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A Systematic Review of the Pros and Cons of Digital Pollution and its Impact on the Environment

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Abstract: Digital technologies are becoming more important in our daily lives. Because of digital technology, our carbon footprint has significantly increased and caused ecological consequences. As gadgets get smaller and have more internal components, there is more trashes produced during manufacture. By 2023, more than 70% of the world's population will own a mobile phone. From the start of the Covid-19 pandemic and the numerous ensuing lockdowns, there has been an exponential increase in the use of video transmission (streaming) all over the world. In fact, according to the International Energy Agency (IEA), watching an hour of video streaming on Netflix entails emissions of 36gCO2. Between 2020 and 2030, the overall amount of data transmission will increase fourteen times. Digital technologies can contribute up to 20% to net-zero energy, materials, and mobility reduction required by IEA by 2050. However, there aren't many summaries of the digital transformation of environmental sustainability. This review presents the implications of the digital world on environmental sustainability, including both beneficial and detrimental aspects. Some methods are based on the network and its energy consumption. The outcomes also show how changes in three key areas—waste management and handling, pollution prevention and control, and sustainable resource management—have preserved the environment. The footprints are also significantly smaller than previously predicted. While subscriptions and data traffic have continued to rise, the footprint of the ICT and E&M sectors has shrunk. As countless individuals are used to digital daily life, this study points out the challenges to govern this issue. This review also points out the potential and problems in this field, which tries to provide a vision for future research, based on the literature overview.

Keywords: *Climate change, CO2 emission, Digital footprint, Digital pollution*

Conflicts of interest: None
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1. Introduction

Today, everything in our lives is digital. It's difficult to fathom a world without smartphones, apps, Wikipedia, online banking, GPS-enabled route planners, and the availability of a vast library of music and movies virtually anywhere, at all times. These things all greatly simplify our lives. However, digital technologies are not only playing an increasingly significant part in daily life, they are also having an impact on business and industry, the switch to renewable energy sources, and the future of our cities. Every action we take every day has some sort of effect on the environment. For sustainability to continue to advance, human awareness and corporate social responsibility are crucial (Batmunkh, 2022). The modernization of our society made great headway throughout the Industrial Revolution. On the other hand, the rapidly industrializing world affects our ecosystem and has various detrimental effects on our biodiversity and ecology.

Modern organizations' "low carbon" policies involve digital technology as a key component, and many organizations account for it in their carbon emissions (CIGREF, 2021). The spread of knowledge has increased the cross-border integration of digital technology. This indicates that the digital economy has produced considerable economic gains. Previously, it was widely believed that economic growth and environmental pollution were at odds with one another (Lu et al., 2017). Similar technological advancements in information and communication have led to pollution, which harms our quality of life and democracy. More people than anyone understand are affected by information and communications technology (ICT) and digital pollution (Environment & Myanmar, 2021). Digitalization also provides new approaches to combating climate change and preserving the environment. This review is full of excellent examples, and reporting on them is a big part of what we do here at RESET. This review mainly contributes to the positive and negative effects of digitalization on climate change and environmental issues, the opportunities that emerging technologies such as artificial intelligence, big data analytics, social media, and blockchain could address environmental issues, and the current issues as well as the open research directions of digital transformation in the context of environmental sustainability. To demonstrate how digital technologies preserve the environment against pollution and degradation of natural resources, we outline the publications in this review in a systematic way.

2. Materials and methods

Today, everything in our lives is digital. It's difficult to fathom a world without smartphones, apps, Wikipedia, online banking, GPS-enabled route planners, and the availability of a vast library of music and movies virtually anywhere, at all times. These things all greatly simplify our lives. However, digital technologies are not only playing an increasingly significant part in daily life, they are also having an impact on business and industry, the switch to renewable energy sources, and the future of our cities. Every action we take every day has some sort of effect on the environment. For sustainability to continue to advance, human awareness and corporate social responsibility are crucial (Batmunkh, 2022). The modernization of our society made great headway throughout the Industrial Revolution. On the other hand, the rapidly industrializing world affects our ecosystem and has various detrimental effects on our biodiversity and ecology.

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Table 1: Method details and findings (Batmunkh, 2022)

Authors	Brief Intro	Methodology	Finding (CO_2e/hr)
A. Andrae & Edler, (2015)	Calculated the electricity consumption of networks and estimated global electricity consumption of ICT.	They have estimated the worst- and best-case scenarios as 1 GB/hour and 3 GB/hour. Electricity consumption includes production, data centers, networks, and devices. Using global electricity and assumption of 3 GB data per hour. In total 2 billion people means 5230 exabytes and 570 TWh. This means a 1 h of video requires 0.304 kWh of electricity. Converting it to CO_2, watching 1 h video produces 72 g in the best-case scenario.	72 g–216 g
Hintemann, (2015)	Calculated energy and data center electricity consumption.	They have used fixed networks of low quality. 720-pixel video consumes 280Wh energy that equates to 130 g CO_2. Their method was a top-down approach which	100–175 g

		means they calculated the energy of data centers and networks then compared them to the volume of video streaming. Thus, according to their calculation, 1 h of video consumes 220–370Wh	
Obringer et al., (2021)	Included water and land footprint, focused on video conferencing and 7 social media applications.	They have estimated 1 h of video streaming requires 7 GB and 441 g CO2e. A standard resolution of 3 GB is used in the calculation. They measured CO2 based on HD or 4K video and stated 1 GB = 28–63 g CO2.	84 g–252 g
The Shift Project, (2019)	Estimated total impact of watching a video online included data center, network, and device impact.	They use a weighted average including viewing time, devices, network, and region. 1 petabyte ~72 mWh, bitrate of 3 Mbps, and 0.519 kg CO2e/kWh. The hypothesis is 10 min of watching a video with 1080p quality. According to their calculation: watching 1 h of video consumes 0.519 kg CO2e/kWh which is 280 g CO2e.	280 g

