologies.

Among the measures the Shift Project proposes to advance toward digital sobriety are:

- **Limit offerings of flat rates whose prices are uncoupled from the volumes consumed.** Instead, offer low-cost subscriptions that give access to more limited volumes of data. This would result in consumption regulation mechanisms, by setting up an adjustable pricing system to access data.
- **Regulate addictive design techniques.** Addictive design means the techniques of building platforms that broadcast content aimed at maximising the amount of time spent by the user on the platform. Auto-play videos (like those on TikTok, YouTube or Netflix), embedded advertisement videos, and recommendations and notification mechanisms. Regulation in this field would aim to redesign platforms to orient behaviours to a more precise selection of the content consumed. Therefore, it would reduce the volume of content consumed and would be more consistent with a user's needs and behaviours.

5

Data centres and enterprise networks: the brains of the internet

Most of the world's internet protocol traffic goes through data centres. These "brains of the internet" process, store and manage most of the internet's data, from streaming video and gaming, to email, social media, online collaboration, and scientific computing.

With over 4 zettabytes of data traffic expected to be generated annually by 2022, data centres will continue to play a vital role in the receipt, computation, storage, and management of information. But the boom in data centres over the last decade is coming to an end. According to the IDC, the number of data centres worldwide peaked at 8.55 million in 2015.[133] After that, the numbers began declining and the figure was expected to drop to a forecasted 8.4 million in 2017. Following this downward trend, by 2021 the number of data centres is expected to be down to 7.2 million data centres globally, more than 15 percent fewer than in 2015.[134]

Conversely, the number of hyperscale data centres is growing non-stop and 2019 closed with 512 of these large facilities (a 31 percent increase from 390 at the end of 2017) with that number expected to continue growing in 2020.[135] This is the result of a consolidation process of data centre facilities in an effort to reduce operating costs and become greener. Moreover, businesses are now renting an increasing amount of server power from third-party providers, and the vast majority are turning to hosted or hybrid cloud services. According to the Uptime Institute, half of all workloads will be run outside enterprise data centres by 2021, either in cloud or non-cloud data centres or at the network edge.[136]

Data centre energy consumption

Everything that happens in the virtual world impacts the physical one. With rising global connectivity driving up demand for data centre services, energy use (mostly electricity) is likely to soar, with multiplier effects. For every bit of data that travels the network from data centre to end-user, another 5 bits of data are transmitted within and among data centres.[137]

At the time of writing, there is no certainty on what the global energy consumption of data centres is because only a few companies, including Google, Apple, Switch, and Facebook, publicly report such data. Estimates vary depending on the source. Some studies estimate that in 2010 data centres consumed one percent of the global electricity use, most conservative estimates suggest that this level of consumption was not reached until 2018.[138]

Using this conservative approach, the International Energy Agency (IEA) claims that the growth in energy use has been substantially decoupled from the growth in data centre computing because energy consumption has only increased six percent since 2010, while global IP traffic has increased more than ten-fold, and at the same time the global data centre storage capacity has surged by a factor of 25.[139]

[133] IDC 2018

[134] Ibid.

[135] CRN 2020

[136] Cisco 2020

[137] IEA 2019

[138] Masanet and Lei 2020

[139] Ibid.

How is energy used in a data centre?

Data centres are composed mainly of servers, precision cooling equipment (such as chillers and computer room air conditioners) and power equipment (such as switchgear, uninterruptible power supply and battery backup) that ensures adequate power supply both to the servers and the cooling systems.

On average, servers and cooling systems (including energy distribution) account for more than three-quarters of the direct electricity use in data centres, followed by storage drives and network devices.

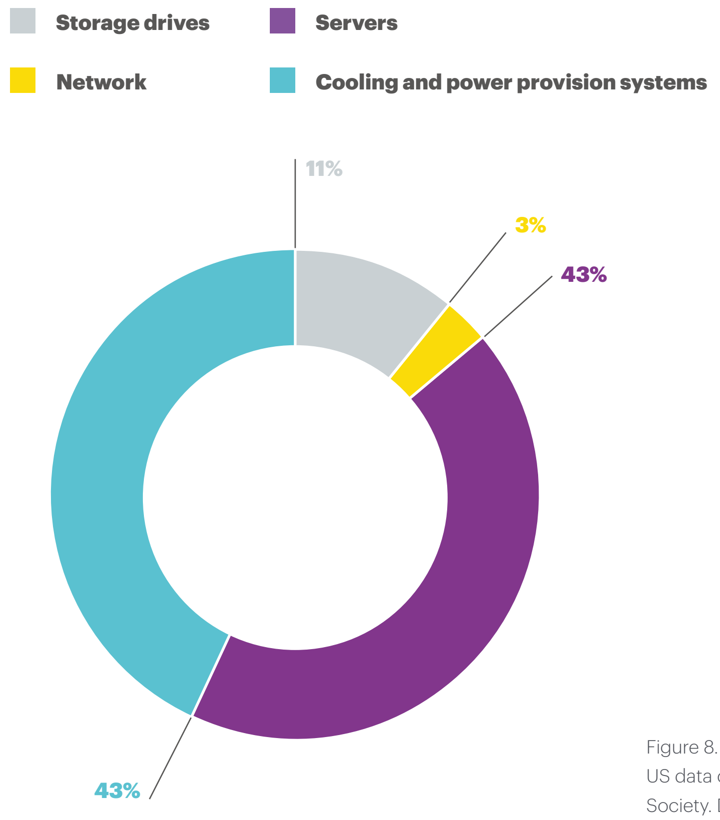


Figure 8. Breakdown of energy use in a typical US data centre. Image source: Digital Future Society. Data source: Shehabi (2016).

