Paakat
Revista de tecnología y sociedad

The Polluting Cloud. A Socio-environmental analysis of the Digital Carbon Footprint

La nube contaminante. Un análisis socioambiental de la huella de carbono digital

http://dx.doi.org/10.32870/Pk.a12n22.730

Domingo Rafael Castañeda Olvera*
http://orcid.org/0000-0002-3930-1674
Universidad Tecnológica Fidel Velázquez, México

Received: November 25, 2021
Accepted: February 14, 2022

ABSTRACT

The notion of Digital Carbon Footprint refers to the amount of Carbon Dioxide released into the atmosphere as a result of an individual's activity, organization or community derived from the use of Information and Communication Technologies. The main objective of this research is to contribute elements to the debate on the high environmental impact of the global digital activity, emphasizing the current context characterized by an increasingly intensive use of interconnected electronic devices as well as digital resources that cloud storage requires. We conclude that the increase in the Digital Carbon Footprint has a high socio-environmental impact, a fact that takes us away from the carbon neutrality indicated by the 2030 Agenda and will only be mitigated as long as it intertwined with new energy management model (renewable energy) that optimize both the infrastructure (date centers) such as the very use of the Internet, as well as the cloud information storage.

Keywords
Digital Carbon Footprint; Ecological Footprint; Renewable Energies; Digitalization; Information and Communication Technologies

RESUMEN

La noción de huella de carbono digital se refiere a la cantidad de dióxido de carbono liberada a la atmósfera como resultado de la actividad de un individuo, organización o comunidad, derivado del uso de las tecnologías de la información y la comunicación. El objetivo central de este trabajo es aportar elementos al debate sobre el alto impacto ambiental de la actividad digital global, y poner el foco de atención en el contexto actual caracterizado por un uso cada vez más intensivo tanto de los dispositivos electrónicos interconectados como de los recursos digitales que requiere el almacenamiento de la información en la nube virtual. Concluimos que el incremento de la huella de carbono digital tiene un alto impacto socioambiental, ya que nos aleja de la carbononeutralidad señalada por la Agenda 2030 y solo será mitigado en tanto se entrelace con nuevos modelos de gestión energética (energías renovables) que optimicen tanto la infraestructura (data centers), el uso mismo del internet, como el almacenamiento de la información en la nube.

Palabras clave
Huella de carbono digital; huella ecológica; energías renovables; digitalización; tecnologías de la información y la comunicación

* Full-time professor, Academic Division of Sustainability Sciences, Fidel Velázquez Technological University, Mexico. PhD in Sociology, Metropolitan Autonomous University, Mexico. Postdoctoral studies at the Development Studies Unit, Autonomous University of Zacatecas, Mexico. Email: rafaelcastaneda7@gmail.com

INTRODUCTION

The notion of digital carbon footprint (DCF) has been proposed as a measure to describe and analyze the environmental impact of one of the phenomena that characterizes modern societies: digitalization. With the arrival of the 4th industrial revolution,[1] a significant percentage of humanity began to make intensive use of interconnected electronic devices, of services that offer information management through the network, as well as its storage in the virtual cloud.[2]

By January 2021, there were already 4.6 billion active internet users worldwide (59.5% of the world's population). Of this total, 92.6% (i.e. 4.32 billion) accessed the Internet through mobile devices, essentially smartphones (Statista, 2021).

This massive digitization process triggered two phenomena: first, a growing need for electronic devices in the global market, increasingly faster, with greater information storage capacity, more efficient, with better design, etc.;[3] second, new information management models were required for handling and storing information.

These new models required the construction of a larger infrastructure to house information and communication technologies (ICT). Complex and sophisticated systems were built, highly technical and air-conditioned, with high cooling requirements and multiple fire safety equipment. Spaces that required kilometers of cabling for their interconnection (sometimes trans-continentally), which implied significant energy consumption and ecosystem impact, such that some of these data centers consume, for example, the same amount of electricity as some intermediate cities (IEA, 2017).

Despite there being a growing demand for electronic devices and a greater presence in almost all areas of human life, the objective of this research will not focus on the ecological footprint represented by this increase in devices; we will focus on analyzing the DCF involved in the interconnectivity and management of information on the network and its storage in the digital cloud.

It is important to note that although the notion of DCF is still in its formative stage and there is still debate as to which indicators should be considered

[1] More than an arrival of new technologies, the 4th industrial revolution, or revolution 4.0, is marked by the transition to new cyber-physical systems, where software, digital technology in communications, nanotechnology and the Internet of things will play a fundamental role. , since they will build on their predecessor, the 3rd industrial revolution, the one that digitized everything (Schwab, 2016).
[2] The cloud (cloud computing) is the metaphorical name that has been given to the space that describes the global network of servers. It is not a physical space itself, but a network of interconnected remote servers, whose function is to store and manage data, run applications, and deliver content or network services (video streaming, social networks, email, software, etc.) (Rajaraman, 2014).
[3] This explosive phenomenon in the electronics industry is important for the purposes of our research, due to the significant increase in HCD globally, not only as a result of its manufacture and distribution, but also of the management of its last stage, that of generation. of waste, since it is estimated that only 20% of the material with which most of these devices are made is recycled or reused, because their production is based on the logic of planned obsolescence, which supposes a very important global residual load (Osibanjo and Nnorom, 2007).

methodologically, we will start with the analysis of this second element, interconnectivity and information management/storage, leaving out other elements for future studies.

