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FOREFSIGHT Brief 027

Early Warning, Emerging Issues and Futures

November 2021

The growing footprint of digitalisation

Background

The Foresight Briefs are published by the United Nations Environment Programme to highlight a hotspot of environmental change, feature an emerging science topic, or discuss a contemporary environmental issue. The public is provided with the opportunity to find out what is happening to their changing environment and the consequences of everyday choices, and to think about future directions for policy. The 27th edition of UNEP's Foresight Brief explores the environmental impact of internet use and the increasing digitalization of the economy. It outlines some of the mitigating factors that can be implemented to green our digital future.

Abstract

Since 2010, the number of internet users worldwide has doubled, and the global internet traffic has grown 12-fold. The digital services that we enjoy are sometimes referred to as "dematerialized technologies", but is this really the case? Computers, servers and other electronic devices require large amounts of natural resources. The energy to run them emits high amounts of CO_2, and programmed obsolescence and the low percentage of recycling are generating e-waste. The vast majority of data in the cloud are not used. Without denying the many benefits brought by these technologies, including for the environment, it is important for users, services providers and policy makers to understand what the impacts are and to learn how we can move towards greener digital technologies.

Introduction

Over the last decade, the importance of the Internet and related digital technologies in our personal as well as our professional life has increased exponentially. The "life in the cloud" - with our music, photos, movies, emails, documents, the social networks stored on distant servers, accessible instantaneously from PC, laptop or mobile phone, from almost any corner of the earth - has become the new norm. In addition, most of our economic transactions have become digitalized. It is estimated that 60% of global GDP will be digital by the end of 2022 and that 70% of new value created in the economy over the next decade will be based on digitally enabled platforms (World Economic Forum 2019).

Although half of the world's population remains disconnected (UN Secretary General 2020) there are now 4.2 billion social media users. 5.2 billion people use a mobile phone today, making mobile phones the most widely used internet device in all countries (Kemp 2021). Since 2010, the number of internet users worldwide has doubled and the global internet traffic has grown 12-fold (International Energy Agency [IEA] 2020). More than half of the world's population (4.7 billion people) used the Internet in 2020 - with more than one million people coming online for the first time each day.

The COVID-19 crisis has accelerated the onward march of digital transformation. Much of our resilience to COVID-19 was based on digital technologies, including the development of vaccines, risk modelling and contact tracing. Many employers and educational institutions also migrated to an on-line format, with web conferencing becoming standard in most developed countries for work