When efficiency means profits

Typically, most enterprise data centres focus on reliability rather than on efficiency, because their managers are essentially rewarded for maintaining uptime, not for doing it efficiently. Hyperscale data centres and commercially operated cloud data centres, such as Google Cloud, Microsoft Azure, IBM Cloud, and Amazon AWS, are much better optimised for efficiency.[140] These operators have strong business incentives to waste less energy, because it is a relevant operating cost that affects profit margin. This translates into substantial differences in efficiency performance. More efficient servers and data centre facilities, higher server utilisation and use of renewable energy mean that the carbon footprint for the same server performance on the AWS cloud is estimated to be 88 percent lower than the median of an enterprise data centre.[141]

In a global survey by Supermicro in 2019, a large percentage of data centre leaders reported that overall data centre performance, with metrics like total cost of ownership (TCO) and return on investment (ROI), were their primary measures of success. Whereas success factors more closely associated with green data centres, such as efficiency, power usage efficiency (PUE), and total cost to the environment (TCE) were mentioned much less often (Figure 9).[142]

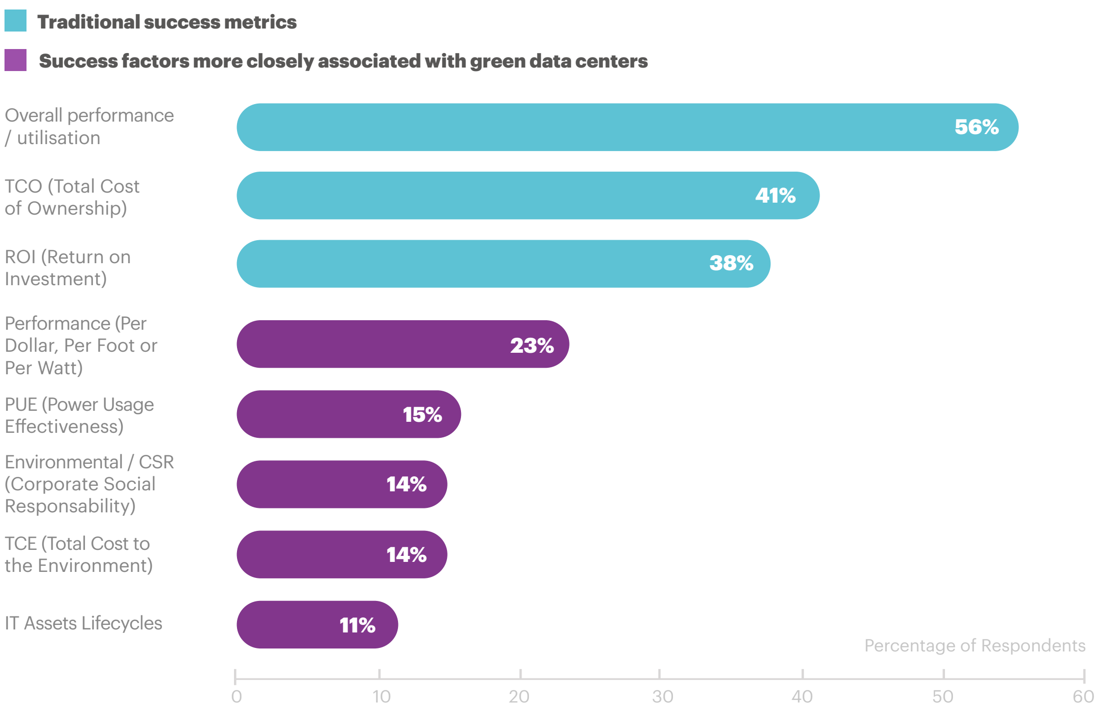


Figure 9. Results of a survey on success factors of data centre infrastructure. Image source: Digital Future Society. Data source: Supermicro (2019).

[140] Sverdlik 2020 [141] Bizo 2019 [142] Supermicro 2019

Data centre users are not much more environmentally aware either. In its first annual Data Centres and the Environment report in 2018, Supermicro found that many businesses underestimate the importance of efficiency. Only 28 percent of respondents said that they actually consider environmental issues in the selection of data centre technologies, and just nine percent indicated energy efficiency as the top criterion when setting data centre design strategy. Instead they prioritised security, performance and connectivity.[143]

All in all, data centres are becoming more energy-efficient over time. The Uptime Institute has tracked the energy efficiency industry average globally over the last 12 years (Figure 10). Energy efficiency has been consistently improving year after year with the only exception being 2019, probably due to more extreme weather conditions and lower utilisation in many data centres as certain workloads moved to public cloud services.[144]

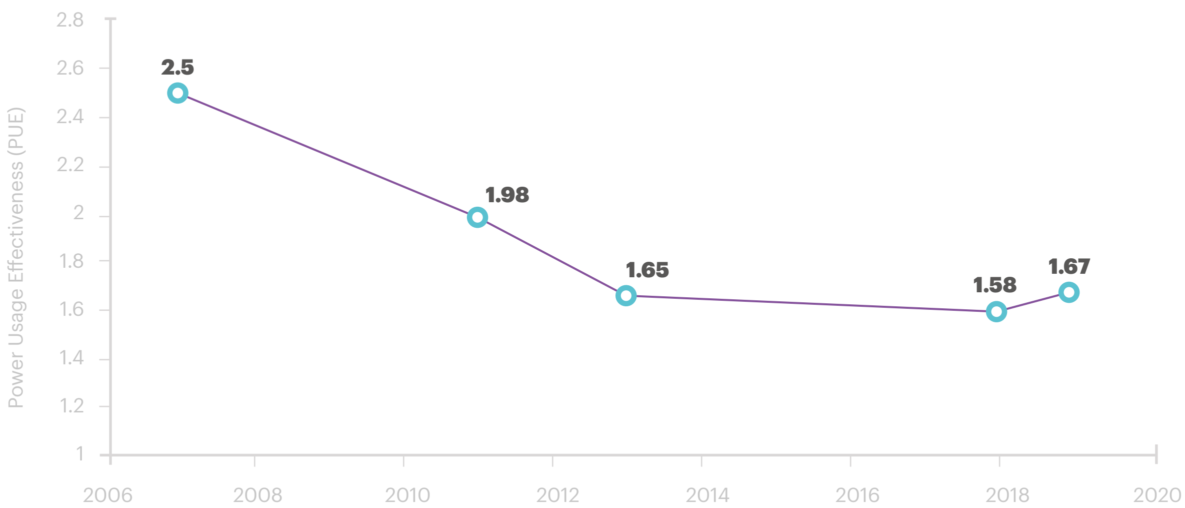


Figure 10. Evolution of the global average annual PUE. Image source: Digital Future Society. Data source: Uptime Institute 2020.