To this end, this research will begin with the conceptual delimitation of the central term in order to, in a second section, provide elements that contribute to the understanding, study and debate on the effects of DCF in the current context. Finally, some conclusions are proposed.

We thus seek to join the debate on the series of anthropogenic impacts on the environment that occur in modern societies and that are calling into question life itself on the planet, adding to the analysis of the viability of the Sustainable Development Goals (SDGs) of the 2030 Agenda and its commitment to carbon neutrality in relation to DCF.

Digital Carbon Footprint

The DCF is the amount of CO2 released into the atmosphere as a result of the activities of an individual, organization or community; specifically, those related to the use of ICTs (Páez & Velásquez, 2020).

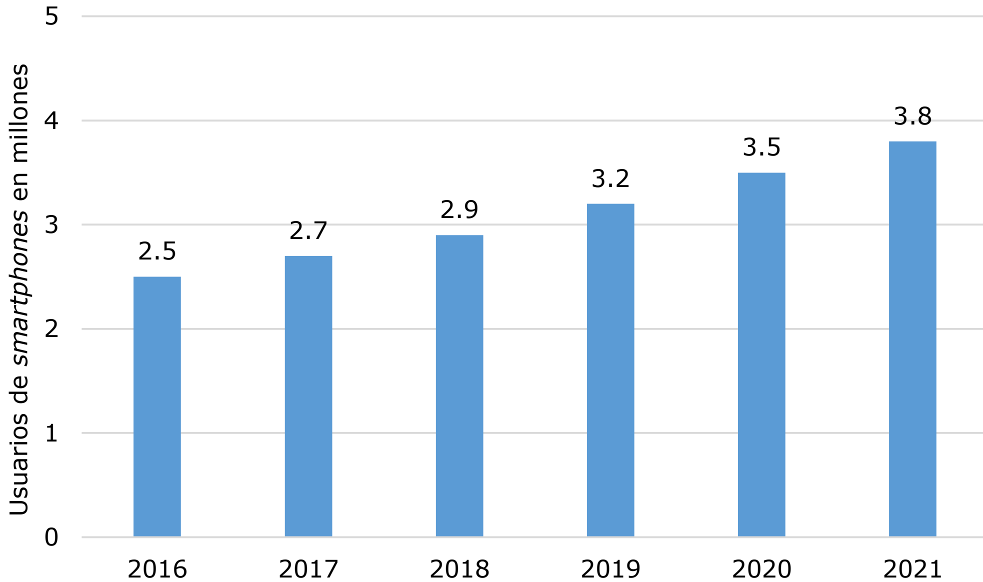
Since the internet was created more than 50 years ago, the use of ICTs has grown exponentially, to the point of becoming a fundamental element in contemporary societies. It would be impossible to think of the modern human being without the presence of the Internet, since it is present in a large number of spheres (from education, finance and the military to telecommunications, sports, leisure and entertainment). This phenomenon, as already mentioned, brought with it a demand for a greater number of devices (Graphic 1), a fact that was evidenced and multiplied in a scenario such as that posed by the pandemic resulting from the SARS-CoV-2 virus.

The interconnectivity and management of information through the internet requires equipment operating 24 hours a day, seven days a week: data centers (data processing centers). With the study of the ecological footprint of these servers, we will begin the analysis of the DCF.

Socio-environmental impacts of DCF

In this second section we will analyze DCF focusing on two elements: data centers and the management/storage of information in the cloud, from a socio-environmental perspective.

Graphic 1. Number of smartphone users worldwide, 2016-2021



Source: developed by the author with data from Statista (2020).

Carbon footprint of brains and digital veins: data centers

Data centers can be considered the brains of the internet. Their role is essential for the intensive flow of data and information in various areas of contemporary societies. They are spaces that house computer systems that process, distribute and store data with networked equipment, routers, switches and storage systems, in addition to having complex systems for cooling, ventilation and backup power supply, security and fire protection (Masanet et al., 2020).

These servers provide computing and logic in responses to multiple and increasingly complex requests for information on a global, second-by-second scale.[4] This forces storage units to be designed to hold the billions of files and data required by such requests, which means that network devices are constantly connected and require the services of these data centers.

