# Pollution Ranking of the most Popular Digital Platforms

Natalia Molinero Mingorance, *Member, IEEE*

**Abstract**— In the last decade, the number of internet users has increased more than 1000%, reaching 5 billion users. The ICT sector is responsible of billion tons of greenhouse gas (GHG) emissions yearly, representing 7% of world emissions, tripling the ones produces by the aviation industry. This is mainly due to the massive data centers that process this ever-increasing amount of information. This work evaluates the most popular digital services running on those data centers: Facebook, Instagram, TikTok, YouTube, Netflix, Amazon, Zoom, Skype, and Spotify. Finding the emissions they cause is challenging because of the lack of both, available data and detailed methodology. Hence, the pollution generated and its causes have been collected from several sources and contrasted with different simulations. This exhaustive research, not pursued before, confirms that video streaming services are the most polluting ones. To date, such a complete analysis of the damage to the environment caused by these applications has not been carried out and it is hoped that this paper will contribute mainly in three ways: raise awareness of our digital carbon footprint; disseminate knowledge on how to estimate pollution from our online behavior; and pointing to the causes of the issue to find optimal solutions.

**Index Terms**—data center, energy consumption, sustainability, video streaming

## 1 Introduction

MOST recent public statistics show that there are 5 billion internet users [1]. This amount of traffic flowing through the telecommunication networks produces an average of 45 $gCO_2Eq$ per gigabyte (GB) which is almost 100 million tons $CO_2Eq$ a year [2]. This is a remarkable traffic growth is driven mainly by video streaming [3]. In fact, the ICT, and the Entertainment and Media (E&M) sectors have a great influence on environmental pollution due to the high requirements on energy and the associated emissions [4].

One of the main reasons of this carbon footprint are the data centers, that need huge amount of energy to store, transmit and receive the digital content. Users' equipment (specially televisions and laptops), the mobile networks and other internet elements are also considered in this study.

The goal of this paper is to enunciate the commercial names of the most polluting digital services in the world to identify where actions should be taken. The applications studied in this paper have changed our daily lives in the recent years and mostly everyone has used any of them. This is why this paper pretends to outline the importance of being aware of our digital carbon footprint, with the most relevant and accurate data available. The difficulty to provide objective numbers of the pollution we are causing has led to evaluate different methods and review many sources. However, even the most conservative figures are relevant in terms of damage to the environment.

The findings reveal that users spend most of their time interacting with different social media services and, especially, consuming content on streaming platforms which are, indeed, the most polluting ones given the type and quantity of data involved as will be shown in the following sections. Other services such as online gaming platforms or messaging applications were initially considered but not found comparable in terms of volume of active users, size of data served and pollution significance.

Thus, the platforms for this study are:

1) Social media: Facebook, Instagram and TikTok
2) Video-on-demand: YouTube and Netflix
3) Retailing: Amazon
4) Video conferencing: Zoom and Skype
5) Streaming music: Spotify

As the exact pollution data and the complete methodology applied to support them is not publicly available, in the interest of creating this classification, different methods have been used. First, research on the literature where several sources have been reviewed to find: number of active users, volume of data transferred, chosen device by consumers, energy consumption and pollution generated, all of them, for a given period of time. Then, some available simulators have been used to verify this information with special attention to the methodology considered to obtain those numbers. After a critical comparison of the different results derived from each methodology, a ranking of the most polluting platforms has been established for each of them, as well as a global ranking, which suggests that the giant usage of videos and the necessary high computational load and storage, are the main responsible of the digital contamination.

Therefore, the paper is organized as follows: Section 2 is the Literature Review where we highlight findings that support our path of investigation and allow us to fill in

• *Natalia Molinero Mingorance is with the Polytechnic School, European University, 28670 Madrid, Spain.*
*E-mail: eng.nataliamolinero@gmail.com.*

some gaps. Then, Section 3 is a theoretical introduction of the elements present in the social media platforms, from the user devices to the companies' data centers. Section 4 explains the methodology followed to obtain the different classifications: research-based and simulations, focusing on the parameters considered on each, which will explain the differences in the results and their relevance. In Section 5, we present the different rankings for the methods followed. Then, in Section 6, we discuss these differences and include an analysis of the reasons, as well as a comparison of the results with some well-known sources of emissions, such as the vehicle's pollution. Section 7 ends the paper highlighting the conclusions, including the way the companies should report their emissions, and the future lines of work. We especially focus on those targeted to reduce the energy consumption on the most polluting elements, data centers, by paying attention to the source of the problem: the elevated computational load required to process heavy traffic such as video.

## 2 Literature Review

A. Batmunkh [4] analyses the social media platforms: YouTube, Netflix, Facebook, and TikTok by focusing on the emissions caused by their data centers. It states that social media is one of the main contaminants in the IT sector. The study is based on four public estimation methods, the volume of data and usage time. The formulae of these methods are not critically reviewed in spite of the differences in the results. In this paper, we also take figures from the official reports published by the digital services' providers, considering them as the most trustful source, but also comparing them with the secondary research. Moreover, the present work evaluates more elements in addition to data centers and more digital platforms, with the aim of extracting more solid conclusions.

P. Suski et al. [5] highlights the lack of accurate information from providers and presents the results of a survey of 91 users to note that online video streaming is highly relevant for the climate change, and it depends on indicators such as viewing duration, resolution, and bandwidth of the video. Following this idea, we have measured the pollution of the evaluated platforms with online tools. As we also have found an approximation on the total number of active users for each platform, the global footprint was estimated. The different publicly available data and methodologies and the empirical testing will be compared in the Discussion Section.

More estimations on the digital platforms environmental harm have been made in the past. As R. Obringer et al [2] reported, a common streaming service requires 7 GB per hour when using Ultra HD or 4K quality which translates in a carbon footprint of 441 $gCO_2Eq$ an hour. Proportionally, streaming 4 hours a day will result in monthly emissions of 53 $kgCO_2Eq$. Reducing the quality from HD to standard reduces the footprint to 2.5 kg. Considering an average between [6] and [7] most updated data, results in 5.18 billion subscribers estimated for Netflix. Hence, the estimation based on standard quality will lead to 12.95 billion $gCO_2Eq$ which doubles what Netflix recently reported because they account for the use of green energy. The present article considers the new sustainability approaches of organizations (i.e., green data centers).

C. Priest et al, [8] evaluate the sustainable interaction design of YouTube by using a life cycle assessment (LCA). They estimated emissions of 10 million tons $CO_2Eq$ a year and they calculated reductions of 300,000 tons $CO_2Eq$ a year by using a sustainable interaction design. As in the cited work, it has been found the need for official data reported by companies, including users' behavior patterns to facilitate where the energy expenditure happens.

Regarding the main traffic flooding our networks, the importance of video is highlighted on [9], where it is pointed that video is present in most of the digital platforms: video-on-demand, live streaming, video sharing, video conferencing, and video in social media. Some names are mentioned such as YouTube and Netflix. However, a more complete analysis has been needed for the present work, considering the number of active users as well as the time spent on each platform. All these parameters are important to evaluate the carbon footprint of each platform.

## 3 The Source of The Emissions

In order to classify the digital services according to their pollution contribution to the planet, it is useful to understand where the issue is originated. In the case of telecommunication processes, the main $CO_2$ emissions are produced by the electricity usage. Therefore, finding the component where this energy is consumed and its function in the process is key to understand the problem and characterize it. An analysis of the different elements involved in this process has been conducted. The goal of this section is to provide the description of these elements.

