From One Edge to the Other: Exploring Gaming's Rising Presence on the Network

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ABSTRACT

Audio and video streaming and on-demand services have dramatically changed how, and how much, media is consumed. Streaming generally allows a much larger selection of content, and arguably greater convenience. Gaming is the latest medium to place delivery of content into the cloud, via services such as Google Stadia and NVIDIA GeForce NOW. Just as with video streaming, this new ease comes with a hidden cost from the infrastructure used to deliver it, including the hardware cost, engineering cost and the energy to power the data centres and communications networks. Although gaming is currently only 7% of global network demand, with more than 95% of that being made up of downloading content, the possibility of streamed games could rapidly change this network footprint. In turn, this affects the yearly growth of energy impact from IT services. We explore possible futures where growth of these services continues, and we illustrate the implications a decade from now with three possible future scenarios for shifts of gaming practices. Our analyses show that game streaming will cause significant increases in the energy and carbon footprint of games.

CCS CONCEPTS

• Networks → Network measurement; **• Social and professional topics → Sustainability**.

KEYWORDS

gaming, streaming, networking, energy demand

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1 INTRODUCTION

Computer gaming has grown from a $1 billion business based on arcades (1971), into a $152.1 billion dollar global industry[32]. Games have changed from simple 8-bit classics into fully-fledged immersive 3D worlds. Large, bespoke arcade machines slowly gave way to gaming on home PCs, consoles, and dedicated handheld devices. With smartphones and tablets, the barrier to entry for gaming has been reduced further, and games have become very common ways to pass the time in and outside the home.

Gaming has also become a competitive multiplayer experience and with the maturity and expansion of networks, it is no longer a matter of who is the best in a local area, but who is the best in the world. This means game developers are taking advantage of the growth of the Internet and allowing connections to central server locations. Developers can take games global by buying space in a data centre such as those offered by i3D[1]. The packets of game data which is used during actual gameplay can be categorised as being high frequency but small in size for the client[23, 43], since packets are sent often and latency is important, but game information can be passed to other clients with small packet sizes. Game servers can contain significant bandwidth usage due to the multiple connections and concurrent data streams—each being around the sum of the client packet usage multiplied by the number of clients.

As gaming continues to develop quickly, it is important to consider its associated energy demand and carbon emissions, to recognise how the ecological footprint could change. We propose a method for characterising the demands of streaming and downloading, strictly with the view of the network as a consideration. We then view how the network impact of games might change given the recent release and promotion of game streaming platforms that allow a new presentation

[1]https://www.i3d.net/game-hosting/

of Gaming as a Service, challenging the view of the network as a limitless and inconsequential resource. Finally, we look ahead to 2030 and widen the scope to include device manufacturing, to consider what gaming's impacts could be under three different future scenarios.

2 BACKGROUND

Given that game streaming technology has only had recent uptake via the general release of Stadia and GeForce NOW, and the upcoming Xbox cloud platform, literature is scarce concerning game streaming. However, we can draw insight from current understanding of game traffic, gaming trends and video streaming services.

This paper is focused on the possible growth of gaming's impact on the network—in our scenarios demand may remain static but shift to alternative services such as Stadia. Other studies have been undertaken which reflect factors such as latency [42] and whether all games are viable, from an experience point of view, on cloud [24]. Our focus is instead on the data traffic demands generated by streaming games, compared to traffic which is generated by download and updating games, as well as playing multiplayer online games.

There is already evidence that there is market for users to have multiple streaming services and that it only takes a small amount of people to move from SD to 4K to create huge traffic increases [7]. Our view is that this same phenomena may be seen in game streaming, raising gaming's relatively limited traffic (perhaps 9% of Internet traffic volume) to the possibility of streaming 4K while playing (already on offer by Stadia). Existing video streaming services already account for the majority of Internet traffic because of their high bitrates [39], and the amount of time people spend streaming. These services are increasingly an integral part of everyday life and streamed content is becoming a central part of adults' viewing in the UK [36, 48].

An already reviewed cloud gaming solution has shown that it can reduce energy usage compared to conventional equipment [4], and the use of ICT has been identified as having the potential to reduce carbon emissions by 15% through changing services [27]. But, how we design and steer services to make them sustainable has to be considered when creating new ones [26] (such as game streaming) as well as how we engage with users to raise awareness and encourage sustainable practices, such as by providing more information and being transparent about the impacts of services on offer.

To play Stadia at 4K, it is recommended by Google that there be a download speed of 35 Mbit/s [44]; however in the UK only 54% of people have the claimed "superfast broadband" level of 30 Mbit/s. Fixed broadband speeds are doubling globally and mobile speeds are tripling [6], which might allow more demanding services like 4K game streaming to become more viable for more people. Currently mobile is the most likely device for a user to play on [31], but gaming in general uses less than 0.21% of data outside of downloads [8]. However, the data from video streaming services containing gaming content, such as YouTube and Twitch, is a significant part of traffic that is not separated to be classed as gaming.