However, despite the fact that this intensive and complex flow of information is now globalized, there currently are no government offices that compile accurate statistics on the energy use of these complexes, either on a national or global scale, so sophisticated mathematical models must be used to estimate their energy expenditure and, therefore, their ecological footprint.

[4] Every minute, nearly 695,000 stories are shared on Instagram globally, 500 hours of content are uploaded to YouTube, and nearly 70 million messages are sent via WhatsApp. See www.statista.com/grafico/17539/data-created-online-in-a-minute/

One of these models, called bottom-up, takes into account the installed capacity of ICT devices in different servers and their characteristics with respect to energy expenditure, thus arriving at an estimate of total energy use (Koomey, 2011).

Based on these studies, it has come to be estimated that these data centers accounted for 0.8% of global electricity use in the last ten years (GSMA, 2020), although some studies have estimated a higher expenditure ranging between 1.1% and 1.5% (Belkhir & Elmeligi, 2018); it is projected that, if trends continue, they will soon demand up to 7% of global energy demand (Cook et al., 2017).

Data processing centers use an estimated 400 terawatts per hour (TWh) annually. This annual energy consumption exceeds that of many countries around the world (Masanet et al., 2020), contributing 0.3% of total global CO2 emissions which, when added to 2% of global ICT CO2 emissions, places this sphere as one of the most polluting on a global scale.[5]

A fundamental point of analysis is the location of data centers, as this denotes their geostrategic function. The Asia Pacific region has the most data centers (95), followed by the United States and Canada (79). Together they account for 72% of the total. Europe, on the other hand, has 24% and Latin America only 4%. The United States and China, of course, rank first and second in terms of availability zones with 69 and 31 centers, respectively (Christian, 2018) (map 1).

Map 1. Global data center locations

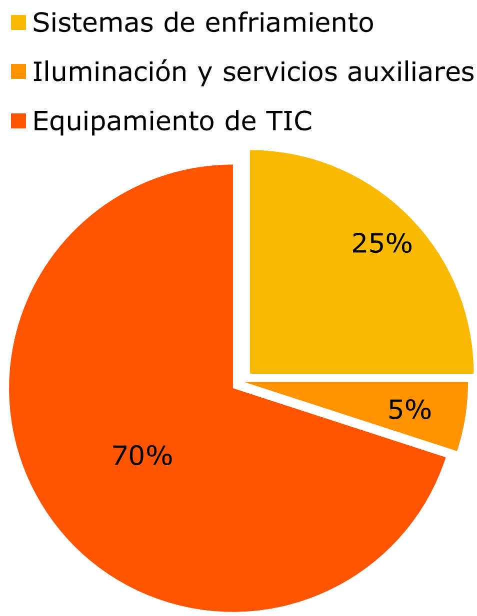
Source: Christian, 2018.

[5] See https://www.iea.org/reports/digitalisation-and-energy

As pointed out, the operation of these sophisticated data centers involves huge CO_2 emissions mainly related to the consumption of electricity required for their operation (Shehabi et al., 2016). From an ecological footprint perspective, the need for power and cooling is not a problem in itself, but rather most of these cooling systems are inefficient and use unnecessary amounts of electricity.[6]

Data processing centers require large amounts of energy, which is dissipated as heat in relatively small areas because the equipment is sensitive to high temperatures.[7] This heat must be removed continuously (Graphic 2), which increases cooling requirements, accounting for much of the total energy consumption of these centers.

Graphic 2. Heat loss in data centers



Source: developed by the author based on Marius (2021).

However, the estimation of total CO_2 emissions is poor due to the lack of data on the precise location of a large number of these centers, as well as the intensity of their emissions. They are only a small number of digital companies (Google, Apple, Facebook, among others) publicly report this location, which has also shed light on their use of renewable energy sources for their operations (Cook et al., 2017).

[6] See https://www.iea.org/reports/data-centres-and-data-transmission-networks

[7] This fact directly connects the energy consumption of data centers with the water footprint, since cooling also requires the vital liquid, which would lead to the need to integrate water treatment methods into these physical spaces, for which there is little information. One of these studies (Bakar, Shehabi and Marston, 2021) analyzes the carbon footprint of data centers added to the water footprint.

Since most of the electrical energy required by the ICT sector is still produced under fossil combustion models, it is assumed that the use of this digitized technology scheme emits large amounts of greenhouse gases (GHG) into the atmosphere. If we consider that worldwide the total electricity generation capacity via renewable energies reached only 2,351 GW, it means that only one fifth of the energy required worldwide was generated under an alternative energy scheme (IPCC, 2021), which makes it difficult to think that the escalating energy demand of this sector has been accompanied by its generation via non-fossilized energies.