The performance of any of the analyzed platforms (i.e., Facebook, Instagram, YouTube, TikTok, Skype, Zoom, Netflix, Amazon, and Spotify) depends on the following parts:

- Data Centers: content user requests are mainly delivered by data centers as most of the software-based digital content is processed there. The servers located at these buildings store and process massive amounts of data and need to be running 24/7. This means they are highly power demanding and heat producers, so they also need refrigeration (water consumption). In addition, the information they supply needs to be redundant (being stored somewhere else) which implies more power and water consumption. At present, many companies report their data on electricity consumed and $CO_2$ emissions produced by their data centers, because it is known that they are one of the most polluting pieces in the service delivery process. Although data centers from big providers have started to use renewable sources of energy, they also need to cope with the bandwidth growth. Consequently, they are not highly energy efficient in the sense of [10]. Considering an emission of 32 $gCO_2Eq$ per GB, it is estimated that the data storage and transmission in the world emits 97 million tons $CO_2Eq$ a year [2].

- Users' interaction: the time users spent on a digital service and the size of the data exchanged during that given time contribute to the energy consumption. Users' behavior is not publicly reported by organizations but there are estimations and surveys published by third party companies.
- Core and Edge Networks: the path where the information travels from and to the users are primarily optical fibers, switches, routers, and repeaters. The energy consumed by this equipment has been estimated and agreed [8].
- Residential Access Network: the journey taken by the information to travel from the edge network to the user home (Wi-Fi) relies on different technologies (DSL, fiber) that will result in different power requirements, and usually, general estimations for broadband access are considered [11].
- Cellular Networks: 3G, 4G and 5G networks electricity usage should be also considered. In fact, more than 50% of the network's energy consumption is due to the wireless part which also tends to develop faster than the fixed network [3]. In Europe, fixed data traffic per connection was 293 GB/month in 2021 and it is expected to reach 454 GB/month in 2023 (an increment of almost 55%), while mobile data traffic per connection was 4.5 GB/month and it is expected to reach 16.2 GB/month in 2023 (an increment greater than 90%). Video-based applications drive up mobile data traffic, being the global average usage per smartphone 11.4 GB [12].
- End User Devices: the studied platforms can be mainly used in smartphones, laptops, and TVs. Each of these devices has different power requirements. Therefore, knowing the type of consumer devices it is crucial to assess the total repercussion on the global warming.

Finding solid data on the energy consumption of the components listed previously is almost impossible because of the scarcity of official reports by the internet providers and the different standards and regulations existing around the world. Usually, organizations report their data centers consumption which contemplates servers, storage equipment and network devices inside their buildings [13]. In these reports, the energy consumption and associated $CO_2$ emissions are classified according to three scopes:

- Scope 1: these are the emissions directly produced by companies. In most of the services under study, the companies own the data centers, so they are included here. Other activities can be incorporated but normally, as data centers are the key component, their energy consumption is reported separately. This is the case of Netflix [14].
- Scope 2: it involves the energy bought by the companies. In some cases, the energy is acquired to feed data centers, so we have found the data centers emissions are reported under this section. This is the case of Zoom [15].
- Scope 3: these are indirect emissions resulting from the company's activities outside their control. If companies host data center services with external providers, such as the case of Spotify [16], data center emissions are reported here in addition to scope 1 and 2 because they use third party storage and processing services.

Some companies use scope 1 and 2 to account for their data centers, such as Facebook [17], Google [18] and Amazon [19].

In any of these scopes, the organizations do not specify the expenditure due to the use of their service nor the network elements consumption, which probably would need third parties involved and new policies, agreements and regulations to provide these data unambiguously. While the end-user-equipment consumption is decreasing, data centers and networks show a relatively strong increase due to the progressively higher bandwidths. In the world, the network interconnecting users, and data centers accounts for approximate 25% of the total energy consumption and associated emissions [3].

In order to complete the comparison among platforms, this work is sustained with online estimators and experimental tests on end users' devices, which use methodologies that consider the consumption due to the network and use of the service of the digital communications system.

According to the authors of [20], the energy consumption is distributed in:

- Data center use: energy required to house and serve data. This accounts for an estimated 15% of the complete platforms' system.
- Network use: data transferred across the network. This accounts for an estimated 14% of the system.

- Consumer device use: end users interacting with a product or service. This accounts for an estimated 52% of the system.
- Hardware production: embodied energy used in the creation of embedded chips, use of data centers, use of networks, and the use of consumer communication devices. This accounts for an estimated 19% of the system.

The referenced authors have estimated the following data:

- Annual Internet Energy: 1988 TWh
- Annual End User Traffic: 2444 EB

At present, most of the companies are compromised to use green energy to feed their data centers and there are many of the analyzed ones using 100% of renewable energy. However, this does not mean they do not generate GHG emissions. In fact, they publish location-based and market-based data. The location-based method reflects the average emissions intensity of grids on which energy consumption occurs (using mostly grid-average emission factor data). The market-based method reflects emissions from electricity that entities have purposefully chosen (or their lack of choice) [23]. The market-based method allows organizations to take credit for the green electricity they purchase by applying emissions factors. In this work, we have selected the market-based information, which are more conservative than the location-based ones.

# 4 METHODOLOGY

Once the system elements contributing to the pollution of the applications were identified, several rankings have been obtained according to different methods. First, data from each platform have been collected from literature: a series of attributes to provide a comparison between the chosen applications have been put together from published indicators such as number of active users, average time spent on it by most of the people, power consumption and $CO_2$ emissions. Likewise, online calculators to get more insights have been helpful to support this work. Besides, some empirical tests were performed with available software to estimate emissions caused by normal usage. The experimental testing has been carried out on a smartphone (Samsung Galaxy S21 Ultra 5G with Android 12) and a laptop (Dell XPS 15 9500 with Windows 10 Pro). The following paragraphs describe the methodology used to create each ranking.

## 4.1 Investigation-based assessment

The lack of objective available information has led to take several approaches to find answers. First, available literature, i.e., official organizations' "Environmental, Social and Governance (ESG)" reports, internet reports, news and blogs have been compared. The numbers obtained from these sources have been examined and an average is presented as the selected value to compare the GHG emissions produced by the selected platforms.

In the cases where the material was procured by the digital platform's organizations, no average is calculated, and the reported value is shown.

In relation to YouTube, there were not an ESG report. Instead, it was found for Google. This source has been utilized; first, because no other official data is available; second, because, as described in Section 3.2, video streaming is the most energy consumption type of traffic on companies' data centers, so we consider the GHG from Google are mainly due to the video processing; the third reason is that we have compared those numbers with data from other publications (i.e., [22] estates that YouTube produced 702 billion $gCO_2Eq$ ) which are similar numbers to the Google's report, so our approach is justified.

Respecting Zoom, as the platform is mainly used for professional purposes, the number of monthly active users is counting only the working days (an average of 20 days a month).

With this data, we have created the first ranking "Ranking 1. Pollution due to data centers".