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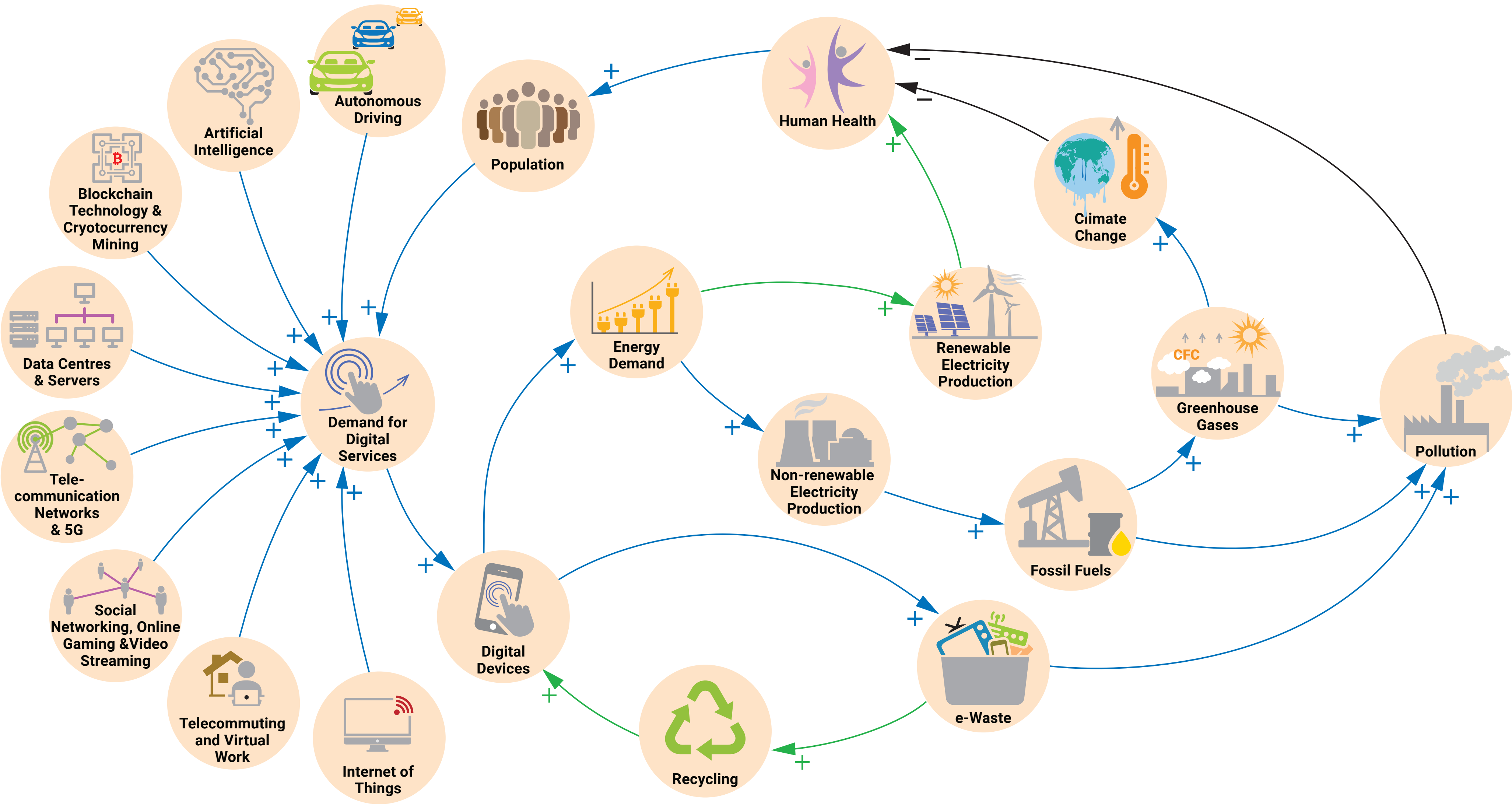
and school, as well as for keeping in contact with family and friends.

The digital advances made are staggering when we look at the short time scales of their technical implementation. But they also come at a cost, as the production of the hardware and the electricity needed to fuel this Internet explosion both leave a large environmental footprint. The digital economy brings opportunities to lower our environmental impacts, e.g. replacing flying to conferences by videoconferencing, and many other benefits (see UNEP 2019a; UNEP 2020). This foresight brief therefore asks and answers the question: how can we begin to green our digital future?

A Systems Thinking Perspective



Demand for digital services drives production and supply of digital devices causing an increase in energy demands. Electricity supply through fossil fuels that are polluting and increase greenhouse gases will worsen climate change and in turn adversely impacts human health. Digital devices, if built and operated using renewable energy resources and with recyclable components such as batteries, will help improve human health through reducing pollution and climate change. This approach in turn leads to a more sustainable reinforcement of demand for digital services. (+) Influence is in the same direction, (-) influence is in the opposite direction.

Why is this issue important?

Internet traffic has grown exponentially, with 2020 being a special year as the global internet traffic increased by almost 40% during the 1st wave of the COVID-19 crisis. This is a trend that will further increase as the digital divide closes. This growth was prompted by telecommuting, sharp demand for video conferencing, online gaming, video streaming and social networking. Although it is difficult to estimate, these changes did reduce the demand for mobility and corresponding emissions, but what was the environmental footprint from the technology itself?

A straight answer is not easy, because it depends on many factors, such as how the electricity for the production and use of digital equipment is produced, e.g. from renewable energy or from coal powerplants. Here are some average numbers: a search query emits around 1.45 grams of CO_2 (Gröger, 2020). With 50 queries a day, a single person comes to 26 kg of CO_2e (**Carbon dioxide equivalent**) per year. This does not sound like a lot, but needs to be multiplied by the billions of people searching the internet each and every day. Google itself reported a carbon footprint for 2018 of 4.9 million tons of CO_2e and an electrical energy consumption of 10 TWh[1] (Google, 2019), which represents a fourth of the electricity consumption of New Zealand or Hungary (IEA, 2021). Listed below are some of the effects of such high internet use and digitalisation.