[143] Supermicro 2018

[144] Lawrence 2019

Regionally speaking, in 2018 European and US data centres had an average reported PUE ranging between 1.7 and 1.8.[145] China's average PUE in the same year was reported to be between 2.2 and 3, although this value goes down to 1.5 for China's 15 largest cloud and data centre companies.[146] Furthermore, the electricity consumption of China's data centre industry is on track to increase by 66 percent between 2019 and 2023.[147]

In 2016, Google set a pioneering benchmark for the energy efficiency potential of data centres. And the company's data centres were able to reduce PUE to an average of 1.1 in the last quarter of 2019.[148] Part of this success is due to the use of machine learning to cool its data centres more efficiently. At first, it helped the tech firm cut its cooling energy costs 40 percent by making recommendations to human operators. Today, cooling is fully controlled by an algorithm.[149]

Cooler is not always better

Although data centres can be found all over the planet, location is also an important factor for energy performance. Both Apple and Facebook have built data centres near hydropower resources to get access to affordable, reliable, and clean energy.[150] Companies building data centres also look for cooler climates. In 2017 Google bought 109 hectares of land in rural Sweden, near the Arctic Circle, where the cool climate allows the data centres to save energy on cooling.[151] In 2018 Microsoft launched Project Natick, their research project to determine the feasibility of underwater data centres powered by offshore renewable energy.[152]

Access to fibre networks, the price of energy, the source of energy, and the surrounding environment all play a role in choosing where to build data centres. It can be argued that locating these facilities in remote areas may be bad business, and also bad for the environment. Long distances affect the reliability, latency and cost of distributing data due to the energy required for transmission, including potential power losses.

[145] Open Compute Project 2018

[146] Greenpeace East Asia 2020

[147] Ibid.

[148] Google 2020

[149] Knight 2018

[150] CB Insights 2019

[151] Moss 2017

[152] Microsoft 2020

How data centres generate e-waste

E-waste is another relevant by-product of a data centre's refresh activities. Data centres need to periodically replace ageing technology to take advantage of new product features and enhancements that support their business goals, including energy efficiency.

Data centres deal with the "optimal refresh cycle", the periodic replacement of existing servers with new ones. The optimal data centre refresh rate depends on a trade-off between reducing capital expenditures and e-waste vs reducing operational expenditures such as energy costs. Keeping servers longer appears to reduce acquisition costs and e-waste, but new servers are more energy-efficient and provide more computer cores and better performance. According to Supermicro's survey, today the average server refresh cycle stands at 4.1 years, with the refresh cycle getting longer, not shorter.[153]

One solution, an example of circular thinking, is using disaggregated servers. By using disaggregated server architecture, data centres can reuse longer life cycle sub-elements of servers, such as the power supply, to enable a reduction in refresh cycle costs as well as e-waste. Despite these benefits, circularity is far from a common industry practice. Today, only 37 percent of data centres worldwide report applying circular thinking and repurpose their hardware to other tasks to extend product life cycles.[154]

[153] Supermicro 2019

[154] Ibid.

From data centres to district heating

Residual heat is another type of waste produced by data centres. But far from treating it as waste, a growing number of data centres are redirecting the heat from their hot aisles to nearby homes, offices, greenhouses and even swimming pools. The ability to reuse excess heat from servers is being built into new data centres, helping to improve the energy efficiency profile of these facilities, and pairing it with heat-consuming operations like district energy systems, creating a closed-loop system that has no waste.

This is not a new idea and dozens of facilities in Europe and North America are already benefiting from this circular thinking. In fact, using waste heat is expected to become a major industry trend in the near future, especially in the Nordic countries where heat demand is high.[155]

In Denmark, Facebook's Odense Data Centre has been designed to recover 100,000 MWh of energy per year, enough heat to warm 6,900 homes. This energy will be recovered from the servers and recycled by a newly constructed heat pump facility powered by 100 percent clean and renewable energy.[156]