## 4.2 Social carbon footprint calculator

The "Social carbon footprint calculator" [24] is an online tool that calculates the $gCO_2Eq$ per day and per year for a user, based on the time spent in the social platforms. Using the average time spent on YouTube, Facebook, Instagram and TikTok found to complete Table I, those figures have been obtained (the evaluation is done only for those platforms, because the rest are not available in the calculator). The social media carbon footprint calculator works by taking the number of minutes spent on each social media site and multiplying them by the estimated emissions per minute for that site and multiplying the daily figure by 365 to calculate the annual footprint.

Its authors explain that the average emissions per minute for each app were sourced from Greenspector and measured on a Galaxy S7 smartphone. They run 1-minute tests and average 3 homogeneous measurements [25]: they launch each application and wait 20 seconds, scroll through the news feed or the "Discover" tab and measure the consumption.

They follow a complete Life Cycle Inventory (LCI) part and a simplified Life Cycle Assessment (LCA). The LCI is predominant in their model to ensure reliable and representative data [26]. This methodology consists in the following steps:

- Energy consumed on a smartphone: measurement of the energy and data exchanged for the smartphone part (via laboratory measurement)
- Data exchanged on the network: measurement of the energy consumption of the server part (via a partner), considering requests processed by the server, Power Usage Effectiveness (PUE), server type and the electrical emission factors of a particular country. As it is not specified, we assume

the authors used the France's emission factor, 0.057 $kgCO_2Eq/kWh$ from [27], more updated than 0.035 $kgCO_2Eq/kWh$, which is used in the following methodology explained, in Section 4.3.

This way, the unit footprint by user journey is obtained taking into account the device, the network and the data center.

In this paper, we have computed the daily pollution per user with this calculator and we have used it to obtain the monthly pollution by multiplying by 30. Then, using the researched number of monthly active users for each of those platforms, accessing through smartphones (for the cases where this information was not available, we have used half of the total monthly active users; this is the case of Instagram and TikTok) and considering the average time spent on the platform, we have obtained the monthly total pollution and the annual total pollution for each application. Using these data, we created the second ranking, "Ranking 2. Pollution due to full system for phone users (online Calculator)".

## 4.3 Carbonalyser tests on smartphone

In the same way, using the results provided by the application "Mobile Carbonalyser" [28], we have estimated the annual total pollution. This simulation could be run for all the analyzed platforms: Facebook, Instagram, YouTube, TikTok, Skype, Zoom, Netflix, Amazon and Spotify.

However, Skype had to be left out of our evaluation because reliable sources to find the average time spent on the platform by users was not found. The tool obtains the energy consumption, the pollution associated and the data exchanged for the time the user is running the app.

The Carbonalyser uses the "1byte" model was developed by The Shift Project for its report "Lean ICT – Towards digital sobriety", published in October 2018.

Similar to the social carbon footprint calculator methodology already described, it calculates the electricity consumption coming from data traffic, by modelling the electricity consumed by:

- Data centers through which data transfer
- Networks infrastructures (network consumption is calculated for WIFI network)
- The device used to browse the Internet, i.e., an average consumption measured for the smartphone

The calculated electricity consumption is linked to GHG emissions by the carbon intensity factor of the selected location. The factor describes emissions lead by electricity generation, following the electrical mix of the location. The following factors are applied:

- European Union: 0.276 $kgCO_2Eq/kWh$
- France: 0.035 $kgCO_2Eq/kWh$
- United States: 0.493 $kgCO_2Eq/kWh$
- China: 0.681 $kgCO_2Eq/kWh$
- Other (average world carbon intensity factor): 0.519 $kgCO_2Eq/kWh$

As in 4.2, the tests were run in Spain, so the European Union or the world carbon intensity factors can be assumed. Taking the number of monthly active users accessing through smartphones (for the cases where the information was not available, we have used half of the total monthly active users: i.e., Instagram, TikTok, Zoom, Amazon and Spotify), we have obtained the consumption of 1 minute of normal interaction with the latest version of each application in their default settings (the results of 5 tests were averaged). The monthly total pollution was derived by multiplying those results by 30 and by the number of monthly active users. Then, we calculated the annual total pollution by multiplying the last result by 365. This way, we have created the third pollution ranking "Ranking 3. Pollution due to full system for phone users (Carbonalyser)".

## 4.4 Carbonalyser tests on computer

These estimations follow the same principles as the previous one, but this time, the 1-minute tests for each platform was performed 5 times in the testing laptop and averaged. They were run using the Firefox browser, as this analyzer is a Firefox add-on. In addition, the researched number of users for each application accessing through PC was used to estimate to annual total pollution due to each platform. Skype could not be included, as it does not work on Firefox. For Instagram, TikTok, Zoom and Spotify, the number of monthly active users accessing though PC was not available, so half of the total volume was used. Consequently, we have created the fourth ranking, "Ranking 4. Pollution due to full system for laptop users (Carbonalyser)".

## 4.5 Carbon footprint using different carbon factors

In order to obtain pollution results that can be really explained, the Methodology in [29] was applied to obtain the total system emissions and the emissions only due to the data centers contributions, so we can compare those results with the ones obtained in the previous Rankings. The steps followed to obtain these results were:

1. Gather the data transfer per visit in GB, for the smartphone users: this was obtained from the Carbonalyser tests that show the data exchanged per minute. That number was multiplied by the average time spent in the platform, obtained from the research to create Ranking 1.
2. Gather the data transfer per returning visit in GB, for the smartphone users: this was obtained through an approximation; i.e., two thirds of the new visitors' traffic, as we consider some data is already saved in cookies and cache.
3. Gather monthly visitors using smartphone: obtained through research as in Ranking 3, Section 4.3.

4. Apply a carbon factor (due to renewable energy sources) of 50 g/kWh, as suggested by this methodology.
5. Apply the Annual Internet Energy / Annual End User Traffic = 0.81 TWh/EB or 0.81 kWh/GB, also from [29].

Likewise, we obtained the same data for laptop users. In order to check how the different carbon factors found in the literature can change the results, for a global grid carbon factor of 442 g/kWh provided by [29], and for a global carbon factor of 519 g/kWh, taken from [28], we calculate the following parameters:

- Energy per visit in kWh (E): [Data Transfer per Visit (new visitors) in GB x 0.81 kWh/GB x 0.75] + [Data Transfer per Visit (returning visitors) in GB x 0.81 kWh/GB x 0.25 x 0.02]
- Emissions per visit in $gCO_2Eq$ (C): E x 442 g/kWh (or alternative/region-specific carbon factor)
- Annual energy in kWh (AE): E x Monthly Visitors x 12
- Annual emissions in $gCO_2Eq$ (AC): C x Monthly Visitors x 12

Annual Segment Energy:

- Consumer device energy: AE x 0.52
- Network energy: AE x 0.14
- Data center energy: AE x 0.15
- Production energy: AE x 0.19

Annual Segment Emissions:

- Consumer device emissions: AC x 0.52
- Network emissions: AC x 0.14
- Data center emission: AC x 0.15
- Production emission: AC x 0.19

Once we calculated the results for smartphone users and laptop users, using both carbon factors, we sum the results (i.e., smartphone plus laptop users) for each social media application to obtain the total pollution. Therefore, in this approximation, we are missing users accessing through TVs, tablets, and other devices. However, we can compare the results applying this methodology with the ones resulting from methodologies explained in Sections 4.2 to 4.5. Following the same approach, we obtain the total contribution due to the data centers for these users, so we can compare with Ranking 1. This method will provide two rankings: "Ranking 5. Pollution due to full system for a carbon factor of 442 g/kWh (Formulae)" and "Ranking 6. Pollution due to full system for a carbon factor of 519 g/kWh (Formulae)".