Increase in Energy Demand

If the Internet was a country, it would be the sixth biggest electricity consumer on the planet, using up to 7% of the global electricity consumption (Andrae 2020; eon 2021) and is responsible for up to 3.8% of global greenhouse gas (GHG) emissions (Bordage 2019) - that is more than international air traffic with a share of 2.5% of GHG emissions (Lee *et al*. 2021).

> *"If the Internet was a country, it would be the sixth biggest electricity consumer on the planet,..."*
>
> Andrae 2020; eon 2021

In Germany for example, it was calculated that the 400 large and more than 50,000 small data centres in 2018 alone consumed 14 TWh, representing 2.7% of the total German electricity consumption, and about the same amount as the city of Berlin consumes (Hintemann 2019). All data centres, networks and devices together in Germany consume 55 TWh - the equivalent of 10 middle-sized coal power plants (Klumpp 2018; Statistica 2021). This is an increase of almost 40% since 2010 (Hintemann 2019).

Although energy savings due to gains in efficiencies have flattened the curve of energy usage, global trends such as cryptocurrency mining, cloud usage, artificial intelligence, virtual and augmented reality, autonomous driving, the "Internet of Things" and the foreseen implementation of 5G will drive further increases in energy demand.

Photo credit: Belen Desmaison

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Impacts from mineral and metal supply chains needed for digital products and energy technologies

Bits and bytes are invisible to our eyes, but the engines that run this hidden network are built from materials extracted from the earth. This extraction process, as well as the production process to turn the minerals into cell phones, computers and servers, comes with its own environmental footprint across the lifecycle. Similarly, the increasingly level of green energy technologies that power digital technologies also have supply chains based on extensive use of metals and rare earth minerals.

In countries struggling with political instability, where governance for the mining sector is weak, the extraction of these minerals can be linked to violence, conflict, human rights abuses and severe environmental damage. In many cases, the global reserves for these key minerals overlap with areas that experience fragility, conflict and violence. Cobalt, graphite, copper and rare earths are of particular concern as significant deposits are concentrated in vulnerable regions. Substantial reserves of 18 key minerals are found in states with that have **high rankings** on the 2017 corruption perceptions index (International Institute for Sustainable Development [IISD] 2018).

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[1] TWh = 1,000,000,000,000 Wh

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Increase of e-waste

The lifetime of our digital hardware is relatively short - often only a few years. The challenges of proper collection and, in the best-case scenario, recycling are still enormous.

In 2019, a record 53.6 million metric tonnes (Mt) of e-waste was produced, the equivalent weight of 125,000 Boeing 747 jumbo jets – which is more than all of the commercial aircraft ever created. This makes e-waste the world's fastest-growing domestic waste stream, fuelled mainly by higher consumption rates of electric and electronic equipment, short life cycles, and few options for repair. Only 17.4 per cent of e-waste was officially documented as formally collected and recycled. Only 78 countries have e-waste legislation (Forti *et al*., 2020).

As less than 20% of e-waste is formally recycled, the remaining 80% either ends up in landfills or being informally recycled – much of it by hand in developing countries, exposing workers to hazardous and carcinogenic substances such as mercury, lead and cadmium. E-waste that is disposed in landfills, contaminates soil and groundwater, putting food supply systems and water sources at risk (United Nations 2017; UNEP 2019b; Forti *et al*. 2020). These hazardous substances are threatening human health through direct contact as well as contamination of soils and water. This is affecting mostly the poorest population in the least developed countries and therefore has significant societal and environmental impacts.

What are the main findings?

As digitisation and the consumption of digital services increases and will accelerate in the future as the digital divide is addressed, it is important to consider the impact that this has on the environment.

- **Energy consumption and CO_2 emissions:** The good news is that rapid improvements in energy efficiency over recent years have helped to limit energy demand growth from data centres (**Figure 1**) (IEA 2017; Shehabi *et al*. 2018; Masanet *et al*. 2020).