In 2020 it is projected that the energy demand for digital things will be around 10% of total energy demand, with that doubling to about 20% in 2030 [1]. Modellers already assume that there will be continued growth of video services. The additional traffic that could be generated from games being played via video streaming could increase energy demand at both the network and the data centre level, thus increasing the energy costs of IT beyond the projected levels. It is therefore important that growth of these services is managed carefully, rather than be allowed to grow "organically", driven by technical innovation and the market. Newzoo identifies the so-called "cloud gamer" as a new, growing category of players that want to enjoy high-quality games without spending on hardware [32].

3 GAMING'S RISING PRESENCE ON THE NETWORK

When exploring 'gaming' on the network, we endeavour to look at all impacts on traffic that can come from a game. This includes installation, online features which directly relate to game data, and game updates. We do however ignore parts associated with gaming but caused by other factors. Other work for example suggested advertisements associated with free mobile games account for an average of 65% of the total traffic for a given game [22].

Consoles historically did not support or require network connectivity, but since the seventh generation of consoles (which include the Xbox 360, PlayStation 3 and Wii) there have been games that provide additional downloadable content or periodic patches (which can include bug fixes, new features and new content). PC gaming has had access to online features and network play for decades, but similar to consoles, they did not typically require frequent updates or provide downloadable content until more recently (the past two decades). As online game stores for digital distribution have become more popular, the impact on the network to play a game even once has increased. 'Day one patches' [28] which bring content and fixes via an initial download (even on the same day as the game's physical release) are also increasingly popular. Often, access to online features are restricted until a game is patched to the current version. These patches allow developers extra time to improve games past the point of submission for certification and manufacture of physical media (optical disc or cartridge) [50]. Patches, particularly Day One patches, can often be large, as an example, the first patch for Fallout 76 was 44 GiB on console[49]; this is a significant portion of the total installed game size of 74 GiB. Game patches which change the game for balance purposes or to add new features to constantly growing games are also a common and possible way of delivering content now [10]. The benefit of new streaming platforms to consumers in this regard is that they do not need to wait for a long download to play their games, as game updates are applied at the data centre. Since updates often restrict access to online features before this is completed, which leads to high volumes of users updating at the same time. This was seen with the recent *Modern Warfare* update [47], where a 87.5 GiB download was required to continue playing online. On top of all this, consoles themselves now include firmware updates to the console's operating system, built-in features and apps, further adding to network consumption.

We captured the network packets being sent and received via our router in order to measure the usage of each device we monitored. For individual games, we investigated further the ports that they used in order to get a more accurate view of the traffic. The mobile device used (individual mobile apps, Stadia measurement and GeForce NOW measurement) was a Samsung Galaxy S8 device running Android 10.

Mobile

Mobile devices are the most commonly used devices for playing video games [30]. However, mobile games need to be carefully designed for the amount of network usage, as well as the initial download size of the app, due to the fact that many mobile data plans are limited. As well as this, mobile games offer a different gaming experience to consoles and PC, given the smaller screen size and hardware constraints of the devices. Mobile gaming is hugely responsible for the further uptake of gaming, yet mobile data traffic has at least 2.5 times the energy footprint of WiFi over traditional broadband [41]. Therefore, adding more applications for video streaming (such as gaming) run over mobile data, which only adds to the problem.

Initial mobile measurement was done with two regular mobile games. The first one is *Old School RuneScape* (OSRS), a game which is online-only and constantly sends packets to reflect what the user is doing. This is to ensure the rest of the players have the correct view of the virtual world, but also so that each player's experience points can be stored on the central server. The second game we measured is *Football Manager 2020 Mobile* (FM20), which has some online features but is not designed as an online-only experience. Both of these titles are examples of typical mobile games, with each having over 100,000 downloads on the Google Play store.

We measured ten minutes of gameplay from *OSRS* on a mobile device. During the measurement period, a player was engaged in gameplay typical of OSRS, which is combat-driven. The resulting data was a mere 662 kilobits (80 KiB), an average of only 17 bytes per second. However, the initial download of the game to the Android device was 772 megabits (92 MiB). On the other hand, FM20 was a higher initial download of 9200 megabits (1.07 GiB). When we tested the measurements through ten minutes of playing the game, there was no observed data transfer from the mobile device; this reflects the fact that it is not multiplayer. In the same vein, we present two of the other most popular mobile games in the table below; *Clash of Clans* (CoC) and *PlayerUnknown's Battlegrounds* (PUBG). PUBG is a popular app store game and makes up 0.65% of all mobile traffic, which is unusual for a mobile game [8], as shown by the difference in data it produces per second in an online match compared to the others. PUBG and OSRS are worth comparing, as both are online-only games but show vastly different data usages.