3. Results and discussion

3.1. Climate change and carbon dioxide

Long-term changes in temperature and weather are referred to as "climate change" (United Nations, 2020). These changes could be caused by natural processes, such as oscillations in the solar cycle. However, human activity has been the main contributor to climate change since the 1800s, particularly the burning of fossil fuels like oil, coal, and gas (Oo & Thin, 2022). Fossil fuel combustion produces greenhouse gas (GHG) emissions, which serve as a blanket over the Earth, trapping heat from the sun and increasing temperatures (NASA, 2022). Carbon dioxide (CO2) and methane are two examples of GHG emissions that are contributing to climate change. These are produced by a variety of activities, such as burning coal or gasoline to heat buildings or clearing land for development. Landfills are also a significant source of methane emissions. Among the major emitters are energy, industry, transportation, buildings, agriculture, and land use.

The gas, CO2 which absorbs and radiates heat, is the most significant GHG on Earth (PRI, 2020). In contrast to oxygen and nitrogen, which make up the majority of our atmosphere, greenhouse gases (GHG) absorb heat emitted from the Earth's surface and re-emit it in all directions, including back toward the surface. The natural greenhouse effect of the Earth would be insufficient without CO2 to maintain a constant global surface temperature above freezing. People are accelerating the natural greenhouse effect and raising the earth's temperature by releasing more CO2 into the atmosphere. The NOAA Global Monitoring Lab found that in 2021, CO2 alone was responsible for roughly two-thirds of all the GHGs created by humans that had a heating effect (Blunden & Arndt, 2020).

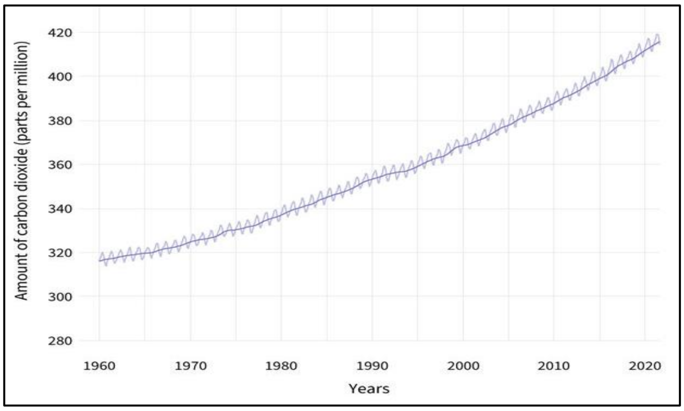

Figure 1: The present record of atmospheric CO2 concentrations started with observations collected at Hawaii's Mauna Loa Observatory. This figure shows the station's average monthly CO2 measurements since 1960 in parts per million (ppm). The Northern Hemisphere's seasonal highs and lows are made up of small peaks and valleys that are brought on by the vegetation's growth in the summer and decomposition in the winter. The main factor causing the long-term trend of rising CO2 levels is human activity. Using data from the NOAA Global Monitoring Lab, an image from NOAA Climate.gov. (Rebecca, 2022)

The primary reason for the rising CO2 levels is the global consumption of fossil fuels. Thousands of years ago, plants removed carbon from the atmosphere through photosynthesis but we add carbon to the atmosphere today through fossil fuel combustion. Since the mid-20th century, every decade, yearly emissions from using fossil fuels have grown, from the 1960s, when an annual average of 11 billion tons of CO2 was produced, to the 2010s, when an average of 35 billion tons of CO2 was produced Figure 1, according to the Global Carbon Update 2021 (IPCC, 2022; NASA, 2022).

Global atmospheric CO_2 was at 315 ppm when Mauna Loa Volcanic Observatory started conducting continuous observations in 1958 (REBECCA LINDSEY, 2022). Today's CO_2 levels are the highest in recorded human history. The earth's surface temperature was 4.5–7.2 degrees Fahrenheit (2.5–4 degrees Celsius) warmer than it was before industrialization when atmospheric CO_2 levels were this high. Sea levels have also risen by at least 16 feet and perhaps as much as 82 feet since 1900. By the end of the century, human CO_2 emissions maybe 75 billion tons per year or higher if the world's energy needs continue to rise significantly and are predominantly fulfilled by fossil fuels Figure 2. Conditions not witnessed on Earth in almost 50 million years atmospheric CO_2 levels of 800 ppm or higher—could exist (IPCC, 2021).

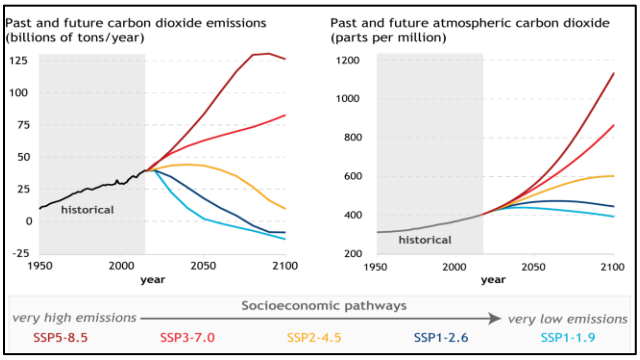

Figure 2: Future socioeconomic scenarios that are likely to result in plausible annual CO_2 emissions (left) and atmospheric CO_2 concentrations (right) by the century's end. A common socioeconomic route is a set of assumptions regarding future population increase, regional and global economic activity, and technological advancements that are internally consistent. These routes are used by models to estimate a range of potential future CO_2 emissions; for simplicity, the picture merely displays the mean value (IPCC, 2021)

3.2. Digital pollution

The general public currently has little knowledge of digital pollution. This issue is as terrible as urban air pollution and is quite genuine. The digital resources we use every day, such as the internet, mobile devices like smartphones and tablets, streaming, and emails, pollute in ways we cannot see. All new technologies contribute to this pollution, which has two main sources: the operation of the Internet network and the production of computer hardware. The web uses a tremendous amount of electricity. Although well-dematerialized, the Internet nevertheless needs an infrastructure to function. This infrastructure—a network of cables, antennae, data centers, etc.—allows the Internet and the cloud to function, but it also physically pollutes our globe. The internet would rank as the sixth most polluting nation in the world if it were a country.