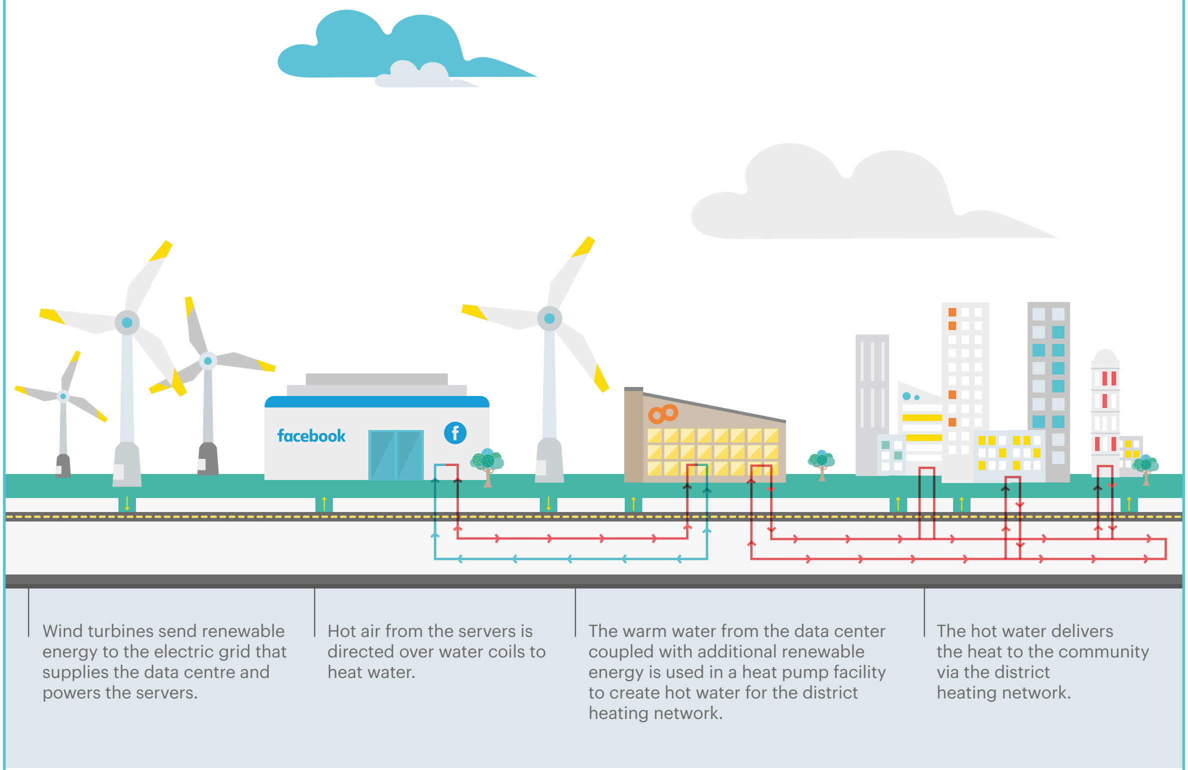


Figure 11. Heat recovery process at Odense Data Centre (Denmark). Digital Future Society. Data Source: Facebook (2017)

[155] Wahlroos et al. 2017

[156] Facebook 2017

Water consumption: The forgotten metric

Water consumption is rarely considered when monitoring and reporting a data centre's environmental impact. Still, data centres consume a huge amount of water for cooling. The cooling process for data centres often involves evaporating water with cooling towers or evaporative coolers.

Since many data centres operate in areas where water is or may soon become scarce, water usage effectiveness (WUE) is becoming a critically important metric. Today WUE is included in the ISO standard for data centres (ISO/IEC 30134-5:2017), a voluntary international standard that provides common standards, but whose adoption is rare.[157]

WUE is calculated as the ratio between water used at the data centre and electricity delivered to the IT hardware. According to a US Department of Energy report, the WUE of an average data centre in the US is 1.8L per kWh.[158] Facebook claimed in March 2019 to be the first and only company (to their knowledge) to report WUE numbers publicly. In 2017, their data centres reported being nearly eight times more efficient than the industry standard, with an average WUE of 0.24 L/kWh, avoiding the use of over 5.6 billion litres of water, the equivalent of filling 18.5 million bathtubs.[159]

Future now challenge: carbon-neutral data centres

The digital transformation must be carbon-neutral. In Europe, data centres and telecommunications (including cloud services) will need to become more energy-efficient, reuse waste energy, and use more renewable energy sources. They can and should become climate neutral by 2030, according to a recent communication of the European Commission.[160] In the UK, in line with the country's commitment to reach net-zero GHG emissions by 2050, data centres are also expected to meet net-zero targets.[161]

How will data centres become carbon-neutral? In November 2019, TechUK released its UK Data Centre Sector: Energy Routemap with the aim of reaching net-zero carbon emissions. They plan on reaching carbon neutrality through the following 10 target areas and objectives:

1. **Strategies, policies and targets:** Data centre operators should develop clear energy strategies and make ambitious climate change commitments.

[157] International Organization for Standardization 2017

[158] Shehabi et al. 2016

[159] Facebook 2019

[160] European Commission 2020

[161] TECH UK 2019

2 **Security of supply:** Data centres need a secure and stable supply of electricity. The sector must be prepared for a range of temporary supply issues.

3 **Energy stewardship:** The sector must demonstrate best practice in energy efficiency, comply with relevant standards and measure progress using robust performance metrics.

4 **Renewables adoption:** The sector must commit to renewable power for its energy needs. Operators should be implementing strategies to reach 100 percent well before 2050.

5 **Becoming an energy prosumer (both a producer and consumer of energy):** The sector needs to find ways to reduce overall reliance on the grid and become a more dynamic player in the energy market.

6 **Disclosure and reporting:** Data centres should measure and report energy consumption robustly and consistently in order to monitor progress and identify trends.

7 **Transparency:** Data centre operators must help customers understand the energy impacts of their digital activities.

8 **Heat reuse:** The sector should make better use of its waste heat.

9 **Air quality:** Operators should adopt practices that minimise air quality impacts from standby generators.

10 **Regulation:** The sector will work with regulators to help make policy fit for purpose.

6

How emerging tech can benefit the environment

The world needs to halve emissions and meet the SDGs by 2030 to limit global warming to 1.5°C and to build a more equitable, sustainable, and fair society. If sufficient policy and investment is implemented, digitisation can be a key driver to meet the SDGs. Some reports already point out that mobile communication technologies are having a major climate-positive impact on our planet.