Between 2010 and 2020, global IP traffic (i.e., the amount of data that crossed the internet in a given period) increased more than tenfold, while the demand for storage in global data centers increased 25%, multiplying the number of computer instances executed by servers (measured to manage applications used in cell phones) by more than six (Masanet et al., 2020). This is explained by the fact that the average global internet usage is almost seven hours per day.[8]

If we add to this scenario that the new technological revolution includes the arrival of the Internet of Things (IoT), where a whole series of everyday devices and appliances (from alarms, light bulbs and climate controllers to televisions, household appliances, showers and security equipment) will be added to the electronic devices connected to the network, the energy demand of homes will increase exponentially on a global scale.

In addition, we must consider the analysis of an important pollution niche: the cable requirements for non-satellite interconnectivity ("the veins of digitization"), which is still by far the largest information flow: 99% of information traffic is through this interoceanic cabling infrastructure, and only 10% is via satellite (Map 2).

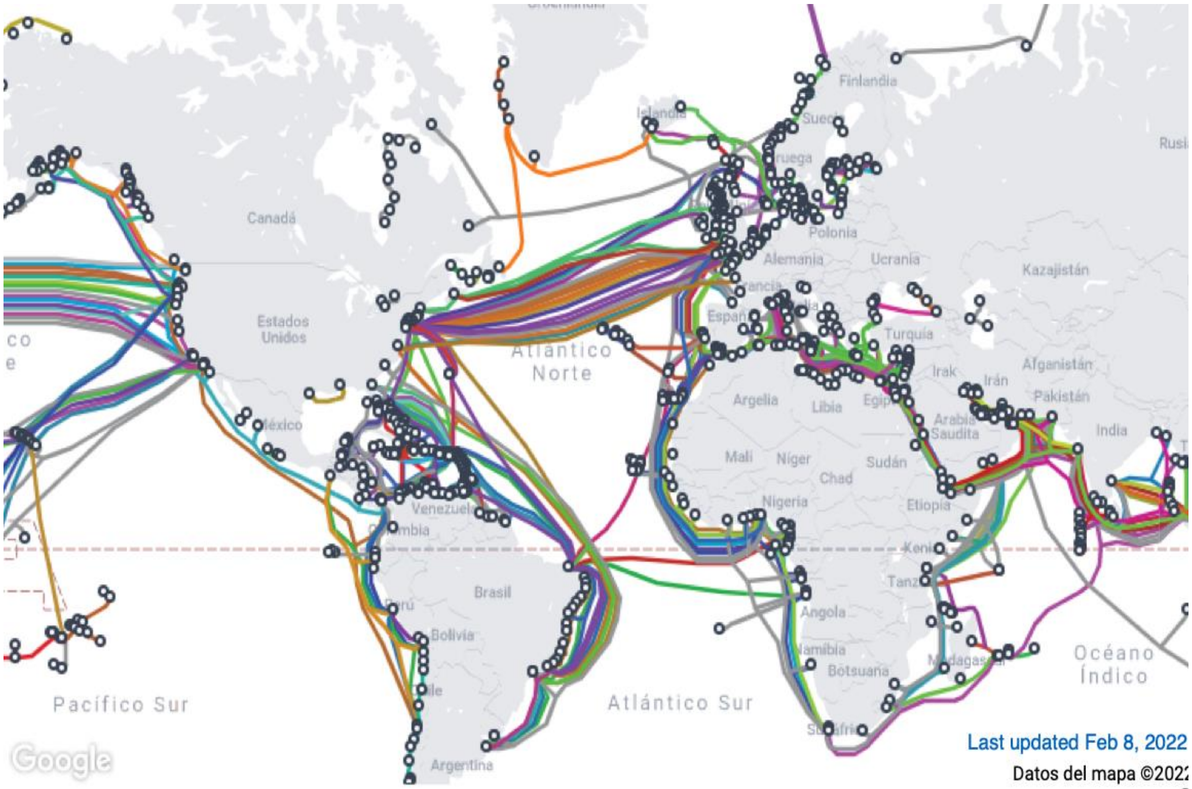
Seventy-five percent of the information carried by this submarine cabling infrastructure is data, while only 4% is voice messaging; this infrastructure is what allows an e-mail to travel 6,000 kilometers under the sea in 60 milliseconds. And despite the fact that the existence of these cables dates back 30 years and in some regions up to 40 years, studies around their environmental impacts are scarce; there are some analyses on their effects on habitat loss, noise, the chemical pollution they cause, their heat emissions and that of the effects of the electromagnetic fields they generate (Taormina et al., 2018).

Likewise, the risk due to entanglement, introduction of artificial substrates and the creation of reserve effects have already been studied,[9] although there are huge gaps regarding the impact of this infrastructure on marine biomes. What is certain is that, by introducing foreign elements into this natural environment, physical and biological changes are produced, chemical and suspended sediment contamination is generated, as well as electromagnetic effects and ultramarine noise.

[8] See www.statista.com/grafico/17539/data-created-online-in-a-minute/

[9] See https://www.centralvozip.com/europaamerica-latina-proyecto-de-cable-submarino-ilustrado-con-diagrama-y-mapas-interactivos/#more-612

Map 2. Global Submarine Cable Map



Source: Global Bandwidht Research Service (2021).