Realizing the issue and its scope is the first step. Web searches are just the beginning of the process when it comes to the environmental impact of everything we do with digital technologies. Although the Internet may appear to be highly abstract, its operation is dependent on several very tangible components, including cables, servers, data centers, and routers, to mention a few. Electricity is required to construct and run all of this machinery. According to (The Shift Project, 2019), 2020 will see 3.3 percent of global energy usage go toward digital. This includes watching on-demand videos, sending emails, putting images in the cloud, using applications, or scrolling through social media because the majority of the world's electricity still comes from fossil fuels. CO_2 is produced by all the little things we perform on our phones and computers every day. For example:1 email produces 10g CO_2eq; An average of 294 billion emails are sent each day; Between 1995 and 2015, the weight of web pages raises by 115 on average.; 1.6 kg of CO_2eq is emitted during a 30-minute television program; 30 million tons of CO_2 emissions were produced through online video streaming.

Globally, digital pollution accounts for 3.7% of CO_2 emissions, which is 50% more than air travel (2.4 percent) (BITCI NWES, 2022). Digital pollution, however, is a problem that is hardly ever acknowledged, much less solved. Online activities such as emailing, searching, and streaming are frequently believed to have little impact on the environment. Digital pollution is frequently underestimated since it is invisible. The three components of digital pollution are e-waste, habits, and production.

3.3. Impact

The most frequently discussed topics are manufacturing and e-waste, and for good reason: as gadgets get smaller and have more internal components, there is more trash produced during manufacture and in the environment than ever before. Modern smartphones have about 54 components each, compared to the 10 components found in the mobile phones used in the 1960s. Both the methods used to separate components and the reality that more components are becoming necessary are troublesome. Additionally, the massive internet infrastructure is frequently overlooked. These include data centers, servers, submarine fiber-optic cables, relay antennas, wifi boxes, and much more. These components all work together to process every online activity you do.

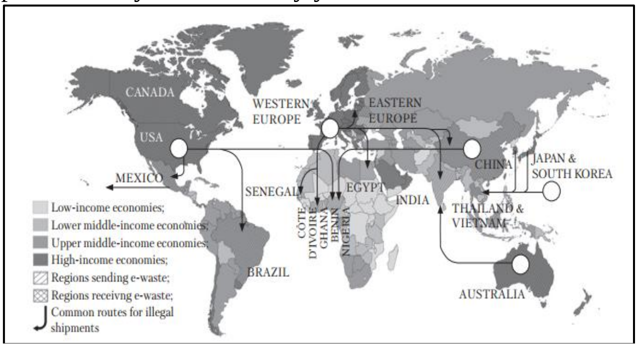

Figure 3: Map of distribution of countries by income and e-waste emigration (VishneVsky, V. P and Harkushenko, 2021)

As a result, each time an email is sent, the entire world may get it. The preservation of outdated, environmentally hazardous, and resource-intensive technological structures is also a result of the ever-widening "digital divide" between innovative leaders and less technologically advanced economies, which positions the latter as a raw material colony and hazardous waste endpoint. (European Commission, 2020). The map of e-waste emigration provides compelling evidence of such an "institutional-environment trap" by (VishneVsky, V. P, and Harkushenko, 2021) as shown in Figure 3.

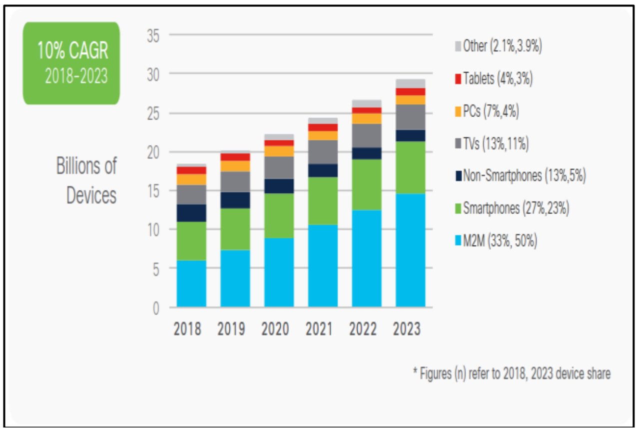

Figure 4: Global device and connection growth (Source: Cisco Annual Report, 2018–2023 (Cisco, 2020)

The number of mobile devices is rising more quickly than the global population. By the end of 2023, according to Cisco's Annual Internet Report (2018-2023), smartphones will have had the second-fastest growth. Figure 4 illustrates how mobile subscriber growth will proceed at a pace of 2% each year. This implies that by 2023, more than 70% of the world's population will own a mobile phone (Cisco, 2020). The Internet represents a threat to climate change, but because so many people use it for so many varied purposes, it is very challenging to govern. Video on the Internet is one of the most power-hungry. More information is contained in 10 hours of high-quality video than is available in all of the text-based English entries on Wikipedia. In 2018, online videos accounted for 80% of entire data flows globally, with the other 20% made up of websites, data, video games, etc. These internet videos can be separated into several categories, including social networks, streaming services like Netflix and Amazon Prime, and "Tubes" like YouTube. Given that numerous criteria must be accounted for each category, the range of categories used to describe video usage demonstrates how challenging it is to control. Massive volumes of data are stored as a result of rising video consumption, further harming the environment and undermining the goals of the Paris Agreement.