  Nonetheless, the total energy consumption and the related GHG emissions of ICT are on a steady rise.

- **Energy consumption:** Rose from 700 TWh in 2010 to 1,500-3,000 TWh in 2020 and 8,000 TWh including the grey energy needed to manufacture the equipment (Bordage 2019; Andrae 2020).

Global trends in internet traffic, data centre workloads and data centre energy use, 2010-2019

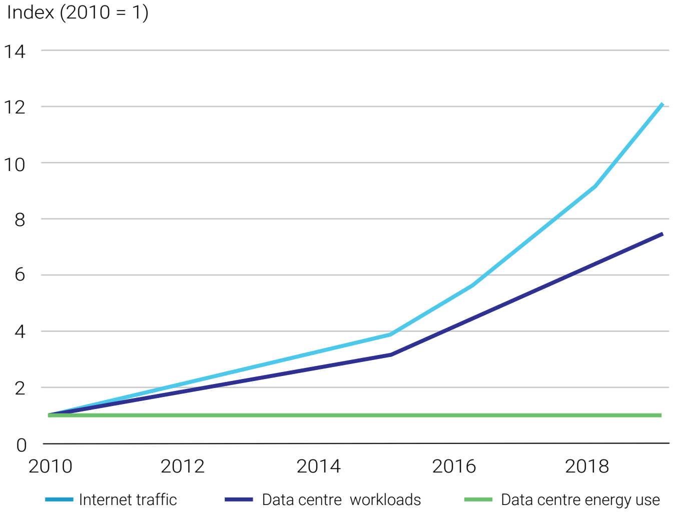

Figure 1: *Global trends in internet traffic, data centre workloads and data centre energy use, 2010-2019 (IEA 2020)*

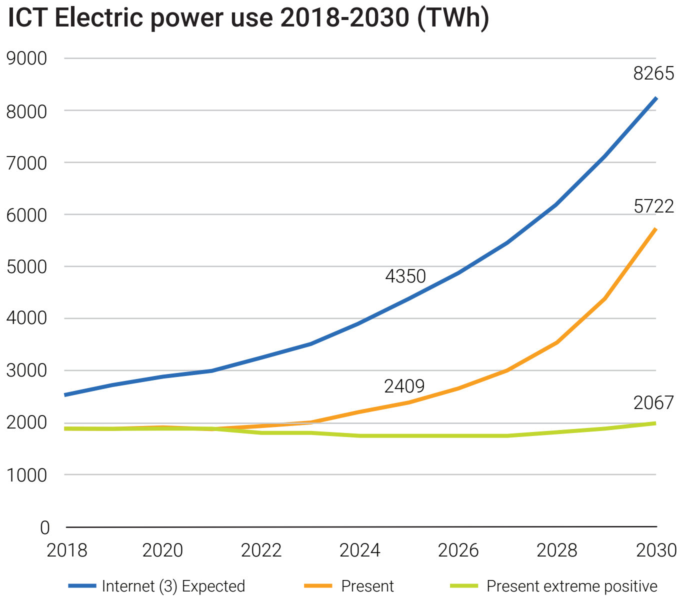

Figure 2: *ICT electric power use scenario. (Andrae, 2020)*

- **GHG emissions:** These emissions increased from 0.8 to 1.5-2 Gt of CO_2e, not accounting for the manufacturing process, which can add another 10-40% to these values (Malmodin and Lundén 2018; Bordage 2019; Bieser *et al*. 2020).

  Scenarios for the ICT's future energy consumption show important increases (**Figure 2**): estimates between the most optimistic and pessimistic studies suggest that up to 2030, energy demand for the use phase may grow only slightly to 2,000 TWh or even up to over 8,000 TWh (Andrae and Edler, 2015; Belkhir and Elmeligi, 2018; Hintemann, 2018; Bordage, 2019; Efoui-Hess, 2019; Andrae, 2020; Bieser *et al*., 2020; Obringer *et al*., 2021).

- **Emission savings:** Energy efficiency gains in the use phase have been important in recent years; however, they can no longer compensate for the continued rise in for example screen size and power requirements of end consumer products - a classical "rebound effect".