The scarcity of studies around this phenomenon forces the need to do more research that yields knowledge about the different sensitivity thresholds that allow the analysis of the multiple impacts on species and ecosystems, as well as their synergistic effects, since only a few have been evaluated and little has been documented around the generation of networks of impacts (network impacts), which suggests the need to consider more than one factor of activity or synergistic disturbance (Taormina et al., 2018).

This series of effects can be added to those already known such as ocean plasticization, chemical pollution, eutrophication and anthropogenic encroachment, especially in closed and shallow areas, especially for commercial and sport fishing purposes, as well as massive and unsustainable tourism (Wheeling, 2017). Hence, the effects due to interactions between different types of disturbances remain highly speculative, because in essence the environmental impact of cabling is still poorly understood.

We consider that reflection and debate on DCF should guide analysis tables around environmental issues in the short term. The new scenarios generated by the pandemic, with the advent of interconnection dynamics such as home office and homeschooling, will multiply DCF, added to the generalized trend that IoT brings with it.

The network's carbon footprint: the polluting cloud

Analyzing the DCF implies, in addition to studying data centers, investigating the role that the internet plays in contemporary societies. Digitalization is part of today's civilization, to the extent that dependence on this digital scheme is reflected in almost all aspects of human life, becoming the nerve center of modern individuals.

The complex modern system mounted on the internet supports our financial activities, transportation and telecommunications, education, labor, etc., in such a way that it seems to be the central nervous system of global life today.

The ecological footprint of the energy requirements of this system has grown exponentially in recent years due to the fossil model on which it is based, and is expected to increase even more in the immediate future. Add to this phenomenon, of course, the demands of interconnectivity and digitalization resulting from the global pandemic caused by the SARS-CoV-2 virus.

Globally, the energy demand of internet-connected devices, as well as the enormous amount of data used for high-resolution video streaming, emails, surveillance systems and the new generation of network-connected devices, has increased 20% annually, consuming approximately 5% of the world's electricity (Andrae & Edler, 2013), although some others claim that the percentage is close to 7% (Andrae & Corcoran, 2015).

This was therefore more than the emissions produced by the aviation sector and a quarter of the global transportation sector.[10] Trends, however, indicate that the use of gadgets, applications, the internet and the systems that support them will double by 2025.[11]

One of the biggest energy consumers is video streaming. In 2020, video streaming traffic reached 80% of the total traffic generated by the data consumer on the network (Carbon Trust, 2021), although some agencies report up to 87% (IEA, 2017). That meant, in real numbers, that every second ran the content of one million minutes of content across the network, a fact that increased with the offering of video streaming services from Facebook and Twitter (Cook et al., 2017). These broadcasts are also observed by stored mail, sent, sent with attached data and even by commercial search engine orderings (Table 1).

Studies by some agencies specialized in the subject report that the average CO2 consumption of videos transmitted online is more than 300 million tons per year, similar to what countries such as Spain, Holland or New Zealand produce in total. It is also

[10] See https://www.centralvozip.com/europaamerica-latina-proyecto-de-cable-submarino-ilustrado-con-diagrama-y-mapas-interactivos/#more-612
[11] See https://www.bbc.com/future/article/20200305-why-your-internet-habits-are-not-as-clean-as-you-think

stated that the transmission of ten hours of HD quality movies requires more bits and bytes than all the articles published so far by platforms such as Wikipedia.[12]

Table 1. CO^2 emissions from internet activities

Network activity	Carbon dioxide emitted (CO^2/annual)
Video viewing on YouTube	1 gram
Stored mail	10 grams
Email sent	4 grams
Email sent with attachment	50 grams
Google search	0,2 grams
Web Browser	1.76 grams (per viewed page)

Source: developed by the author based on Ozcan and Apergis (2018)and ClimateCare, 2021.