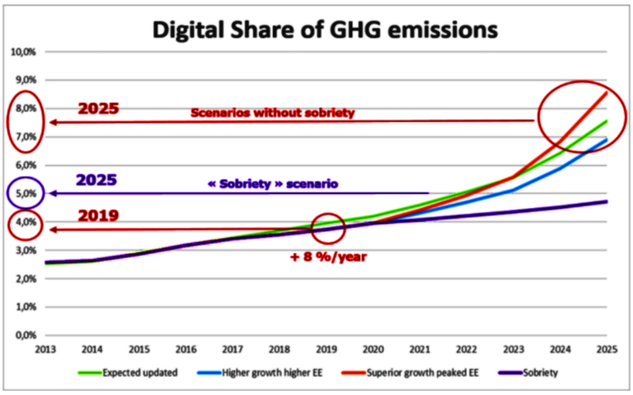

Figure 5: A graph showing the digital share of GHG emissions under a 'digital sobriety' scenario and a scenario without 'digital sobriety'(The Shift Project, 2019)

According to the (The Shift Project, 2019) report, an email with attachments that is longer than 4g CO2e can produce 50g CO2e when sent. Not only that, but each time a search query is run, around 0.9 g of CO2 are produced as part of the carbon footprint and emitted into the sky, and every open web page needs to maintain a connection to its server. Even though it may appear innocent, viewing videos online is one of the most CO2e-intensive hobbies. Watching a video for an hour is the same as plugging in a refrigerator for a full year or emitting 130g of CO2 into the atmosphere. The majority of data traffic on the internet comes from streaming, and the entire number of online videos accounts for 1% of all greenhouse gas emissions. By 2025, the percentage of GHG emissions attributable to digital technologies is predicted to quadruple from its current level of 4%, and the energy needed for this industry is growing by 8% annually. Online half-hour television viewing generates 1.6 kg of carbon emissions (Figure 5).

According to a study by the French Environment and Energy Management Agency (ADEME) (Court & Auditors, 2016), a company with 100 people produces more than 13 tons of CO2 annually, which is the same as 14 roundtrip flights from Paris to New York. According to several experts, sending an email is equivalent to using a light bulb for 24 hours. This year, the digital world will certainly exceed aviation in terms of pollution, for the reasons below:

- 10 billion emails are sent per hour worldwide.
- Kilos of fossil fuels and chemicals, as well as tons of water are consumed to make our devices.

A carbon footprint is the entire amount of GHG emissions that a person, an organization, or a product is responsible for, both directly and indirectly. The carbon footprint is typically described as the entire carbon equivalent life cycle of emissions and consequences from all goods and services. The ICT (Information and Communication Technology) sector includes all corporate and consumer devices. The expansion of carbon emissions and ICT footprints are accelerated in recent years. The ICT and Entertainment and Media (E&M) sector, according to the World Economic Forum, has a significant environmental impact because of its carbon footprint, energy use, and energy supply (Tomitsch, 2022). A Swedish study revealed that the carbon footprint (CO2) has grown six times and ICT sector data traffic has grown four times during 2005-2015. From the analysis done by (Malmodin & Lundén, 2018), the use of smartphones is the largest carbon footprint producer among all devices.

Table 2: Carbon footprint of the most popular applications by watching hours (Batmunkh, 2022).

Activity	User Engagement		Carbon Footprint (CO2) per hour			
User number	Watch hours per day	Uploaded data	Obringer	Shift Project method	Andrae method	Hintemann and Hinterholze
YouTube	1 B hours	1.65 GB/HD/	168 g	280.26 g	72 g	135 g
Netflix	6 B hours	1.5 GB hour/HD/	1008 g	1681.56 g	432 g	810 g
Facebook	0.1 B hours	210 TB	16.8 g	28.026 g	7.2 g	13.5 g
TikTok	2 B hours	500 TB	336 g	560.52 g	144 g	27 g

The hourly carbon footprint of internet usage by way of total watching hours is due to various methods (Batmunkh, 2022; Ferreboeuf, 2019; Laura et al., 2021). The duration of the actions and the size of the video's data were significant disparities. The fact that they all collected the data in various methods may account for the variations in the outcomes. Hintemann and Hinterholze emphasized resolution and user devices (Hintemann, 2015), while Andrae emphasized that since his methodology is based on networks and electrical usage, a wireless network requires less energy (A. S. G. Andrae, 2019). They emphasized the fact that data volumes are growing faster than networks' and data centers' need for electricity. In their hypotheses, only (Obringer et al., 2021) took into account the footprint of water and land. They proposed calculations of carbon, water, and land footprints in several different countries. These techniques each have unique qualities: Obringer et al. calculated with consideration for environmental sustainability while Hintemann and Hinterholze's method was focused on the device and resolution. The best- and worst-case scenario estimates provided by Andrae's technique are helpful. Following is the computation. According to (Laura et al., 2021), 135 g of CO2 is typically produced in one hour of streaming video, while it would be 13.5 g of CO2 by using Facebook. Netflix has 6 times more watching hours than YouTube, Facebook has 0.1 less, and TikTok has twice as many as the other three programs combined. Netflix multiplies by 6 to equal 280.26 g of YouTube or 1681.56 g of CO2 equivalent as a value. All other uses multiply in the same way. The study calculations served as the basis for the results displayed in Table 2.