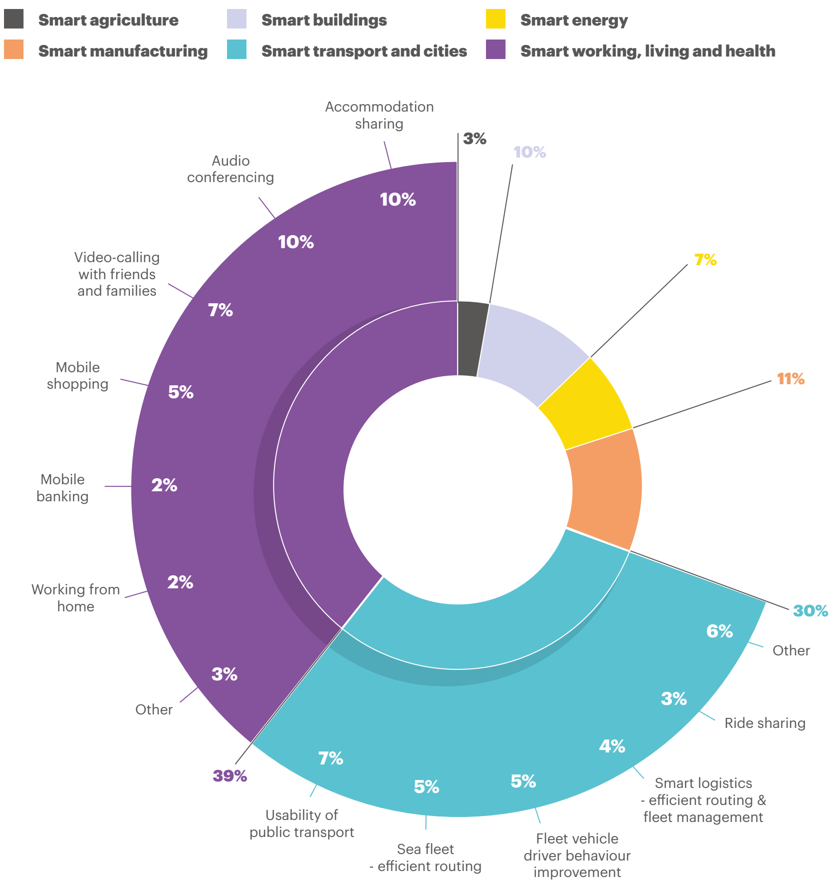


Figure 12 Enabled avoided carbon emissions by category in 2018. Image source: Digital Future Society. Data source: GSMA (2019).

In 2018, mobile communication technologies were estimated to have avoided 2.135 million tonnes of CO_2e globally, equivalent to nearly all of Russia's GHG emissions for 2017.[162] This is almost 10 times more than the carbon footprint of the mobile sector.[163] Most of these avoided emissions resulted from a decrease in energy use — electricity, gas, and fuel consumption.

In that same year, mobile communications technologies enabled a 1.44 billion MWh decrease in electricity and gas usage, and 521 billion litres less fuel used globally.[164] These totals are enough electricity and gas to power more than 70 million houses for an entire year in the US, and enough fuel for all 32.5 million registered UK passenger cars to drive for 19 years.[165]

Smart M2M technologies coupled with behavioural change around the personal use of smartphones are an alternative solution to high emission products and services across all sectors. Through the enablement effect, mobile communications technologies can improve energy efficiency in buildings, reduce transport emissions, decrease energy use in manufacturing, and improve coordination and distribution efficiency of smart grids.

[162] GSMA 2019

[163] Ibid.

[164] Ibid.

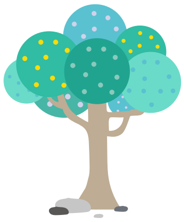
[165] Ibid.

AI for the earth

In 2018, the World Economic Forum (WEF) published a wake-up call report to leverage AI's transformative potential to address the Earth's environmental challenges.[166] The report envisaged that the intelligence and productivity gains of AI can unlock new solutions to society's most pressing environmental challenges, such as climate change, biodiversity, ocean health, water management, air pollution, and resilience.

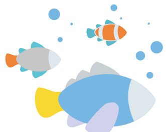
Climate change

- Clean power
- Smart transport options
- Sustainable production and consumption
- Sustainable land-use
- Smart cities and homes



Biodiversity and conservation

- Habitat protection and restoration
- Sustainable trade
- Pollution control
- Invasive species and disease control
- Realizing natural capital



Healthy Oceans

- Fishing sustainably
- Preventing pollution
- Protecting habitats
- Protecting species
- Impacts from climate change (including acidification)

Water security

- Water supply
- Catchment control
- Water efficiency
- Adequate sanitation
- Drought planning

Clean air

- Filtering and capture
- Monitoring and prevention
- Early warning
- Clean fuels
- Real-time, integrated, adaptive urban management

Weather and disaster resilience

- Prediction and forecasting
- Early warning systems
- Resilient infrastructure
- Financial instruments
- Resilience planning

Figure 13. Priority action areas for addressing Earth challenge areas. Digital Future Society. Source: PwC 2018.

Aware that, left unguided, AI can also accelerate the environment's degradation, WEF advocates for the responsible use of AI. AI adopters must ensure that sustainability principles are embedded alongside wider considerations of AI safety, ethics, value, and governance.[167] This translates to developing checks and balances to ensure that evolving AI systems remain "friendly" and must incorporate the health of the natural environment as a fundamental dimension.

[166] WEF 2018

[167] Ibid.

In 2017 Microsoft launched AI for Earth, a programme to put AI technology into the hands of the world's leading ecologists and conservationists.[168] The initiative intends to bring game-changing environmental innovations by offering access to data, machine learning tools, and systems to share and build on the work of others.[169] One of the main outputs of the programme is the Planetary Computer, a platform that grants the AI for Earth community access to, and capacity to analyse, trillions of data points collected by people and by machines in space, in the sky, in and on the ground and in the water.[170]

In 2019, a group of volunteers from academia and the tech industry gathered to launch Climate Change AI, an initiative to seize the potential of machine learning to help tackle the climate crisis.[171] As part of the initiative, a 22-person team — including some of the world's leading AI and climate researchers — published a paper detailing how artificial intelligence can tackle climate change, through either effective engineering or innovative research in 13 different areas, including transportation, climate prediction and education.[172]

Starting in 2021, as part of the European Green Deal, the European scientific and industrial community will collaborate to develop a high-precision interactive model of the Earth. This ground-breaking initiative, named Destination Earth (also known as the European Space Agency Digital Twin Earth Challenge), will offer a digital modelling platform to visualise, monitor and forecast natural and human activity on the planet.[173, 174] The initiative aims to increase the exposure and understanding of Earth satellite observation data combined with AI, IoT and machine learning, cloud computing and data analytics in support of sustainable development.

[168] Microsoft 2020

[169] Ibid.

[170] Ibid.