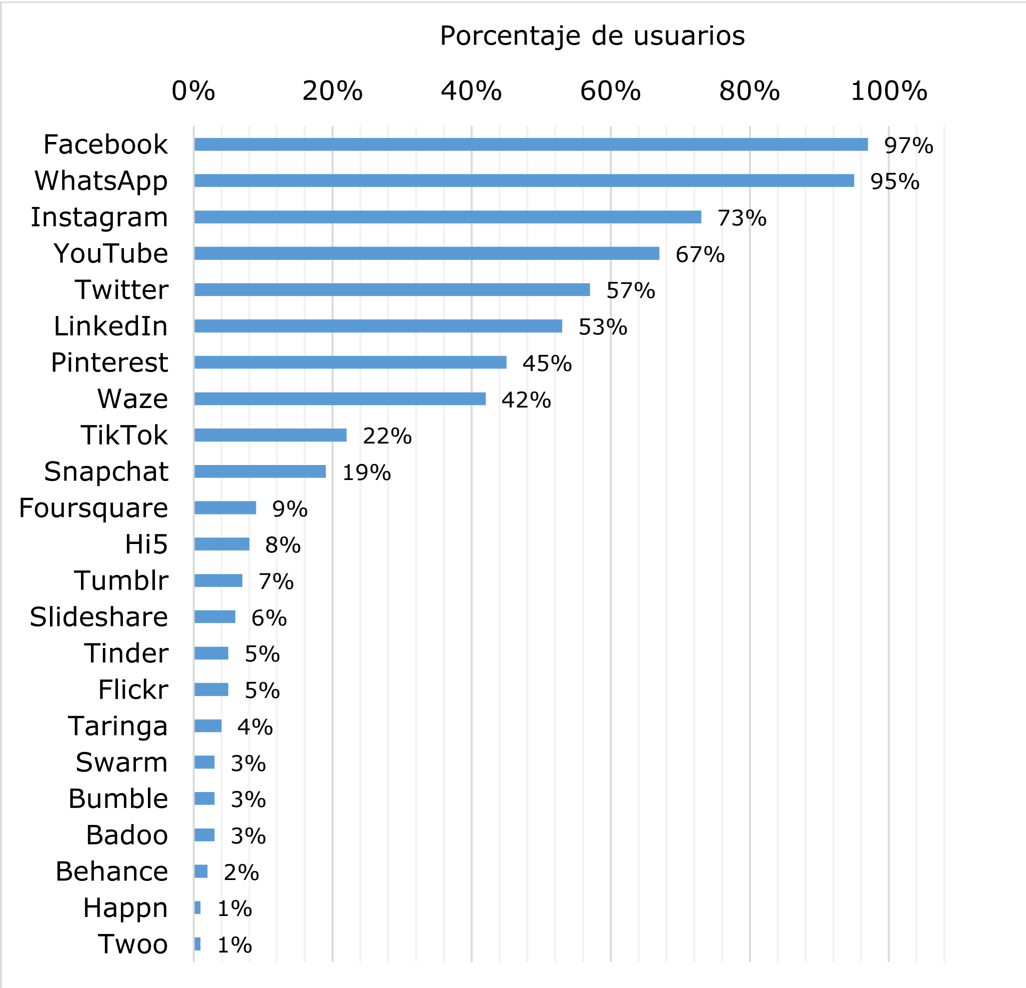
In another order of ideas, derived from the mobility restrictions implemented globally by covid-19, technological dependence skyrocketed its numbers as video calls, emails, instant messaging and virtual entertainment replaced face-to-face social interactions; the transit of a significant number of jobs to home (home office) as well as virtual education (homeschooling) increased these numbers by 40%, which posed a scenario that, in a significant percentage, will remain that way in the immediate future; this implies that the 3.8 billion internet users before the pandemic will increase to 5 billion in 2025, driven by this use of virtual space (Bertoli et al., 2022).

In Mexico, this trend during the pandemic was reflected in the increasingly widespread use of social networks: Facebook, WhatsApp and Instagram are, above YouTube and Tik Tok, the most widely used (Graphic 3).

In the same respect, real-time entertainment showed its highest numbers in the five months following the onset of global confinement, which brought it close to a percentage close to 71% of the bytes downloaded during this period. Platforms such as Netflix accounted for 35% of data traffic via streaming (Sweney, 2020). Streaming an hour of video in Full HD requires between 220 and 370 watt-hours of electrical power, depending on the streaming medium (mobile device, tablet or TV) (Koomey, 2020). This adds up to about 100 to 175 grams of CO2, which would be equivalent to driving one kilometer in a small car (Hintemann & Clausen, 2016).

[12] See https://theshiftproject.org/en/article/oil-what-are-the-risks-for-the-future-of-europe-supply-the new-shifts-report-about-peak-oil/

Graphic 3. Social networks with the highest percentage of users in Mexico, January 2021



Source: developed by the author with data from Statista (2021).

The two most common platforms that stream music, Spotify and Apple Music, emitted around 200 to 350 million kilograms of GHGs between 2015 and 2016, which, paradoxically, is more damaging than the ecological footprint resulting from both the production and disposal of CDs (Hintemann & Clausen, 2016).

The digitized economy has also been studied in this regard. Cryptocurrencies consume a large amount of energy: transactions of Bitcoin, probably the most well-known digital currency, consumed about 819 kWh, while the system as a whole produced about 22 megatons of CO_2 in 2018, equivalent to the carbon footprint of cities such as Hamburg, Vienna and Las Vegas (Foteinis, 2018).