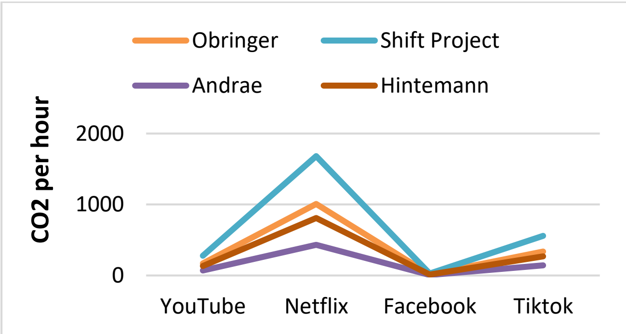

Figure 6: CO2 generated by applications hourly.

3.4. Forecast for future

Most people think the internet and ICT have less harmful effects on the environment. If we compare the result for boiling water or a Paris to New York two-way flight as shown in Figure 7, then 1 h of video streaming is almost the same as boiling a kettle. But if we look at daily use as Figure 8, it produces 13 times as much CO2 as a flight (Batmunkh, 2022). Therefore, using the internet for activities like viewing films online or browsing is seen as an invisible pollution that leaves a sizable carbon footprint.

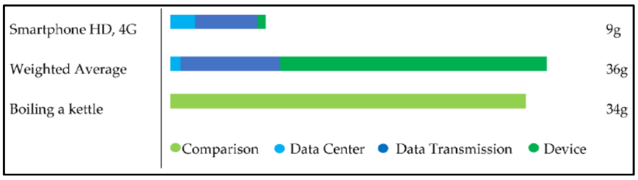

Figure 7: One hour streaming of CO2 emissions (Batmunkh, 2022).

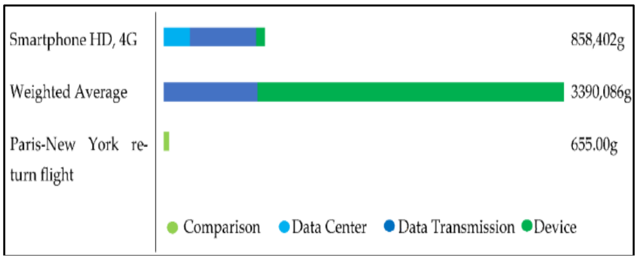

Figure 8: One-day streaming of CO2 emissions (Batmunkh, 2022).

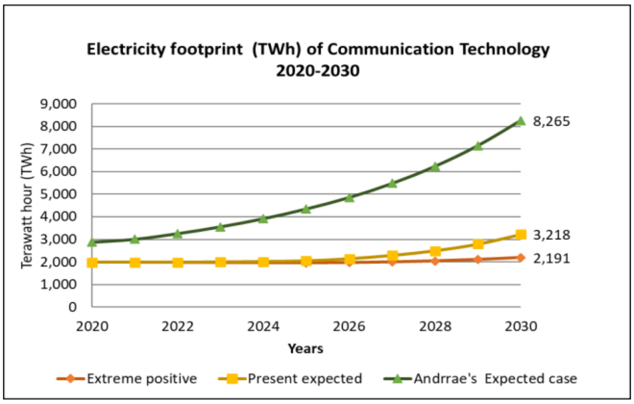

Figure 9: Trends for ICT electric power use 2020 to 2030. (A. S. G. Andrae, 2020)

Figure 9 shows the summary of the present predictions. From the perspective of overall electricity consumption, fixed optic fiber broadband or Wi-Fi-based computing is currently preferred over wireless 5G-based computing. The "extremely positive" scenario implies that there won't be a slowdown in electricity intensity improvements after 2021, i.e., no declining annual advances over the baseline period of 2022 to 2030 (expected case scenario) and that networks and data centers will continue to experience 20% improvements through 2030. Then, between 2020 and 2030, the overall amount of data transmission will increase fourteen times while ICT power will essentially remain the same. In such an "extremely good" scenario, networks and data centers will use 54 percent less electricity than in Andrae's study (A. S. G. Andrae, 2020).

Major ICT companies are accelerating their attempts to cut their GHG emissions and reduce carbon emissions across the board, and several companies have now shown that the industry is prepared to put its money where its mouth is. Momentum for Change Initiative of the UN is displaying some of the top instances that demonstrate how the industry can play a critical role in producing significant reductions in emissions over the next 15 years (UNCC, 2016).

Such businesses are increasingly using renewable energy, primarily wind and solar, driven by consumer expectations that ICT companies do their part to battle climate change as well as rational economic considerations. For instance, Google has invested millions of dollars in renewable energy projects like a solar facility in Chile and a wind farm in Sweden. By 2035, Adobe plans to run every aspect of its business using only renewable energy. Facebook Inc. has lately set a target of using clean energy for 50% of its operations by the end of 2018, with a goal of 100 percent. The ICT industry continues to be a net source of worldwide GHG emissions due to its high energy demand. In comparison to the aviation industry, data centers that power digital services today account for approximately 2% of the world's GHG emissions. ICT has possibly helped businesses cut worldwide GHG emissions by 20 percent by 2030 according to the GeSI, (UNCC, 2016), and consumers in using and conserving energy more wisely. By 2030, the industry might assist in reducing the generation of about 12 gigatons of CO2, as seen in Figure 10.