[171] Climate Change AI 2019

[172] Rolnick et al. 2019

[173] European Commission 2020

[174] Copernicus Masters 2020

Exponential technologies and the carbon law

Limiting global warming to 1.5°C requires moving from incremental steps to an exponential leap in climate ambition. This is the approach proposed by the Exponential Roadmap Initiative (ERI), who pursue the goal of reaching net-zero GHG emissions by 2050. To do that, ERI proposes to follow what they call the "carbon law," which is an exponential trajectory, inspired by Moore's Law, that cuts GHG emissions in half every decade.[175]

To follow the carbon law, ERI presents an Exponential Roadmap containing 36 solutions and seven strategies to scale the transformation across six sectors: energy, industry, transport, buildings, food consumption, and nature-based solutions (sources and sinks).[176] These solutions require the involvement of cities, businesses and individuals, and are meant for a fast transformation to improve efficiencies in energy and material usage, reduce demand for energy-intensive activities, electrify as much as possible, produce electricity from renewable energy sources, shift agriculture from a carbon source to a carbon sink, and scale up carbon capture and storage.

Achieving the planned rapid transition across all economic sectors to shift towards sustainable consumption and production patterns requires a digital revolution. The exponential technological development that AI, cloud computing, blockchain, 5G and the IoT can bring, will be part of it. With the right implementation, these technologies can considerably reduce energy consumption and material waste in all sectors, while supporting global health, sustainability, biodiversity, and economic goals. They can also accelerate shifts to new disruptive business models.[177] There is still a missing piece that can make a significant impact in this much-desired new scenario, which is deeply connected with digitalisation: the circular economy.

Closing the loop with digitalisation

The digital revolution can redefine how production and consumption are being shaped, powering a new circular economy that works for people and planet alike. By implementing circular business models that circulate and use materials more efficiently, industry in the EU could cut an estimated 296 million tonnes CO_2e per year by 2050 (56 percent of total GHG emissions), and industry globally could cut an estimated 3.6 billion tonnes per year globally.[178]

Circularity is strongly aligned with the digitalisation trend that is spreading across every industry. Digital solutions can provide real-time data about an item's location, condition, and availability. They can also increase traceability of materials, ease of access to products and services, and make processes more convenient and effective.

175 Falk et al. 2019

176 Ibid.

177 Ibid.

178 Material Economics 2018

For example, recycling can have many synergies with digitalisation. Using sensor technology and IoT can rapidly reduce the cost of making different materials and products, supporting the automation of dismantling and sorting that is fundamental to more cost-effective recycling. Apple's iPhone-recycling robot Daisy, that takes apart iPhones to recover valuable materials inside, is an example of this synergy.[179]

According to Climate-KIC, leveraging the full potential of the digital circular economy requires four key conditions:[180]

1. **Technology:** Digital technologies need to be well incorporated into business models. Data needs to be available, accessible, of good quality and streamlined to allow interoperability in different environments.

2. **Marketplace:** Digital solutions need to be intuitive, accessible, and easy-to-use, as well as competitive on price, quality, and convenience. As part of the circle, consumers need to change their behaviour and recirculate the materials back into the market after their use.

3. **Policy:** Implementing circular models requires supportive and flexible institutional, political, and regulatory environments with adequate economic instruments to influence their ability to succeed.

4. **Skills & Knowledge:** Finding the right interdisciplinary combination of knowledgeable and skilled employees can be challenging, especially if a lack of financial resources limits access to key and scarce personnel.

[179] Deahl 2018

[180] Climate-KIC 2019

7

Conclusions and recommendations

Towards a greener digital future

Digitalisation is quickly becoming essential in the fight against climate change and achieving the SDGs. The Paris Agreement goal of limiting global temperature rise to 1.5°C and developing within the planetary boundaries will inevitably require the discerning use of emerging tech. And, to exploit their full enablement potential, production and consumption systems must also change from a linear to a circular way of operating.

This will require innovative ways of regulating and using the full toolbox available including legislation, non-legislative policies, awareness, education, funding, and mindset. Digital technologies should no longer be considered as a silo. On the contrary, digital policies must be further integrated with other sectoral policies, including those related to the environment, climate change, energy, transportation, agriculture, construction, and manufacturing.

A pioneering example of this approach is currently being led by the European Union, through its Shaping Europe's Digital Future campaign. This new policy package combines the EU's Digital Strategy with the European Green Deal to achieve a climate-neutral Europe by 2050 in addition to addressing other environmental challenges.[181] This new approach will be implemented domestically, and also in the EU's foreign policy agenda.[182]

It is essential that the digital revolution has sustainability at its core. Emerging technologies are still far from that. Although sustainability is ascending the agenda of many big players in the tech sector, the sustainability of supply chains remains a critical challenge with ample room for improvement. Emerging tech developments, like new AI applications, edge computing and IoT, are still in a learning mode that is not sufficiently putting sustainability at its core. And, despite gaining attention and momentum, climate change and sustainability aspects are not being fully embraced in policymaking either. The development of digital industries must also adequately consider the real possibility of rebound effects, thoroughly covered by research but with little consideration in practice.

The sustainable and fair use of resources is still a pending subject. The amount of resources extracted to produce a single digital device is staggering and recycling practices are far from widespread. In recent years, the digital industry has made efforts to improve its track record on mineral sourcing. However, the focus has been limited to a few conflict minerals in the Democratic Republic of the Congo and the African Great Lakes region, while other conflicts remain.

Despite redoubled efforts, e-waste is growing steadily year after year, and the circularity gap is widening. Several projects and initiatives prove that adopting sustainable design, following a cradle-to-cradle approach, improving waste management practices, recirculating materials, and development of effective e-waste policies bring concrete results.

The digital world is inherently connected to the physical environment. Living in a world of finite resources means that the digital realm cannot be considered as limitless. Still, digitalisation relies on an often-perceived "infinite" capacity of the ICT infrastructure to grow

[181] European Commission 2020

[182] Ibid.

faster and further. Questioning user consumption and behaviour patterns, such as the digital sobriety movement, is a barely existent debate.

In the global north, the digital revolution is being led by high-tech industry players. As such, it does not always adequately consider the specific challenges that least developed countries face to embrace the opportunities of emerging tech. Nearly half of the world currently live in low-income and middle-income countries and face myriad challenges including poor ICT infrastructure, lack of financial resources, low availability of skilled professionals, and high vulnerability to climate change. If these challenges are not addressed, the predicted potential of emerging tech in addressing the UN SDGs and the climate crisis can only be partially realised.