### 4.6 Comparison between the carbon footprint methodologies

At this stage, three methodologies are available to obtain the social media carbon footprint due two data centers: Section 4.1, from literature, and Section 4.5, applying the formulae for smartphones and laptop users, using two different carbon factors.

In addition, five methodologies are presented to compute the complete system pollution: Sections 4.2 to 4.5. In the latter, we compared the results for each methodology for all platforms, so we can discuss which platform is the most polluting for each methodology.

Finally, by averaging all the data center pollution rankings for each application, we obtained the overall most polluting platform due to data centers and, by averaging all the full system pollution rankings for each application, we obtained the overall most polluting platform due to the full system.

This provided the two final classifications: "Ranking 7. Average Pollution due to data centers (All Methodologies)" and "Ranking 8. Average Pollution due to full system (All Methodologies)"

### 4.7 Greenhouse gas equivalencies calculator from the EPA

The Greenhouse Gas Equivalencies [30] calculator allows to convert emissions or energy data to the equivalent amount of carbon dioxide ($CO_2$) emissions of well-known pollution sources. The calculator helps to translate abstract measurements into concrete terms everyone can understand, such as the annual emissions from cars, households, or power plants.

The Greenhouse Gas Equivalencies Calculator uses the AVoided Emissions and geneRation Tool (AVERT) [62] U.S. national weighted average $CO_2$ marginal emission rate to convert reductions of kilowatt-hours into avoided units of carbon dioxide emissions. The emission factor used is $7.09 \times 10^{-4}$ metric tons $CO_2$/kWh. In this paper the emissions data has been input in the calculator, instead of the energy data, so this metric is implicit in the provided equivalent emissions.

Concretely, the calculator has been used to obtain the equivalent miles driven by an average gasoline-powered passenger vehicle and the equivalent pounds of coal burned [31] for the most polluting platforms according to the two final rankings described in Section 4.6: "Ranking 7. Average Pollution due to data centers (All Methodologies)" and "Ranking 8. Average Pollution due to full system (All Methodologies)", but also for the overall least pollutant ones, so we can argue in the Discussion Section if even the most conservative numbers are still important in terms of damage to the environment.

## 5 RESULTS

The following sections present the rankings developed according to the literature and tools found. Then, we compare them to make conclusions about the most environmentally damaging platform. The parameters for each ranking can be found in the Supplemental Material of this paper; there is a table for each of them, and they are cited in the following sections, where the data is presented with charts that allow to better extract conclusions at a glance.

### 5.1 Investigation-based assessment

Table I (see Supplemental Material) has been populated with the average data obtained from the different sources indicated next to each item. This is the "Ranking 1. Pollution due to data centers".

According to this ranking, Netflix is the most energy demanding platform with 156.56 TWh a year. Because of the use of renewable energies, it is not the most polluting one. Instead, it is YouTube, followed by Spotify. Spotify's power consumption data has not been found from a verified source. However, in their Equity Impact Report, it is explained that the availability of renewable energy offered by their providers varies across regions, which suggests that not all their data centers use a high percentage of renewable energy.

Therefore, for this ranking:

- The most polluting platform is: YouTube, with 950.11 billion $gCO_2Eq$ yearly.
- The least polluting platform is: Netflix, with 6.3 billion $gCO_2Eq$ yearly.

Both of them account mainly for the energy consumed by their data centers and they apply renewable energy factors.

### 5.2 Smartphone Model Simulator

"Ranking 2. Pollution due to full system for phone users (online Calculator)" (see Table II in the Supplemental Material) has been created using the web simulator from [24], which uses a methodology [25], and the data found to populate Table I, considering only users accessing to the smartphone's application. In that degree:

- The most polluting platform is: TikTok, with 24,660 billion $gCO_2Eq$ yearly.
- The least polluting platform is: YouTube, with 5,780.16 billion $gCO_2Eq$ yearly.

### 5.3 Carbonalyser tests on smartphone

The results from these tests are available in the three first columns of Table III in the Supplemental Material, which was completed as in 5.2 to obtain the annual pollution, resulting in "Ranking 3. Pollution due to full system for phone users (Carbonalyser)".

In the same manner, contemplating only users accessing to the smartphone's application:

- The most polluting platform is: Facebook, with 85,424.09 billion $gCO_2Eq$ yearly.
- The least polluting platform is: Amazon, with 3,217.45 billion $gCO_2Eq$ yearly.

### 5.4 Carbonalyser tests on laptop

The results from these tests are available in the three first columns of Table IV in the Supplemental Material. As in 5.2 and 5.3, the annual emissions were obtained to create the "Ranking 4. Pollution due to full system for laptop users (Carbonalyser)".

Here, we consider users accessing from their laptop:

- The most polluting platform is: Zoom, with 1,719.90 billion $gCO_2Eq$ yearly.
- The least polluting platform is: Amazon, with 135.36 billion $gCO_2Eq$ yearly.

### 5.5 Carbon footprint using different carbon factors

Tables V and VI show the total emissions caused by smartphone and laptop users. Table V shows the annual emissions due to the full system and due only to data centers, for a carbon factor of 442 g/kWh. Equivalently, Table VI considers a carbon factor of 519 g/kWh. These originate "Ranking 5. Pollution due to full system for a carbon factor of 442 g/kWh (Formulae)", "Ranking 6. Pollution due to full system for a carbon factor of 519 g/kWh (Formulae)", "Ranking 7. Pollution due to data centers for a carbon factor of 442 g/kWh (Formulae)", and "Ranking 8. Pollution due to data centers for a carbon factor of 519 g/kWh (Formulae)".

The calculations are shown in detail in Tables IX to XII of Supplemental Material. Tables IX and X correspond to a carbon factor of 442 g/kWh, for smartphone users and laptop users, respectively. Similarly, Tables XI and XII, correspond to the calculations with the carbon factor of 519 g/kWh.

Therefore, for "Ranking 5. Pollution due to full system for a carbon factor of 442 g/kWh (Formulae)":

- The most polluting platform is: Netflix, with 411.31 billion $gCO_2Eq$ yearly.
- The least polluting platform is: Amazon, with 0.25 billion $gCO_2Eq$ yearly.

Proportionally, for "Ranking 6. Pollution due to full system for a carbon factor of 519 g/kWh (Formulae)":

- The most polluting platform is: Netflix, with 482.91 billion $gCO_2Eq$ yearly.
- The least polluting platform is: Amazon, with 0.288 billion $gCO_2Eq$ yearly.

Equivalently, for "Ranking 7. Pollution due to data centers for a carbon factor of 442 g/kWh (Formulae)":

- The most polluting platform is: Netflix, with 61.70 billion $gCO_2Eq$ yearly.
- The least polluting platform is: Amazon, with 0.04 billion $gCO_2Eq$ yearly.

Finally, for "Ranking 8. Pollution due to data centers for a carbon factor of 519 g/kWh (Formulae)":

- The most polluting platform is: Netflix, with 72.44 billion $gCO_2Eq$ yearly.
- The least polluting platform is: Amazon, with 0.04 billion $gCO_2Eq$ yearly.