Some of the leading large corporations on digital platforms made commitments to renewables-based energy sourcing, a trend that has been augmented by global companies (Cook et al., 2017). This has led to the assertion that, unlike industries such as aviation or heavy industry (who will have a very slow transit to carbon neutrality), the data centers that power these platforms can make this path more easily, through public policies and investment.[13]

In short, we sustain that the increase in DCF has a high socio-environmental impact, as it distances us from carbon neutrality as shown by the 2030 Agenda and will only be mitigated as long as it is intertwined with new energy management models (renewable energies) that optimize both the infrastructure (data centers) and the use of the internet itself, as well as the storage of information in the cloud.

Conclusions

As per our analysis in this research, a myriad of everyday social actions is carried out online; these travel as a packet through data centers and their servers. Therefore, it is a priority to observe and study the energy use that these spaces require; this leads us to a deep reflection on how avid and necessary digitalization is.

However, today it is almost impossible to say with certainty how high the current energy requirements of all data centers around the world are. Current estimates range from 200 to 500 billion kilowatt hours per year, an estimated 3% of the world's electricity. Future predictions also differ considerably, with figures between 200 billion and 300 billion kilowatt hours predicted for the year 2030.

Expert opinions differ due to the absence of official figures reported for data centers and their role in global information storage and management. A large number of these operators are still reluctant to provide information on their energy consumption due to concerns about competitiveness and security. For the time being, we can only get close to the actual figures through estimates, so this, among some other points, will be left for future studies.

What is clear for now is that this digitization model has a high ecological footprint, as it generates enormous amounts of heat as a waste product. Reducing energy consumption of data centers is therefore an important step in bringing digitization closer to sustainability. We venture three scenarios for this: 1) find more efficient ways to cool down data centers, 2) reuse waste heat, and 3) seek to power them with renewable energy.

Furthermore, our digital energy consumption is not only determined by what we do, but also by how we do it; that is, we cannot ignore the fact that the software we use also has a significant ecological footprint. For example, a less efficient word processor needs four times more energy to process the same document in an efficient one. While

[13] See https://iea.org/reports/data-centers-and-data-transmission-networks

it is also true that software updates often cause computers or smartphones to slow down or stop working, forcing consumers to buy new hardware.

Finally, in the immediate future, the growing demand for electricity for digitization will surely also be driven by an increase in smart technologies, such as those we increasingly use at home, in education, in the IoT sector, in industry and in our increasingly tech-savvy cities.

Sustainable digitalization will be viable as long as we learn how to manage digital tools and services in moderation and in the right places. The issue of sustainability must include, of course, the analysis of products and services throughout their life cycle, aiming to optimize their use as well as the base energy sources, and seek more alternatives to the major players in our digitized world.

This implies a joint effort of manufacturers, consumers and digital service providers, who must tend towards reducing the environmental impact of this increasingly digitized civilization; the incentive for this, the subject of future research, will ultimately come from public policies and the set of regulations to be managed on a global scale.

The digital revolution, without management in favor of carbon neutrality, is bound to increase our consumption of resources and energy, accelerating damage to the environment and the reaching of points of no return.

Although some digital developments optimize human life, doing so unchecked threatens to undermine the sustainability of the planet. Ensuring that digitalization is put at the service of sustainable development, and that digitalization itself is implemented and applied in this sense, will have to be a political and social priority in the near future.

REFERENCES

Andrae, A. y Edler, T. (2013). *On Global Electricity Usage of Communications Technology: Trends to 2030.* Sweden: Huawei Technologies.

Andrae, A. y Corcoran, P. (2015). Emerging trends in electricity consumption for consumers ICT. *Electrical and Electronic Engineering*. https://aran.library.nuigalway.ie/xmlui/handle/10379/3563

Bakar, A.; Shehabi, A. y Marston, L. (2021). The environmental footprint data centers in the United States. *Environmental Research Letters, 16(6)*. https://data.lib.vt.edu/articles/dataset/The_environmental_footprint_of_data_centers_in_the_United_States/14504913

Bertoli, E.; Troilo, M.; Al Mugharbil, A.; Rozite, V. y Le Marois, J. B. (2022). The potential of digital business models in the new energy economy. https://www.iea.org/articles/the-potential-of-digital-business-models-in-the-new-energy-economy

Belkhir, L. y Elmeligi, A. (2018). Assessing ICT Global Emissions Footprint: Trends to 2040 & Recommendations. *Journal of Cleaner Production*, *177*, 448-463. https://www.sciencedirect.com/science/article/abs/pii/S095965261733233X

Carbon Trust. (2021). *Carbon impact of video streaming*. London: Carbon Trust. http://carbontrust.com/resources/carbon-impact-of-video-streaming

Christian, P. (2018). Where are the World's Cloud Data Centers and Who is Using Them? *TeleGeography Blog*. https://blog.telegeography.com/where-are-the-worlds-cloud-data-centers-and-who-is-using-them

ClimateCare. (2021). Together we have cut 100 million tonnes of CO2. *ClimateCare*. https://www.climatecare.org/resources/news/together-weve-cut-100-million-tonnes-of-co2/

Cook, G.; Lee, J.; Tsai, T.; Kong, A.; Deans, J.; Johnson, B. y Jardim, E. (2017). *Clicking clean: who is winning the race to build a green internet?* Washington: Greenpeace.