Recommendations for policy and decision-makers

The findings of this report have generated the following series of recommendations intended for policymakers and key decision agents from the public and private sectors. The recommendations aim to leverage emerging tech in the fight against the environmental emergency while championing a new culture of sustainability around digital products and services.

1 Promote emerging tech as a supporting tool to boost climate action

Reaching net-zero GHG emissions is a commitment adopted by more and more countries around the world. To this end, digitalisation and emerging tech are essential. In 2015, nearly 140 of the 190 countries that submitted national plans to contribute to global climate action highlighted the importance of climate tech.[183] Almost half stressed the urgency of innovation, research and development to achieve their climate objectives.[184] However, especially in developing countries, the inclusion of digitalisation in climate action plans is infrequent, and the mention of emerging technologies is rare.

A deeper understanding and promotion of the benefits that emerging tech can bring to address the climate emergency and environmental challenges are therefore needed. Both must be directed at relevant ministries and climate change-related public bodies, at national and international financial institutions, multilateral organisations — especially those in charge of technology transfer — as well as at entities providing technical assistance and advisory services.

[183] United Nations Framework Convention on Climate Change 2017

[184] Ibid.

2 Design data-driven policies that maximise the use of emerging tech and address rebound effects

For government policies to address environmental challenges effectively, they must be grounded in evidence. The proliferation of IoT and edge computing will spread billions of devices across the planet. Ensuring transparency about the energy they consume and the data they collect is of utmost importance, even when this data is owned by private entities. Governments must ensure that high-quality data is open, available, accessible, and streamlined so that it can operate on different platforms.

To avoid rebound effects that would nullify the positive contributions of digitalisation to energy savings, efficiency policies and strategies must identify and evaluate rebound effects related to ICT. Rebound effects should be integrated into energy efficiency evaluations as well as in LCAs. Further, efficiency strategies should not rely exclusively on technological change, but also on behavioural changes on the consumer side, which will come with increased awareness campaigns to promote more sustainable demand.

3 Go beyond supply-side only practices and promote demand-driven initiatives and policies

It is common practice in the tech industry to address environmental challenges focusing primarily on the supply side. Refreshing old and inefficient equipment and hardware, promoting increased energy efficiency, improving recycling rates, and promoting renewable energy use are examples of these practices. While these are relevant and should be promoted, they represent only part of the picture.

Successful sustainability strategies cover both consumption and production, demand and supply. Equally important to greening the production of end-user devices, and the operation of telecommunication networks and data centres, is the need to address sustainable consumption practices. The industry's environmental agenda should also include initiatives like promoting behavioural change for more responsible use of their devices by consumers (eg extending device lifespan, reuse, repair and refurbishing), avoiding digital and energy waste, promoting digital sobriety, encouraging users to purchase more sustainable options, and adopting sustainable interaction design based on user needs.

4 Combine top-down and bottom-up approaches with actions at different levels

No single policy or entity can resolve the climate crisis. Addressing the global ecological breakdown with emerging tech is a complex endeavour that requires action at various levels, both top-down and bottom-up. Examples of top-down approaches include global action frameworks like the UNFCCC's Paris Agreement and the UN's SDGs. Another is the active involvement of international bodies, like the ITU, developing green global standards for the ICT sector. Regional initiatives, such as linking the European Green Deal with the European Digital Strategy, which will need to be implemented and enforced by EU Member States, are an example to benchmark.

Bottom-up grassroots action is equally vital. For instance, the energy transition relies on the development of decentralised energy networks, or microgrids, which are deployed and operated at a local level. Microgrids bring together a combination of clean technologies such as distributed generation, batteries or local energy storage systems, and renewable resources to help organisations operate autonomously from the traditional electrical grid. These technologies together with the use of blockchain would allow certifying that these energy sources are indeed 100 percent renewable.

5 Adapt the use and deployment of emerging tech to local conditions

When it comes to deploying technological solutions, especially emerging ones, there is no "one-size-fits-all" approach. Countries have different political, economic, social, cultural, and environmental realities. They also differ in national priorities, needs, capabilities, energy resources and stages of development. Finally, each stage of the technological innovation process may require a different mix of actors, institutions, infrastructure, resources, and financing models. For this reason, emerging tech deployments must always be designed and implemented with local conditions in mind.

For example, Nigeria is home to Africa's largest mobile market, with about 173 million subscribers and a penetration rate of 123 percent.[185] But the country's telecommunications infrastructure is poor, with network congestion and low quality of service, and network operators are often fined for poor service.[186] In May 2020, as a consequence of misinformation on social media, the Senate asked the federal government to suspend the deployment of 5G, which was being rumoured to be among the causes of Covid-19 and to have other negative side effects.[187, 188] Unless such local and topical considerations are addressed, opportunities to apply emerging tech for good will be limited.

[185] BuddeComm 2020

[186] Ibid.

[187] Iroanusi 2020

[188] NAN 2020

6 Implement a new circular vision for electronics

Delivering a zero-e-waste economy requires a systemic shift from a linear to a circular model. According to PACE and the E-waste Coalition, building a circular economy for electronics involves taking a "systems approach," addressing two main product life stages.[189]

Stage 1 comprises the design and use of digital devices. Digital products should be designed to last as long as possible, ensuring that they can be maintained, repaired, and refurbished, promoting second use, harvesting of components, and even leasing or rental. For example, Fairphone, a circular mobile phone company in the Netherlands, has launched Fairphone-as-a-Service and Dell in the US already has PC as a Service.[190] Several EU Member States are offering reduced taxation on both second-hand goods as well as repair services.[191]

Stage 2 starts at the end of the product's operational life. Electronics manufacturers should be encouraged to offer buy-back or return systems to collect old devices. They should reuse material and components for reintegration into new devices and send back the materials that they no longer use. Finally, for all discarded components, urban mining practices should be promoted, building a formal recycling industry to extract metals and minerals from e-waste.