### 5.6 Comparison between carbon footprint methodologies

Fig. 1, shows the results for each methodology in all the platforms, so we can visualize which are the most and the least polluting depending on the methodology.

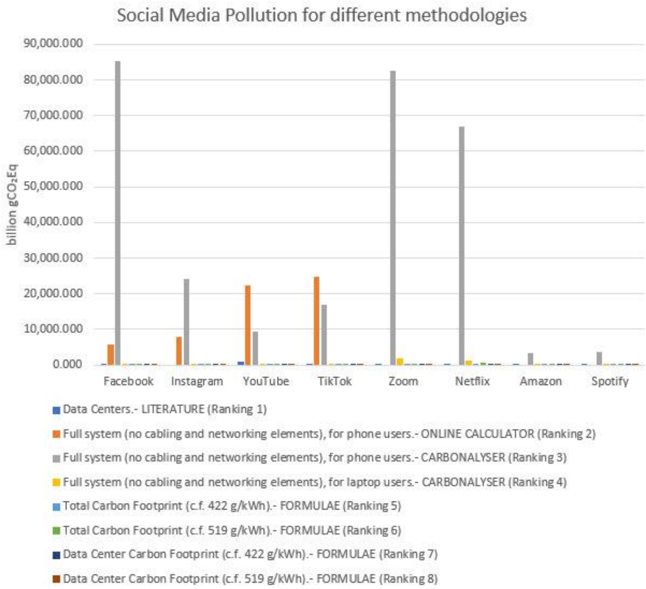

Fig. 1. Social Media Pollution for each platform, according to the different methodologies.

The differences and similarities found in these results will be commented in the Discussion Section. In order to be able to come out with an overall winner, we have considered all the methodologies and averaged the results obtained in the different rankings. This establishes the "Ranking 9. Average Pollution due to data centers (All Methodologies)", where:

- The most polluting platform is: YouTube, with 316.82 billion $gCO_2Eq$ yearly.
- The least polluting platform is: Instagram, with 4.11 billion $gCO_2Eq$ yearly.

And "Ranking 10. Average Pollution due to full system (All Methodologies)", that shows that:

- The most polluting platform is: Zoom, with 21,107.62 billion $gCO_2Eq$ yearly.
- The least polluting platform is: Amazon, with 838.36 billion $gCO_2Eq$ yearly.

The platforms' pollution proportions are shown in Figs. 2 and 3 and the calculations are detailed in Table VII of the Supplemental Material.

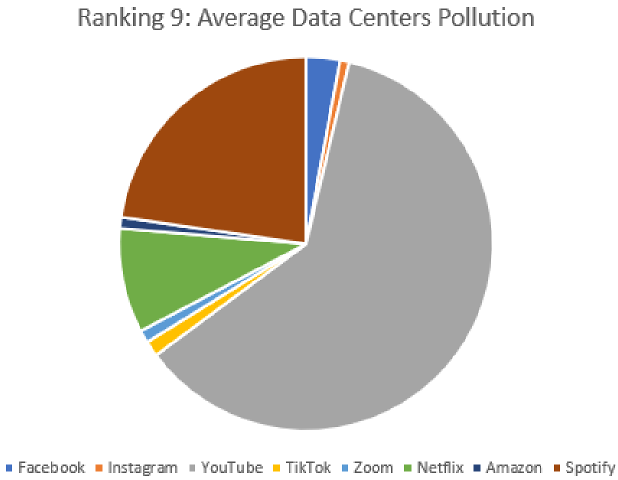

Fig. 2. Ranking 9: Overall (average) data centers pollution for each platform.

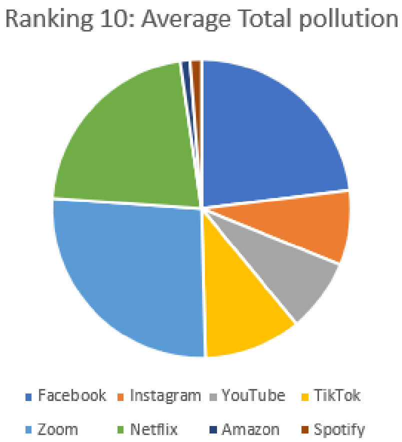

Fig. 3. Ranking 10: Overall (average) full system pollution for each platform.

### 5.7 Greenhouse gas equivalencies calculator from the EPA

Table VIII in the Supplemental Material presents the equivalent miles driven by a gasoline car and the equivalent pounds of coal burned needed to produce the GHG emissions for the overall most pollutant platform, according to Rankings 7 and 8, and for the least pollutant.

Being Zoom the overall most polluting platform produces the same $gCO_2Eq$ as 52.40 billion miles driven by gasoline cars or 23.35 billion pounds of coal burned. The overall greenest platform, Amazon, generates contamination equivalent to driving 2.08 billion miles or burning 927.60 million pounds of coal. In the Discussion Section, we will put these numbers into perspective to show the impact of our online behavior.

## 6 Discussion

In this section, the resulting rankings will be compared. From Fig. 1, we can observe a similar magnitude order in all rankings, except for Rankings 2 and 3 that will be analyzed later.

With the lack of accurate data about how the companies report their emissions, the difference in Rankings 1, 4, 7 and 8 can be explained by aspects such as the number of active users and the consumer devices considered.

Changing the emission factor can vary the results proportionally to that value, as shown in Rankings 5 and 6, as explained in Section 4.5, in order to obtain the contribution due to data centers, we only need to multiply the total system contribution by 0.15; i.e., it is a proportion of the full system's emissions.

The meaningful differences are found in Rankings 2 and 3. The methodology used for Ranking 2 is not fully available and the carbon factor is not published. In addition, there is no mention to the renewable energy factor, which could explain the dissonance in the results obtained. Still, it has been possible to verify some data. For instance, in [25], the authors present the exchanged data for each platform per minute, which is in the same order of magnitude as the one obtained during our tests with Carbonalyser. For example, for Instagram, we obtained 21.5 MB/minute, while they reported 32.46 MB/minute.

The methodology applied for Ranking 3 is based in the energy consumption of a model created in 2018 by empirically measuring the power consumption of a smartphone and a laptop. The data centers and network impact were also estimated in 2018. These two facts plus the absence of mentioning any renewable energy factor, could explain the differences in the results, making them outdated. In effect, Ranking 3 presents results too far from the rest of the rankings, especially for Facebook, Zoom and Netflix, companies that affirm using high percentages of renewable energies.

If we compare the daily user pollution for the platforms available in Rankings 2 and 3, it is clear that there are differences in the methodologies:

- Facebook: 100.12 and 26 $gCO_2Eq$; i.e., 3.9 times bigger in Ranking 3
- Instagram: 91.12 and 30 $gCO_2Eq$; i.e., 3 times bigger in Ranking 3
- YouTube: 28.76 and 18 $gCO_2Eq$; i.e., 1.6 times bigger in Ranking 3
- TikTok: 94.22 and 137 $gCO_2Eq$; i.e., 1.4 times smaller in Ranking 3

These proportions in the daily user pollution are causing the out-of-range results, as the rest of calculations performed to obtain the total pollution use the same data. Actually, the same ratios can be observed in Fig.3.