Foteinis, S. (2018). Bitcoin's alarming carbon footprint. *Nature*, *554*(7690), 169-182. https://go.gale.com/ps/i.do?p=HRCA&u=anon~5571b62c&id=GALE|A660257793&v=2.1&it=r&sid=googleScholar&asid=c7c0f001

Global Bandwidth Research Service. (2021). *Submarine Cable Map*. http://submarinecablemap.com

GSMA. (2020). *The Mobile Economy*. https://www.gsma.com/mobileeconomy/wpcontent/uploads/2020/03/GSMA_MobileEconomy2020_Global.pdf

Hintemann, R. y Clausen, J. (2016). *Green Cloud? The current and future development of energy consumption by data centers, networks and end-users' devices*. Berlín: Border Institute. https://www.borderstep.de/wp-content/uploads/2016/09/ICT4S-Hintemann-Clausen-Green-Cloud-final-2016.pdf

International Energy Agency (IEA). (2017). *Digitalization & Energy*. París: OECD, IEA.

International Panel of Climate Change (IPCC). (2021). *Emissions Gap Report 2021*. New York: United Nations.

Koomey, J. (2011). Growth in data center electricity use 2005 to 2010. A report by Analytics Press. https://alejandrobarros.com/wp-content/uploads/old/4363/Growth_in_Data_Center_Electricity_use_2005_to_2010.pdf

Koomey, J. (2020). Factcheck: What is the Carbon Footprint of Steaming Video on Netflix? *Carbon Brief*. https://www.carbonbrief.org/factcheck-what-is-the-carbon-footprint-of-streaming-video-on-netflix

Marius, O. (2021). This is how we reduce data centers' carbon footprint. *#SINTEFblog*. https://blog.sintef.com/%20sintefenergy/this-is-how-we-reduce-data-centers-carbon-footprint/

Masanet, E.; Shehabi, A.; Lei, N.; Smith, S. y Koomey, J. (2020). Recalibrating global data center energy-uses estimates, *Science*, *367*(6481), 984-986.

Osibanjo, O y Nnorom, I. (2007). The challenge of electronics waste (e-waste) management in developing countries, *Waste Management & Research: Journal* *for a Sustainable Circular Economy*, *25(6)*, 17-46. https://doi.org/10.1177/0734242X07082028

Ozcan, B. y Apergis, N. (2018). The impact of internet use on air pollution: Evidence from emerging countries, *Environmental Science & Pollution Research*, *25*, 4174-4189. https://www.proquest.com/openview/64836b648dc1dcd698bf24aea50be928/1?pq-origsite=gscholar&cbl=54208

Páez, L. y Velásquez, C. (2020). *TIP de TIC. ¿Sabías que tienes huella de carbono digital?* Universidad CES: Repositorio Digital Institucional. https://repository.ces.edu.co/handle/10946/4880#:~:text=Resumen,medio%20ambiente%2C%20aprende%20c%C3%B3mo%20reducirla

Rajaraman, V. (2014). Cloud computing, *Resonance*, *19*, 242-258. https://doi.org/10.1007/s12045-014-0030-1.

Shehabi, A.; Smith, S.; Sartor, D.; Brown, R.; Herrlin, M.; Koomey, J.; Masanet, E.; Horner, N.; Lima, I. y Lintner, W. (2016). *United States Data Center Energy Usage Report.* New York: University of Berkeley.

Schwab, K. (2016). *The Fourth Industrial Revolution*. New York: Crown Business.

Statista. (2020). *Number of smartphone users from 2016 to 2021*. https://www.statista.com/statistics/330695/number-of-smartphone-users-worldwide/

Statista. (2021). Digital 2021. Global Overview Report. *Datareportal*. https://datareportal.com/reports/digital-2021-global-overview-report

Sweney, M. (2020). Streaming´s dirty secret: how viewing Netflix top 10 creates vast quantity of CO2. The guardian, octubre 2021. https://www.theguardian.com/tv-and-radio/2021/oct/29/streamings-dirty-secret-how-viewing-netflix-top-10-creates-vast-quantity-of-co2

Taormina, B.; Bald, J.; Want, A.; Thouzeau, G.; Lejart, M.; Desroy, N. y Carlier, A. (2018). A review of potential impacts of submarine power cables on the marine environment: Knowledge gaps, recommendations and future directions. *Renewable and Sustainable Energy Reviews*, *96*, 380-391. https://www.sciencedirect.com/science/article/abs/pii/S1364032118305355

Wheeling, K. (2017). Do submarine power cables affect marine ecosystems? *Pacific Standard on line*. https://psmag.com/environment/do-submarine-power-cables-affect-marine-ecosystems