7 Advance the establishment of a global tracking system for digital components

With billions of digital devices entering the global market every year, one of the main issues in our production systems is the lack of traceability of component parts during their lifetime. Unless extended producer responsibility (EPR) policies are in place, once warranty periods expire, electronics manufacturers are exempt from any liability for their products, and therefore have no interest in their whereabouts. The responsibility to repair, reuse or dispose of the products falls to consumers. Even with EPR policies in place, enforcing e-waste regulations is challenging due to illegal exports, inaccurate recycling data, and ineffective tracking systems.

Using scalable, public, and decentralised blockchain networks would enable the tracking of every single electronic component, from mineral extraction and processing to use and disposal. This would bring added transparency and ensure accountability. Blockchain networks could be interconnected if universal identifiers were assigned to each item, allowing interoperability and traceability. Such a system would allow for the enforcement of responsible sourcing practices as well as improved e-waste management.

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189 Platform for Accelerating the Circular Economy 2019

190 Ibid.

191 Re-use and Recycling EU Social Enterprises network 2017

8 Organise regular training to better equip professionals and public officers in the field of emerging tech

One of the reasons that explains the absence of emerging tech solutions in environmental policymaking is the lack of awareness and knowledge of policy officers and public servants of the potential that these technologies can bring in addressing the environmental crisis. Amid the emergence of new methodologies, technologies, tools, and approaches to respond to the ecological breakdown, there is a need to provide specialised training in the assessment and response to environmental needs.

Government and private companies should partner to implement regular capacity building and training activities to build knowledge in state-of-the-art technologies, as well as the technical skills and capacities of their staff. The exercise should become a continuous learning process targeting public servants, relevant agents from the private sector and civil society organisations who are also involved in sustainability efforts. Training may be organised, harmonised, and certified with accreditation systems to ensure that common knowledge and expertise are evenly distributed across the world.

9 Foster innovation and enhanced knowledge transfer through widespread participation of stakeholders in collective intelligence practices

The elaboration of national climate change plans and other environmental policies is usually channelled through, or accompanied by, participatory processes. This practice promotes wider participation of stakeholders from the public, private and civil society organisation sectors to ensure that the realities and priorities of the key sectors are considered. This enables the integration of diverse viewpoints, fosters innovation, promotes greater public acceptance, and ensures ownership.

Stakeholders from the emerging tech sector must also be involved in these processes. The lack of adequate and regular cross-sectoral debates and open-discussion forums both in the public and private sectors hampers successful and innovative policymaking. Further, the adoption of collaborative approaches and collective intelligence can be a determinant to addressing global challenges. Existing initiatives show how effective these approaches can be, like Climate Change AI, and the Climate CoLab at the MIT Center for Collective Intelligence, that explore how people and computers can be connected to act more intelligently. And Omdena, the innovation platform for building AI solutions for global problems through bottom-up global collaboration.

10 Ensure the mainstreaming of corporate sustainability across the digital industry

Although more and more tech companies are incorporating green practices and progressing in the achievement of the UN SDGs, the trend is far from widespread. A number of surveys, reports, indexes, and expert opinions confirm that mainstreaming green practices within the tech industry is a long way off.[192, 193, 194] Today, sustainability is defined as a strategic corporate goal by few and is considered part of corporate social responsibility (CSR) policy by many. Consequently, the environmental footprint of the ICT sector continues to grow.

Sustainability should be an intrinsic part of a tech company's strategic goals and the definition and monitoring of sustainability metrics should be part of their balanced scorecards. To this end, policymakers should pursue the harmonisation of incentive-based regulations, and policy instruments to encourage tech companies to prioritise sustainability while gaining competitive advantage. Public procurement policies should also reward top corporate sustainability performers.

11 Embed sustainability into all stages of the digital life cycle

Today, unless mandated, environmental considerations are neither compulsory nor strategic requirements adopted by most companies when designing and producing digital products. Instead, quality, reliability and price continue to be the most important criteria in product design. Similarly, data centres and network operators prioritise traditional success metrics like interoperability, reliability, latency, use, speed, and cost when measuring their performance.

Digital companies should be encouraged to perform more consumer testing, which is usually skipped due to pressing design and production deadlines as well as limited budgets. Accompanied by clear CSR guidelines focused on green research and development, consumer testing could enable the development of more sustainable solutions. Also, by using voluntary schemes, certificates, and labels to assess and certify sustainable development practices, IT producers could more easily meet rising consumer demand for greener products.[195]

[192] Corporate Knights 2020

[193] Supermicro 2018 and Supermicro 2019

[194] Tech UK 2019

[195] Young 2018

12 Improve transparency and accountability with better metrics and reporting of environmental and carbon footprints

Current standards used by digital companies to report carbon emissions do not adequately account for the entire footprint of digital services. Such standards include direct emissions (Scope 1) and emissions from the generation of purchased energy (Scope 2). Companies rarely report all other indirect emissions (Scope 3), such as those associated with the use of fixed and mobile networks.[196]

For streaming services such as YouTube and Netflix (which partially reports its Scope 3 emissions), most of the energy is used in the network, particularly the mobile network.[197] The overall size of the carbon footprint of such services makes it essential that companies assess and report them. As an added benefit, they can identify potential carbon savings unlocked by alternative design decisions and find innovative ways to reduce their overall footprint.

In France, mobile operators and internet service providers will be obligated to disclose the amount of data consumed in their billing periods, as well as its associated carbon footprint, starting in 2022.[198] Although the methodology and means to present this information have yet to be decided, it represents a positive step towards greater transparency and accountability.

[196] Preist et al. 2019

[197] Netflix 2020

[198] Fabre 2020

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Acknowledgements

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- **Frédéric Bordage** – Founder and Director, Green IT France
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Thank you to the following Digital Future Society Think Tank colleagues for their input and support in the production of this report:

- **Carina Lopes** - Head of the Digital Future Society Think Tank
- **Patrick Devaney** - Editor, Digital Future Society Think Tank
- **Olivia Blanchard** - Researcher, Digital Future Society Think Tank
- **Tanya Álvarez** - Researcher, Digital Future Society Think Tank

Citation

Please cite this report as:

- Digital Future Society. (2020). Risks and opportunities of emerging tech in the climate decade. Barcelona, Spain.

Digital Future Society