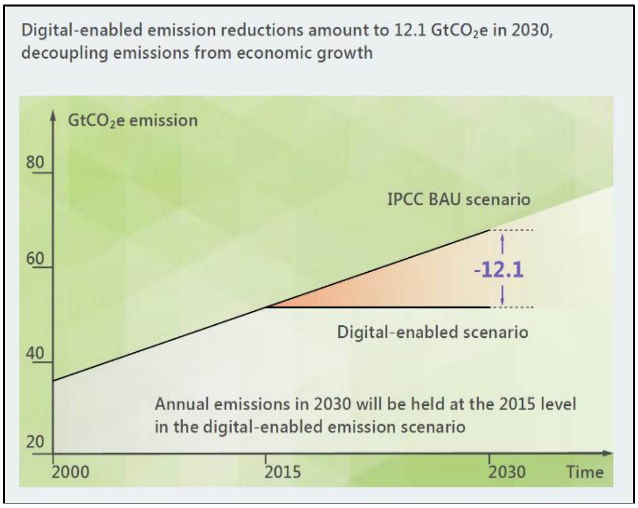

Figure 10: Digital-enabled CO2e emissions trajectory towards 2030, compared to IPCC BAU scenario. Image: GeSI, #SystemTransformation report (2016) (UNCC, 2016)

The main contributors to the worldwide digital effect are users' devices, according to a Green IT study (Bordage, 2019) that focuses on the "Global digital environmental footprint. "Data center and network equipment only come in second. As of right now, the CO2eq consumption of devices (smartphones, tablets, PCs, etc.) in 2019 accounts for 66% of the total consumption of the analyzed types (networks, data centers, devices), and it primarily focuses on the manufacturing phase (about 40% of the total "devices," compared to 26% for use, which includes data storage and transfer). Conversely, concerning networks and data centers, the impact of the manufacturing phase is lower compared to the impact of their use: respectively, 3% and 1% of their CO2eq consumption results from their manufacture, compared to 16% and 14% during their use phase (out of a total of 19% and 15%, according to the aforementioned typology) (Figure 11). This means that firms can concentrate their efforts on adopting ethical purchasing practices, minimizing the impact of manufacturing, and utilizing infrastructure (data centers and networks).

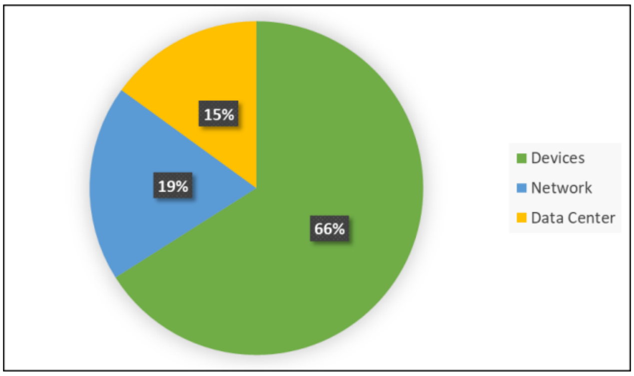

Figure 11: Global usage of CO2 equivalents for digital technology, broken down (Green IT study) (Bordage, 2019)

3.5. Chance to reduction

It is well known that web hosting is both energy- and environmentally unfriendly. As we have already seen, one of the main sources of digital pollution is the network's use of electricity. Thousands of powerful computers and servers, the majority of which are constantly consuming CPUs and hard disks, are typically found at data centers. This indicates that they produce so much heat that the supplier will often require an air conditioning system to maintain a reasonable temperature where they are installed. The major participants in the web hosting industry are conscious of the significance of going green. Because of practical economic factors, marketing effects, or sincere environmental concerns, several of them provide green web hosting services. They make a variety of commitments, such as agreeing to only use renewable energy sources and promising to offset their carbon footprints.

Others go even further, like Infomania, a leader in environmentally friendly web hosting in Europe. especially with the introduction of a charter for the environment with 20 pledges, such as 100% renewable energy, outside air cooling system, without air conditioning, low-energy servers, and waste recycling.

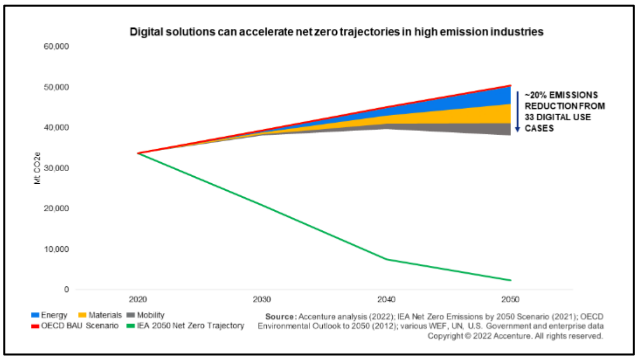

Figure 12: Reaching net zero would be greatly enhanced by digital technology. (Por Redaccion, 2022)

Energy, materials, and transportation are the three sectors with the highest emissions, accounting for 34%, 21%, and 19% of all emissions in 2020, respectively. They are also the industries with the greatest potential to reduce emissions through the use of digital technologies. Four groups of highly influential digital technologies are shown here: technologies for decision-making that support human intelligence, technologies for sensing and controlling that gather data and change physical processes to be more sustainable, and technologies for enabling that are essential for any digital organization today to gain benefits. According to our analysis, digital use cases in the energy sector can reduce greenhouse gas emissions by up to 8% by 2050 (Figure 13 and Figure 14). The efficiency of carbon-intensive operations would be increased, as would building energy efficiency. Renewable energy would also be deployed and managed to utilize artificial intelligence propelled by cloud computing and highly networked facilities with 5G.

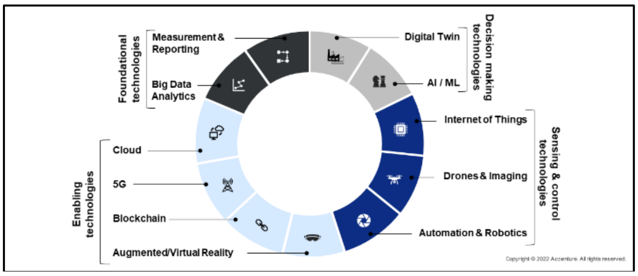

Figure 13: The potential for digital technology to accelerate decarbonization in the energy, materials, and transportation sectors. Image: Accenture

By 2050, digital use cases in materials might provide up to 7% of the reduction in GHG emissions. (WEF & Accenture, 2022). By enhancing mining and upstream production and depending on key technologies like big data analytics and cloud/edge computing, this might be accomplished. Blockchain use cases may also improve process effectiveness and encourage circularity. According to (WEF & Accenture, 2022) analysis, digital use cases in mobility might reduce GHG emissions by up to 5% by 2050. Utilizing sensing technologies like IoT, image, and geolocation to collect real-time data and inform system decision-making would be necessary. In the end, it would enhance route optimization and reduce emissions in both road and rail transportation.