From a holistic environmental footprint perspective, the recent, COVID-induced, trend to online video conferences and home office can be considered as at least partially positive for emissions: although too recent to have detailed data, the coronavirus crisis is likely to greatly reduce transport-related greenhouse gas emissions. The growing energy consumption due to increased digitization is probably only a smaller percentage of this diminished energy consumption (and emissions).

- **Videos:** Available on different platforms and viewed without being downloaded (streaming) – account for up to 80 percent of global data transfer (Efoui-Hess 2019). Most of these videos are not work-related but for leisure purposes. In a single minute close to 400 thousand hours of movies are being streamed on Netflix and 4.5 million videos watched on YouTube (**Figure 3**) (Lewis 2019; Statista 2020).

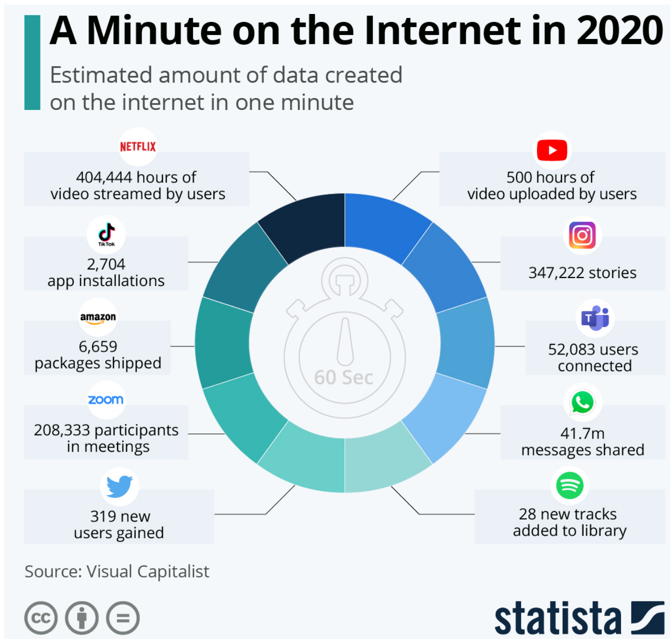

Figure 3: *The estimated data created in a minute on the Internet. (Statista, 2020)*

> *"Today we only use 6% of the data we generate. The other 94% goes to what I call the data landfill."*
>
> Antonio Neri, CEO of Hewlett Packard Enterprise, statement at the World Economic Forum, Davos 2020, quoted by Lucy Ingham (2020).

- **Data centres:** Forming the backbone of the Internet; only a few thousand large-scale data centres exist worldwide, with at most 67 million hosted servers (Bordage 2019; Statistica 2021). They consume around 400-500 TWh of electricity, emitting 200-250 Mt CO_2e (which includes the production emissions) (Bieser *et al*. 2020). About 60 percent of data centre GHG emissions are caused by the IT components such as servers, storage systems and networks. Forty percent of GHG emissions are due to the infrastructure, especially for cooling and air conditioning as well as secure power supply. The amount of energy needed for cooling these systems is huge. Although the heat produced in the server farms could be used for heating nearby households, for example, only 19% of the global data centres do reuse that produced heat. The use phase is responsible for 90% of the GHG emissions (Bieser *et al*. 2020).

  In addition, massive amounts of data stored "in the cloud" consist of old and outdated pieces of information. Antonio Neri, CEO of Hewlett Packard Enterprise, estimates that only 6% of the data generated are being used; the other 94% goes to what he calls "data landfills" (Ingham 2020).

- **Telecommunication networks:** The networks, which connect the user terminals to each other and to data

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centres, consists of 1.1 billion fibre routers, 10 million relays for mobile communication and 200 million internet "connectors" (Bordage 2019). Energy consumption of telecommunication networks in 2020 was around 200-550 TWh, and GHG emissions amounted to 200-250 Mt CO_2e (including production of devices). The use phase for the telecommunication networks is responsible for 90% of its total GHG emissions (Bieser *et al*, 2020).