We could argue that Rankings 2 and especially, Ranking 3, are neither accurate nor even realistic. In any case, the fact is that published objective data are missing. Facing the difficulty of obtaining a valid ranking of the most polluting platforms and, given the uncertainty of the results, we can discuss the possibility of these numbers to be near the real pollution figures but also, we can take the smallest results from the rankings, so we make sure the conclusions are as prudent as possible.

Following this idea, to put into perspective, we created Table VIII explained in Section 5.7. As mentioned in Section 5.5, Zoom is the overall most polluting platform with 21,107.62 billion $gCO_2Eq$, which is equivalent to driving 52 billion miles.

According to [32], this number is close to the total miles driven by light vehicles in the UK per year, 54.40 billion miles. That pollution is also equivalent to burning 23.35 billion pounds of coal, which is slightly higher than the coal consumed in the UK, 19 billion pounds, according to [33].

Regarding the overall greenest platform, Amazon, with 838.36 billion $gCO_2Eq$, it is equivalent to driving 2.08 billion miles. This is more than the annual miles driven by buses and coaches in the UK, 1.8 billion miles. It is also equal to burning 928 million pounds of coal which is comparable to the annual electricity consumption of 1,226 houses [31].

Hence, even the least pollutant service translates in prohibitive contamination figures.

From this evaluation, we can also conclude that the pollution is not as highly dependent on the number of users, as it is in the amount of data exchanged, which is also proportional to the time spent on the social media application. Actually, in Figs. 1 and 2, we can see that Spotify and Amazon are some of the greenest platforms (even if Spotify's data centers are not the most energy efficient, as shown in Fig. 3), as the type of traffic (i.e., data and audio) is not the heaviest. The rest of the platforms deal with big amounts of traffic, especially due to the rise of online video.

## 7 Conclusions and Future Directions

This paper provides eight different rankings with the most polluting platforms in the world following eight methodologies. Overall, Zoom, Facebook and Netflix are the most polluting digital services in the world, according to this examination. But considering only the pollution due to the companies' data centers, YouTube is the winner. The diverse results obtained in the rankings are not only due to the differences in the methodologies applied to create them (some methodologies are not fully available or they are obsolete), but also because of the input parameters needed to compute the pollution; i.e., number of active users, consumer devices, etc., which are not objectively disclosed by companies.

The parameters (and estimations when objective data was not found) used in this paper to create the different rankings would not be needed if digital service providers would gather their service usage around the world and compute, for each country, the GHG emissions based on the electricity generation factors for each region. It is important to consider the complete system in the delivery of a digital service to avoid having inaccurate comparisons among platforms. This will probably require them to rely on third parties to provide these data. This is one of the reasons why some global regulations should be created so all the corporations involved in the digital communications collaborate transparently and include this information in their ESG reports.

An additional solution, from the engineering point of view, could be developing a new networking protocol, probably similar to current ones but including a small field to account for the energy spent in the different parts of the system where the information is transferred, by applying the correct emissions factors, according to the location. At present, our online behavior is quite tracked, especially for commercial purposes, so we could take advantage of this knowledge to help the planet and, as a consequence, our well-being. A solution of this kind could help to identify how to solve the energy issues in the different stages of the digital system and verify if the solutions we are adopting are really efficient. Other solutions to obtain the energy consumption of telecommunications by applying cutting-edge technologies, such as modelling the different components involved in the information journey using metaverse, should be carefully analyzed. Indeed, we should consider if the metaverse development and operation generate more pollution that what it is pretending to save. Actually, metaverse itself is energy hungry. The reasons are that some processes like the high-resolution streaming of 3D objects and the need for training AI models are computationally expensive. The network densification due to the high data rates and the low latency requirements are other reasons that suggest that, unless thoughtfully designed, the metaverse will contribute to the problem rather than solving it.

At present, the fastest solution seems to be the use of renewables. Most of the analyzed companies have recently achieved 100% renewable energy to feed their data centers. However, as seen in the Results Section, this does not mean zero emissions because green energy also produces GHG emissions, especially during the manufacturing and transportation processes. The disruption on the wildlife habitat and the significant quantities of water needed for some of them, are other reasons to avoid the massive generation of energy in the telecommunications industry.

An aspect that could really help is data on users' behavior which would be valuable to optimize the platforms design. This is especially important for video-streaming platforms. In fact, from the explanations in Section 2, we can infer that if every user would low the video resolution from HD to SD, more than 50 $kgCO_2Eq$ will be avoided. Nevertheless, it is well known that the premise of offering video services with lower default resolution is not fully adopted by the digital providers because downgrading the quality of service is counterproductive: it can damage reputation and make companies to lose customers. Other attempts such as charging companies and end users per internet consumption and penalizing high video resolution are measures that have been on the table [3] for long but not applied. This raises the opportunity to create new methods to reduce the amount of exchanged data.

The problem with the quantity of data is not only that it can be proportional to the GHG emissions: in fact, the exponential bandwidth growth may become unsustainable from the network's physical implementation point of view.

This research has induced to pay special attention to video streaming. Within the ICT sector, video traffic has been identified as the major driver of $CO_2$ emissions. It is estimated that 60 % of global data traffic can be attributed to video [3]. It accounts for 69% of all mobile data traffic and it is forecasted to increase 79 % in 2027 [12]. This is facilitated by the "all-you-can-eat" design of the digital platforms that, additionally, allows several users to watch different content at the same time per unique subscription. Other common behavior such as turning on video while doing other activities, leads to the traffic increase. For instance, free video platforms like YouTube, create an unnecessary digital waste, as users tend to play videos to only listen to music [8]. The pandemic also accelerated the uptake of video services, especially streaming and video calling. Innovative advances can lead to the solution to the contamination problem by bringing out more efficient ways of creating, storing, and transmitting-receiving the information without losing the quality of service. We can conclude by stating that the real source of the pollution caused by social media is the amount of data traffic exchanged, especially video. It does not only require huge data centers to be stored, but these servers, and even consumer devices have to process every time bigger volumes of data, and this is computationally expensive, not to mention the economic cost of the energy (renewable or not). Solutions such as lighter, more energy efficient video compression algorithms and video protocols such as [34] - [37], seem to be one of the most sustainable options.

## ACKNOWLEDGMENT

The author wishes to thank European University of Madrid and Banco Santander Universidades. This work was supported in part by a grant from the Singular Alumni Award.

## REFERENCES

[1] J. Johnson, "Global Digital Population 2021," Statista, Apr. 26, 2022. https://www.statista.com/statistics/617136/digital-population-worldwide/ (accessed Jun. 21, 2022).

[2] R. Obringer, B. Rachunok, D. Maia-Silva, M. Arbabzadeh, R. Nateghi, and K. Madani, "The overlooked environmental footprint of increasing Internet use," Resources, Conservation and Recycling, vol. 167, p. 105389, Apr. 2021, doi: 10.1016/j.resconrec.2020.105389.

[3] K. Grobe and S. Jansen, "Limits to exponential Internet Growth," Electronics Goes Green 2020+, Sep. 2020, [Online]. Available: https://online.electronicsgoesgreen.org/wp-content/uploads/2020/10/Proceedings_EGG2020_v2.pdf

[4] A. Batmunkh, "Carbon Footprint of The Most Popular Social Media Platforms," Sustainability, vol. 14, no. 4, p. 2195, Feb. 2022, doi: 10.3390/su14042195.