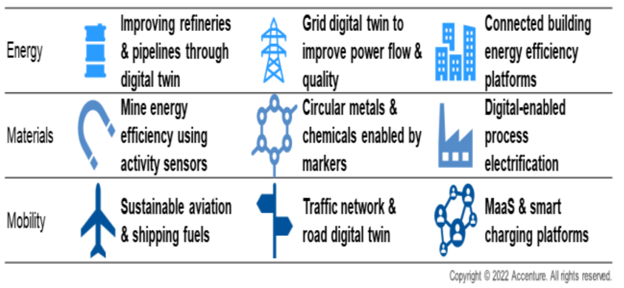

Figure 14: The nine significant applications of digital technology that could help the energy, materials, and transportation industries Image: Accenture

For instance, Mobility-as-a-Service (MaaS) platforms are evolving into sophisticated tools for mobility planning for consumers, promoting a variety of lower-carbon options like bicycles, scooters, and public transportation. Uber's customer app and digital platform, which employs analytics to suggest transportation options for customers, now includes non-rideshare possibilities. According to some studies, replacing individual private automobile use with Maas might reduce emissions by more than 50%. In the energy, materials, and mobility sectors, there are several high-impact, high-priority use cases that, if scaled, can produce the greatest advantages.

3.6. Benefits

The majority of GHG emissions are produced by the transportation industry, mostly as a result of the combustion of fossil fuels by vehicles, trains, trucks, ships, and airplanes. The second highest portion of GHG emissions are caused by the production of electricity. There have been numerous mitigation tactics suggested, most of which focus on lowering the use of fossil fuels and energy demand.(Shukla et al., 2019). Even though just 1.5% of all travel is for medical reasons (US Department of Transportation. Federal Highway Administration, n.d.), telemedicine programs in particular could assist address both problems as they can reduce patient travel (Oliveira et al., 2013; Vidal-Alaball et al., 2019). 3,015,530 patients were seen for medical appointments by the healthcare provider overall in 2020. 640,122 of the daily average of 3,700 digital appointments were in digital form (video appointments and telephone appointments).

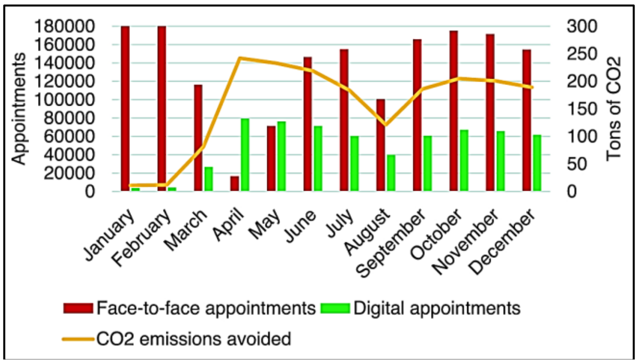

Figure 15: Number of appointments and CO2 emissions saved. Monthly changes in the number of in-person and online appointments made in 2020. The yellow line represents the monthly CO2 emissions averted based on the number of digital appointments multiplied by the typical CO2 savings of 3.057 kg per digital appointment. (Morcillo Serra et al., 2022)

According to estimates, this digital use prevented 1,957 net tons of CO2 emissions (Figure. 15). Similar to this, estimations show that 3,064,646 medical reports were obtained by patients in 2020, saving a net of 4,698 tons of CO2 emissions. Together, these digital health solutions prevented 6,655 net tons of CO2 emissions in 2020. Of the digital appointments, 66,510 were with a generalist practitioner (GP), and 573,612 were with a specialist. Mobile phone applications accounted for 74.7% of video meetings, and computer applications accounted for 25.3% (Figure 15).

As illustrated in Figure 16, the net reductions in carbon for downloaded reports and digital appointments were determined by adding the carbon savings from reduced patient travel and document printing and deducting the emissions from videoconferencing and downloading. By reducing patient travel, a digital consultation significantly (> 99 percent) cut carbon emissions. The failure to print the visit's conclusions on paper also resulted in a negligible (1%) reduction in carbon emissions. According to the computation mentioned above, every digital visit saves 3.057 kg of net CO2 emissions, and every medical report that is downloaded rather than physically collected in the clinic saves 1.5 kg. If a patient has a video appointment and does not need to use a car to drive to a face-to-face appointment, they can access information on the CO2 they have saved after the video appointment. "If this visit has spared you a trip to the practice, you have avoided 3.1 kg in CO2 emissions," reads the statement displayed to users in the private section of the digital site.

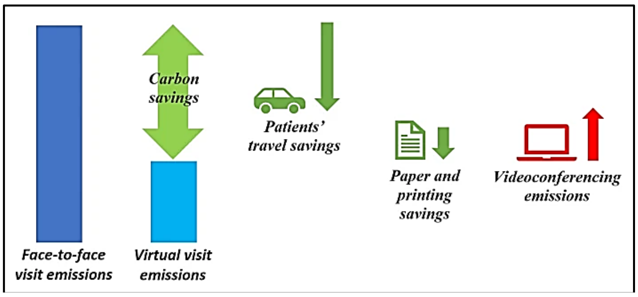

Figure 16: Calculation of the reduced carbon footprint of an internet visit. The carbon savings from avoiding patient travel and document printing were added together, and the emissions from videoconferencing were subtracted to get the overall carbon emissions savings of an online visit.