- **End devices:** The use of computers, notebooks, tablets and smartphones add up to 900-1100 Mt CO_2e. The production and transport of the end devices is responsible for over 50% of their GHG emissions, and this figure could rise (Bieser *et al*. 2020).

- **5G:** As 5G frequencies can travel only short distances, small cell towers about the size of a medium suitcase will need to be placed 250 metres apart. Such a cell may require 200 to 1000 watts of power. Although 5G needs less energy for each GB transmitted than 4G (GSMA 2019; t3n 2019) a large multiplication of antennas is required for its implementation, increasing the demand for electricity. With 4G, the digital devices connect to one piece of infrastructure (a cell tower) at a time, which transmits to the next tower, and so on. With 5G, the devices and equipment will communicate with multiple cell towers and other infrastructure all at once. Traditional data centres will not be enough to achieve this connectivity and latency. To reduce latency many more data centres will be required, many of these "micro data centres" are located right on network edges (i.e. at the base of a cell tower) which could result in increased total network energy consumption of 150-170 percent by 2026 (EMFSA 2019).

  A report found that 5G networks in France could be responsible for 3 to 7 billion extra tonnes of CO_2 released into the atmosphere, representing 1-2% of current emissions (France, Haut Conseil pour le Climat 2020). In addition to the new network requirements, a new generation of mobile devices, capable of working with 5G – needs to enter the market, making currently used cell phones, as well as other technical appliances, obsolete. A rather large impact of 5G will be on battery capacity, due to the increased demand on computing power.

- **Artificial intelligence (AI):** AI is increasingly penetrating human society and is starting to be used all around us, from the living room with speech recognition to cloud solutions for deep learning applications to use in critical infrastructures. AI may cause increased energy consumption in data centres. Researchers at MIT have calculated that the training of a single AI application for speech recognition generates five times as much CO_2 as a car during its entire lifetime (Hao 2019; Strubell, Ganesh and McCallum 2019).

- **Blockchain technology:** A single Bitcoin transaction consumes around 660 kWh (Digiconomist 2020) - which is equivalent to operating a 150-watt refrigerator for about eight months. If Bitcoin was a country, it would rank, with its 60-80 TWh, as number 38 in electricity consumption, just after Belgium and

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higher than Austria. With 37 million tons of carbon dioxide emissions, Bitcoin would rank between New Zealand and Ireland. (Kamiya 2019; Digiconomist 2020). Iran decided to ban the production of bitcoins as there were electricity shortages due to its production (Turak 2021). This rather large impact is due to the choice of methodology for generating Bitcoins. Not all block chain technologies require that much energy. Alternative digital currencies have selected other ways of generating their tokens, and are less demanding on energy.

- **Autonomous driving:** Although autonomous driving cars are still at an early stage of development, a wider implementation would increase the bandwidth needs of mobile communication and the Internet enormously. It is estimated that an autonomous car generates four to eight terabytes of data per day and uploads 25-250 gigabytes of data per hour to the cloud (Kallenbach 2017; it-daily 2021).

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What is being done?

There has been growing attention within industry of their and our digital footprint, and interest is growing in finding environmentally sustainable solutions towards global digitalization:

- **Net Zero Commitments:** Major cloud and data centre operators, including Amazon, Google and Microsoft, as well as smaller and national providers, have adopted climate neutral goals by 2030 or even earlier (Stramski 2020). Many have already implemented measures, such as large investments in wind turbines and photovoltaic facilities. Many companies are off-setting their CO_2 -emissions by, for example, investing in CO_2- or Methane-reducing technologies or in regenerative agriculture and reforestation projects (Apple 2020; RegenNetwork 2021).

- **Relocation of large server farms:** Some companies have moved their server farms entirely into areas rich in renewable energy, such as Norway.

- **Reuse of heat:** Some data centres have started projects aimed at reusing the heat produced in the cooling process for heating nearby buildings (Börje 2019).

- **Gain in energy efficiency:** Efficiency has greatly improved on all levels of technology. So called "hyperscale"[2] data centres for example have drastically improved efficiencies.