[5] P. Suski, J. Pohl, and V. Frick, "All you can stream," Proceedings of the 7th International Conference on ICT for Sustainability, Jun. 2020, doi: 10.1145/3401335.3401709.

[6] G. Kamiya, "Factcheck: What is the carbon footprint of streaming video on Netflix?," Carbon Brief, Feb. 25, 2020. https://www.carbonbrief.org/factcheck-what-is-the-carbon-footprint-of-streaming-video-on-netflix/ (accessed Apr. 23, 2022).

[7] R. Brandl, "The worst websites for CO2 emissions," Tooltester, May 11,

2021. https://www.tooltester.com/en/blog/website-carbon-emissions/#The_sites_that_produce_the_most_carbon_annually (accessed Apr. 23, 2022).

[8] C. Preist, D. Schien, and P. Shabajee, "Evaluating Sustainable Interaction Design of Digital Services: The Case of YouTube," Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems - CHI '19, p. 397, 2019, doi: 10.1145/3290605.3300627.

[9] "The Global Internet Phenomena Report. Growing app complexity: Pavnig the way for digital lifestyles and immersive experiences," SANVIDE, Jan. 2022. [Online]. Available: https://www.sandvine.com/hubfs/Sandvine_Redesign_2019/Downloads/2022/Phenomena%20Reports/GIPR%202022/Sandvine%20GIPR%20January%202022.pdf

[10] E. Björnson and E. G. Larsson, "How Energy-Efficient Can a Wireless Communication System Become?," 2018 52nd Asilomar Conference on Signals, Systems, and Computers, 2018, pp. 1252-1256, doi: 10.1109/ACSSC.2018.8645227.

[11] "Broadband Portal - OECD," www.oecd.org. https://www.oecd.org/sti/broadband/broadband-statistics/

[12] "Mobile data traffic forecast – Mobility Report," www.ericsson.com. https://www.ericsson.com/en/reports-and-papers/mobility-report/dataforecasts/mobile-traffic-forecast (accessed Jun. 12, 2022).

[13] Google, "Efficiency – Data Centers – Google," Google Data Centers, 2013. https://www.google.com/about/datacenters/efficiency/

[14] NETFLIX, "Environmental Social Governance Report 2021 Sustainability Accounting Standards Board (SASB) Report," 2021. [Online]. Available: https://assets.ctfassets.net/4cd45et68cgf/7B2bKCqkXDfHLadrjrNWD8/e44583e5b288bdf61e8bf3d7f8562884/2021_US_EN_Netflix_EnvironmentalSocialGovernanceReport-2021_Final.pdf

[15] Zoom, "May 2022 | 1 Zoom ESG Report FY22 Environmental Social Governance Report," 2022. [Online]. Available: https://investors.zoom.us/static-files/0ddac6eb-3901-4f86-95c2-898bee9c8b95

[16] Spotify, "Equity and Impact Report 2021," 2021. [Online]. Available: https://www.lifeatspotify.com/reports/Spotify-Equity-Impact-Report-2021.pdf

[17] Facebook, "Sustainability Report 2020," 2020. [Online]. Available: https://sustainability.fb.com/wp-content/uploads/2021/06/2020_FB_Sustainability-Report-3.pdf

[18] Google, "Environmental Report," 2021. [Online]. Available: https://www.gstatic.com/gumdrop/sustainability/google-2021-environmental-report.pdf

[19] Amazon, "Amazon Sustainability 2020 Report," Aboutamazon.com, Jun. 2021. https://sustainability.aboutamazon.com/pdfBuilderDownload?name=amazon-sustainability-2020-report

[20] A. S. G. Andrae, "New Perspectives on Internet Electricity Use in 2030," PISRT, 30-Jun-2020. [Online]. Available: https://pisrt.org/psr-press/journals/easl-vol-3-issue-2-2020/new-perspectives-on-internet-electricity-use-in-2030/. (Accessed: Dec. 04, 2022).

[21] U.S. Environmental Protection Agency, "Avoided Emissions and Generation Tool AVERT," EPA. [Online]. Available: https://www.epa.gov/avert/download-avert. (Accessed: Dec. 04, 2022).

[22] K. Bose, "YouTube alleged to be world's 'highest emitting website,'" Energy Live News, Jun. 11, 2021. https://www.energylivenews.com/2021/06/11/youtube-alleged-to-be-worlds-highest-emitting-website/ (accessed May 07, 2022).

[23] World Resources Institute, "GHG Protocol Scope 2 Guidance executive Summary 2 Scope 2 Guidance," 2015. [Online]. Available: https://ghgprotocol.org/sites/default/files/Scope2_ExecSum_Final.pdf

[24] The Burrow, "Social Carbon Footprint Calculator | Compare the Market," www.comparethemarket.com.au. https://www.comparethemarket.com.au/energy/features/social-carbon-footprint-calculator/ (accessed May 26, 2022).

[25] K. DERUDDER, "What is the environmental footprint for social media applications? 2021 Edition," Greenspector, Oct. 26, 2021. https://greenspector.com/en/social-media-2021/#methodologie (accessed Apr. 16, 2022).

[26] O. PHILIPPOT, "How does Greenspector assess the environmental footprint of digital service use?," Greenspector, Oct. 13, 2021. https://greenspector.com/en/environmental-footprint-methodology/ (accessed Jun. 10, 2022).

[27] I. Tiseo, "France power sector carbon intensity outlook 2050," Statista, Oct. 19, 2021. https://www.statista.com/statistics/1190067/carbon-intensity-outlook-of-france/ (accessed Nov. 29, 2022).

[28] "'Carbonalyser': the browser extension which reveals the climate impact of internet navigation," The Shift Project. https://theshiftproject.org/en/carbonalyser-browser-extension/ (accessed Jun. 02, 2022).

[29] Mightybyres and WHOLEGRAIN digital, "Calculating Digital Emissions," Sustainable Web Design, 2021. https://sustainablewebdesign.org/calculating-digital-emissions/ (accessed Jun. 10, 2022).

[30] O. US EPA, "Greenhouse Gas Equivalencies Calculator," www.epa.gov, Aug. 28, 2015. https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator#results (accessed Jun. 09, 2022).

[31] US EPA, "Greenhouse Gases Equivalencies Calculator - Calculations and References | US EPA," US EPA, Dec. 20, 2018. https://www.epa.gov/energy/greenhouse-gases-equivalencies-calculator-calculations-and-references (accessed Dec. 02, 2022).

[32] D. of T. UK, "Road traffic statistics - Summary statistics," Dft.gov.uk. https://roadtraffic.dft.gov.uk/summary (accessed Dec. 07, 2022).

[33] M. Garside, "Coal consumption 2019," Statista, Aug. 05, 2022. https://www.statista.com/statistics/223493/uk-coal-consumption/ (accessed Dec. 07, 2022).

[34] B. Oguzhan Turkkan, T. Dai, A. Raman, T. Kosar, Changyou Chen, M. Fatih Bulut, J. Zola, and D. Sow. " GreenABR: energy-aware adaptive bitrate streaming with deep reinforcement learning". Proceedings of the 13th ACM Multimedia Systems Conference (MMSys '22).