3.7. Advantages and disadvantages

The immediate positive environmental effect of digitalization is dematerialization. Changes in commerce, banking, and administrative processes to electronic document control, digital services, and goods, and remote communication methods based on digital technology to replace physical logistical flow (e-mail and bulletin boards, video conferencing, electronic exchanges, e-government services, etc.) have caused a reduction in time, financial, and material resources extracted from the natural environment. As a result (VishneVsky, V. P and Harkushenko, 2021), the amount of waste generated by enterprises, organizations, and end users decreases, which consequently significantly reduces the anthropogenic burden on ecosystems in certain areas of resource consumption and pollutant emissions. On the other hand, expanding the range of and growing demand for devices, as well as increasing the time of their daily use significantly affect (raise) energy consumption and, therefore, entail growth in GHG emissions.

The "smartness" of automated (robotic) industrial systems, which enhances real-time monitoring and control systems, boosts business process efficiency, and lowers costs, is a more beneficial and environmentally benign outcome of digitalization. Smart power systems, 3D printing, ventilation, and climate control systems in smart buildings, industrial robotics, automated product quality control systems, smart logistics, etc. all help to save resources, customize production, optimize inventory, prevent breakdowns and emergencies, quickly troubleshoot issues, and as a result, lessen the burden that humans place on ecosystems. In Table 3, we list the most obvious benefits of digitization. The environmental disadvantages of digitalization (Table 4), are caused by the growing demand for smart products and digital services, which provokes an increase in energy consumption and GHG emissions and the accumulation of electronic waste. These negative consequences are exacerbated by unfair competition and attempts to maximize monopoly quasi-rent from pseudo-innovation when marketing policies that stimulate excessive consumption for prestige reason substitute for real research and development. In addition, the risks to the ecosystem increase as a result of study 4 on the impact of digital technologies on flora and fauna (Curran, 2020).

Table 3: Environment Advantages of Digitalization (Vishnevsky et al., 2021)

Environment-related manifestations consequences	**Environment-related causal effects**		**Ecosystem consequences**
• Transition to electronic document control • Expansion of commercial and administrative digital services • Spread of digital remote means of communication • Use of "smart" automatic systems in industry and everyday life	• Dematerialization of goods and services • Reduction of physical logistics flows • Flexible response to changes in environmental conditions in real-time to ensure the most efficient use of resources and to minimize costs • Customization of production • Improvement of production monitoring systems, reduction of risks associated with equipment failures (due to undetected technical malfunctions, human factor, etc.)	• Saving renewable and non-renewable natural resources • Reduction of pollutant emissions into the environment (emissions, discharges, waste disposal) • Reduction of risks of manmade disasters	• Reduction of man-caused load

Table 4: Environment Disadvantages of Digitalization by (Vishnevsky et al., 2021)

Environment-related manifestations consequences	**Environment-related causal effects**	**Ecosystem consequences**
• Expansion of the range of devices • Increase in the number of devices as a result of growing demand • Increase in the duration of use of devices during the day • Change/emergence of new technologies of information	• Increasing energy consumption (industrial and domestic) • Increasing greenhouse gas emissions • Increasing industrial consumption of rare earth metals • Increasing electronic waste, including that containing toxic substances • Increasing risk of industrial accidents because of the imperfection of digital technologies and	• Disruption of the cycle of substances in ecosystems • Disruption of food chains and reduction of habitats of organisms, reduction of biodiversity of ecosystems

signal transmission • Accelerated change of device generations (early termination of operation) caused by manufacturers' efforts to gain a monopoly quitrent	the accumulation of errors and failures in the systems • Increasing intensity of wave radiation per unit area • Manifestation of understudied adverse effects in the structure of genomes, the operation of reproductive systems, and the behavioral reaction of living organisms • Growing consumption of natural resources as a result of aggressive advertising and unfair competition (an intentional technological incompatibility of software and hardware, industrial espionage, trade wars)	• Distortion of the system of social values

4. Conclusion

The introduction of state-of-the-art digital technologies in various spheres of public life has a profound and diverse impact (both positive and negative) on the surrounding environment. The positive environmental effects of economic digitalization are associated with the dematerialization of goods and services, improvement of production technologies, decrease in physical logistics flows, reduction of pollutant emissions, etc. The adverse effects are growing industrial and household energy consumption (and, consequently, increasing GHG emissions), accumulating electronic waste, understudied negative effects on the reproductive systems, genome structure, behavioral responses of living organisms, and so on.

The studies made by influential international organizations (OECD, European Commission, Asian Development Bank, etc.) have confirmed the increasing alterations in size and the ecological footprint composition caused by the introduction of digital technologies. In their assessments, digitalization is a generally positive phenomenon, as it may reduce global GHG emissions, among others. At the same time, it should be borne in mind that most of the estimates are predictive. Despite the world's prevailing desire to ensure climate neutrality and environmental loyalty to digital innovations, as a result of the lack of representative observations and because of delayed effects of technological interference in the functioning of ecosystems, the real environmental consequences of digitalization may be underestimated.

The conclusion of this article serves as a benchmark for digital economies and green development projects in many countries and regions. In order for underdeveloped regions to equally benefit from the high-quality economic growth made possible by the digital economy, it is important to balance the digital economy and the share of environmental degradation across sectors. Spillover effects in underdeveloped regions show the importance of learning from the experiences of nearby cities in managing and using the digital economy and reducing or updating backward sectors. The digital economy is a brand-new force for accelerating economic growth and a brand-new concept for fostering socially superior, environmentally friendly development. The government should focus on the development of scientific and technological talents, strengthen the foundations of digital industrialization, use the digital economy as a key starting point for upgrading industrial structure, help businesses increase their level of digital technology innovation, and accelerate the transformation of digital science, according to the apparent influence path of this paper.

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