- **International initiatives:** *EU Green Digital Declaration*: 26 CEOs of companies have signed a Declaration to support the Green and Digital Transformation of the EU. Twenty-seven EU countries plus 2 additional member states signed an EU declaration committing them to leading the green digital transformation. *"Digitalization for Sustainability – Science in Dialogue"* (D4S): is a new European research group that is dedicated to developing a progressive vision for a digitalization that fosters environmental and social sustainability. The project aims at enhancing the science-policy discourse by delivering a comprehensive analysis of opportunities, risks and governance options regarding digitalization and sustainability.

[2] Hyperscalers are computing networks for achieving massive scaling in the area of cloud computing and big data. The infrastructure of hyperscalers is designed in such a way that horizontal scalability is possible. Accordingly, hyperscalers provide a very high level of performance and throughput as well as redundancy.

What are the implications for policies?

Clearly, digitalisation offers many opportunities to connect people, projects and ideas. The trend is clear and the economy is organizing around these new technologies. However, in order to avoid digitalisation becoming an environmental problem itself, different measures and incentives can be adopted by policy makers, companies, service providers and users:

- **Electricity production:** Accelerate the adoption as well as disclosure of renewable energy for ICT industries, including manufacturer and server farms. This should include the procurement of Renewable Energy Certificates.
- **Greening ICT supply chain:** Improve the governance of the ICTsector supply chain, especially with regard to the extraction of rare earth minerals and metals, the recycling of e-waste and the safe disposal of toxic materials.
- **Lifespan:** Extend the life span of servers and other devices using evolutive design and circular economy models to enable the upgrading and replaceability of key components. Ensure reuse or full recycling when decommissioning.
- **Cooling:** Reduce the air-conditioning needed for server farms and re-use the heat generated for other purposes.
- **Digital debris:** Encourage users and institutions to delete cloud content that is no longer used or to archive information to external drives that are switched off when in long term storage.
- **5G:** Study the benefits versus negative impacts of this new technology, as well as alternatives, such as high-speed fibre cables. Consider the installation of one single network of antennas, which can be shared by the various operators to reduce the number of antennas, thus reducing the amount of hardware needed, as well as the radiation exposure.
- **Online behaviours:** Large-scale adoption of environmentally responsible online behaviour by many individuals is vital for combating climate change and promoting sustainability. Small actions such as turning off video during a virtual meeting, reducing the quality of streaming services, decreasing gaming time, limiting time on social media, sending fewer e-mails (and without unnecessary copying) deleting e-mails and non-essential content on cloud-based storage services or unsubscribing from email lists can significantly reduce the environmental footprint of Internet use.
- **Cryptocurrencies:** The framework for the technologies of cryptocurrencies should be assessed. Regulations and policies are needed to guide the type of technologies used and the associated energy requirements.
- **Digital product passports:** The concept of a digital 'product passport' is currently being developed in the EU. It will provide digital information on a product's origin, durability, composition, environmental and carbon footprint, reuse, repair and dismantling possibilities, and end-of-life handling. Different aspects of the product passport would be available to businesses, governments and consumers.
- **Public procurement of Green ICT:** As governments and international organizations procure ICT infrastructure to upgrade their services or to close the digital divide, they should follow best practice in terms of Green ICT.

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Conclusions

The growing potential of the Internet and digital tools comes with both benefits and challenges. On the positive side, it can reduce the need for travel; reduce the costs for monitoring and sharing data and information; it allows for interoperability and thus communication between servers; it delivers near-real time data for improving our decisions or to move to smart cities to better use renewable energies when these are being produced; and it enables easy communication with friends and family around the world. It will offer in the near future novel approaches and solutions for many urgent socio-ecological questions.

On the negative side, the environmental footprint of the digital infrastructure poses serious threats to our planet and future generations. The demand on precious/rare metals needed for the production of and the huge consumption of energy to run the infrastructure constitute serious challenges if we want digitalization to help combat climate change and lower our environmental footprint on the planet.

There are opportunities to seize, and many companies do invest in greening their enterprises. Further efforts, especially in the move to 100% renewable energy, optimized cooling systems of the data centres and the re-use of produced heat as well as used materials are required. Consumers need to adapt their online behaviour in order to reduce their online footprint – less high-resolution videos, less time on the Internet, more email-cleaning, and less cloud storage for photos and emails.

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