[35] C.Yue, S. Sen, B. Wang, Y. Qin, and F. Qian. "Energy considerations for ABR video streaming to smartphones: measurements, models and insights. Proceedings of the 11th ACM Multimedia Systems Conference (MMSys '20)

[36] X. Chen, T. Tan, G. Cao and T. F. L. Porta, "Context-Aware and Energy-Aware Video Streaming on Smartphones," IEEE Transactions on Mobile Computing, vol. 21, no. 3, pp. 862-877, 1 March 2022

[37] S. K. Vittapu and S. K. Chatterjee, "Complexity reduction for HEVC encoder using one-dimensional filtering based constrained one-bit transform," Microsystem Technologies, vol. 27, no. 5, pp. 1901–1912, Sep. 2020, doi: 10.1007/s00542-020-05035-w.

[38] M. Iqbal, "Spotify Usage and Revenue Statistics (2022)," Business of Apps, May 04, 2022. https://www.businessofapps.com/data/spotify-statistics/ (accessed May 07, 2022).

[39] M. Woodward, "TikTok User Statistics: Everything You Need To Know About TikTok Users," www.matthewwoodward.co.uk, Dec. 27, 2021. https://www.matthewwoodward.co.uk/work/tiktok-user-statistics (accessed May 07, 2022).

[40] S. Dixon, "Global Social Media Ranking 2021," Statista, Mar. 08, 2022. https://www.statista.com/statistics/272014/global-social-networks-ranked-by-number-of-users/ (accessed Apr. 16, 2022).

[41] "Average Time Spent Daily on Social Media (Latest 2022 Data)," BroadbandSearch.net, 2022. http://www.broadbandsearch.net/blog/average-daily-time-on-social-media (accessed Apr. 17, 2022).

[42] C. Smith, "26 Amazing Skype Statistics and Facts," DMR, Feb. 27, 2022. https://www.expandedramblings.com/index.php/skype-statistics (accessed Jun. 14, 2022).

[43] B. Dean, "Zoom User Stats: How Many People Use Zoom in 2022?," Backlinko, Jan. 06, 2022. https://www.backlinko.com/zoom-users#zoom-anual-meeting-minutes (accessed May 14, 2022).

[44] M. Iqbal, "Zoom Revenue and Usage Statistics (2020)," Business of Apps, May 04, 2022. https://www.businessofapps.com/data/zoom-statistics/ (accessed May 15, 2022).

[45] R. Brandl, "The Video Call Platforms that Dominate the World," EmailToolTester.com, Mar. 22, 2021. https://www.emailtooltester.com/en/blog/video-conferencing-market-share/ (accessed May 08, 2022).

[46] G. Kamiya, "The carbon footprint of streaming video: fact-checking the headlines – Analysis," IEA, Dec. 11, 2020. https://www.iea.org/commentaries/the-carbon-footprint-of-streaming-video-fact-checking-the-headlines (accessed Apr. 10, 2002).

[47] D. Coppola, "Web visitor traffic to Amazon.com 2019 | Statista," Statista, 2022. https://www.statista.com/statistics/623566/web-visits-to-amazoncom/ (accessed May 28, 2022).

[48] Similarweb, "amazon.com Análisis de tráfico y cuota de mercado," Similarweb, May 2022. https://www.similarweb.com/es/website/amazon.com/#overview (accessed May 15, 2022).

[49] J. Clement, "Top retail websites by global traffic 2020," Statista, Oct. 19, 2021. https://www.statista.com/statistics/274708/online-retail-and-auction-ranked-by-worldwide-audiences/ (accessed Apr. 16, 2022).

[50] S. Dredge, "How many users do Spotify, Apple Music and streaming services have?," musically, Feb. 03, 2022. https://musically.com/2022/02/03/spotify-apple-how-many-users-big-music-streaming-services/

[51] E. Jhonsa, "How Much Could Google's YouTube Be Worth? Try More Than $100 Billion," Stock Market - Business News, Market Data, Stock Analysis - TheStreet, May 12, 2018. https://www.thestreet.com/investing/youtube-might-be-worth-over-100-billion-14586599 (accessed May 28AD).

[52] GREENSPECTOR and Atos, "Consumption of TOP 30 most popular mobile applications," Jan. 2020. Accessed: May 12, 2022. [Online]. Available: https://greenspector.com/wp-content/uploads/2020/01/Atos-GREENSPECTOR-TOP30-benchmark-english.pdf

[53] K. DERUDDER, "Which video conferencing mobile application to reduce your impact? 2021 Edition," Greenspector, Apr. 05, 2021. https://greenspector.com/en/which-video-conferencing-mobile-application-to-reduce-your-impact-2021/ (accessed Apr. 30, 2022).

[54] S. Cook, "60+ Netflix Statistics, Facts and Figures (2019 Version) | Comparitech," Comparitech.com, Apr. 13, 2022. https://www.comparitech.com/blog/vpn-privacy/netflix-statistics-facts-figures/ (accessed May 21, 2022).

[55] C. Tam, "How Social Media Habits are Contributing to Internet Pollution," Earth.org - Past | Present | Future, Sep. 27, 2021. https://earth.org/how-social-media-habits-are-contributing-to-internet-pollution/ (accessed Apr. 24, 2022).

[56] P. Bentley, "What's the carbon footprint of a 4K Netflix binge?," BBC Science Focus Magazine, Jan. 14, 2022. https://www.sciencefocus.com/future-technology/carbon-footprint-netflix-binge/ (accessed May 07, 2022).

[57] J. García, "Sitios web que más contribuyen a la contaminación de internet," Tooltester, Jul. 09, 2021. https://tooltester.com/es/blog/contaminacion-de-internet (accessed Apr. 16, 2022).

[58] A. Huerga, "Cuál es la huella de carbono de nuestra actividad digital," ZeroEmissionsObjective, Jul. 14, 2021. https://plataformazeo.com/es/cual-es-la-huella-de-carbono-de-nuestra-actividad-digital/ (accessed Apr. 16, 2022).

[59] A. Kingsley-Hughes, "How much CO2 are your Zoom meetings generating?," ZDNet, Apr. 23, 2021. https://www.zdnet.com/article/how-much-co2-are-your-zoom-meetings-generating/ (accessed May 2022).

[60] "Climate Action | Life at Spotify," lifeatspotify.com. https://lifeatspotify.com/diversity-equity-impact/climate-action (accessed Jun. 02, 2022).


**Natalia Molinero Mingorance** (Member, IEEE) received the BEng degree in telecommunications engineering from the Europea University of Madrid, Madrid, Spain, in 2013 and the MSc degree in Wireless Communications Systems from the University of Sheffield, Sheffield, U.K. From 2013 to 2017 worked as a Research Associate in the Communications group of the Electrical and Electronic Engineering department of the University of Sheffield. Since 2017, she worked on Netmetrix Solutions, a telecommunications company in Madrid, Spain. In April 2022, she was awarded with the Alumni Singular first prize for her project proposal "New Methods for Energy Efficiency Optimization: Information, generation, storage, transmission and reception" which she is currently developing. Her research interests include energy efficiency in multimedia codifications and in power allocation for wireless signals. She is member of the IEEE, the IEEE Computer Society, the IEEE Communications Society, the IEEE Information Theory Society, the IEEE Signal Processing Society, the IEEE Computer Society Special Technical Community on Sustainable Computing, and the IEEE Entrepreneurship Exchange Community.