Table 1: Data usage for ten minutes of mobile gameplay

	Avg kbit/s	Total Data (MiB)	Game Size (MiB)
OSRS	0.274	0.078	91.5
FM20	0	0	1192
CoC	0.920	0.065	1201.6
PUBG	17.144	1.226	2031.3

4 GAME STREAMING PLATFORMS

Despite their streaming bandwidth requirements, one potential savings of the two game streaming platforms we explore is that they do not require game downloads or patches. This is a point for consideration given that some of the largest complaints come from download lengths of modern games, with 85% of people who play games finding download lengths frustrating [30], but also that the largest impact on the network from games currently is from downloading from stores. PlayStation and Xbox online stores, for example, make up 5.2% of North and South America's download traffic [39]. According to research done by Limelight, 44% of people who game are already interested in 'console-less' gaming, like that offered by game streaming services [31].

Given the minimum requirements (for lowest fidelity) set out by Google and NVIDIA of 10 Mbps and 15 Mbps to run at the lowest quality [34, 44] and the average speeds of 4G connections (20 Mbit/s) in the UK [37], we can expect a great majority of users would not be able to use the streaming services whilst away from a fibre or broadband connection. However, the new 5G installations in the UK and elsewhere are promised to provide much higher average speeds, and there could be further uptake of game streaming services.

Stadia

Stadia offers a 'play anywhere' experience, where users can play the latest and highest quality games with a lightweight client. This is done by streaming the game from a Google point of presence, to allow as low latency streaming as possible—a requirement for high fidelity activities such as gaming. Google's use of the network edge to deliver the gaming content, can reduce the energy footprint of the service and possibly reduce the load of the core network and balance the energy footprint across more locations [40]. Stadia can be played on Chromecast connected to a TV, in the Chrome browser, or using the Stadia app on mobile platforms.

When measuring Stadia, we played 10 minutes of *Metro Exodus* (see Table 2), which when played on console or PC has no impact on the network, due to it being a single-player game. Stadia allows the user to choose the resolution (720p, 1080p or 4K). Before applying the chosen setting, though it will check whether the client is connected to a display that supports the resolution selected; and check if the Internet connection is sufficient enough to support the resolution. Otherwise, Stadia reduces the resolution of the stream. We played this via Ethernet, except for mobile.

Table 2: Data Usage for Metro Exodus on Stadia

	Total (Megabits)	Avg speed (Mbps)
720p	754	10.06
1080p	2043	27.24
4K	3108	41.45
Mobile (720p)	780	10.4

NVIDIA GeForce NOW

To test GeForce NOW, we used the downloadable app on a Windows PC connected via Ethernet. The resolution was set to 1920 x 1080 and the frame rate at 60 FPS. On mobile, we used the comparable 1080p 60 FPS setting, but used a WiFi connection to the router. We observe that GeForce NOW does not use the same amount of data if the frame of the gameplay is not changing. The measurements below were taken from a single match of the "wingman" variant of *Counter Strike: Global Offensive*. The game connects to a single server rather than receiving multiple connections. When playing the game the player relies on low latency gameplay with frequent server updates to tell the client about other player positions. The two games played lasted twelve minutes on PC, and ten minutes on GeForce NOW.

Average Mobile Usage

Using this data and the average time usage of mobile games of 114 seconds [3], we can determine the data usage for a typical mobile game session. Table 4 compares two mobile games to the two streaming services. The average time for all platforms is one hour and 14 minutes [29], the length of which makes data usage more significant per session.

Table 3: Data captures from Counter Strike: Global Offensive

	Total (Megabits)	Avg speed (Mbps)
Gaming PC	652	0.9
GeForce NOW	1356.6	11.9
Mobile GeForce	752.5	6.6

Table 4: Data Usage for a two-minute session on a mobile device

	Total (Megabits)	Avg speed (Mbps)
OSRS	0.114	0.0001
FM20	0	0
Google Stadia	148.1	10.4
GeForce NOW	94	6.6

5 SHOULD I STREAM OR DOWNLOAD?

We need to consider the perception of the Internet as a limitless resource. Home broadband plans in the UK are now sold as 'unlimited' although download and upload speeds differ significantly. In reality, broadband providers are working with scarce resources allocated for network services [25]. Full consideration for the impact on the environment can therefore be lost due to the perception that data volume is limitless. This means consumers may pay a competitive price for their broadband, but the energy and environmental cost of using data-intensive services such as Netflix, Stadia or Steam is not accounted for in this price.

To help raise user awareness, one approach might be to use the data traffic generated as a proxy for external energy impact. Consider that streaming games via a cloud service is marginally cheaper: the in-home power consumption of a Google Chromecast is 5 W, compared to 112 W for an Xbox One [9]. Other costs remain the same, with displays being used for both devices and the cost of games being similar on the platforms. A purely rational, economic actor might therefore choose to use the Chromecast, relying on a flat tariff resource seen as limitless (home broadband data) versus one that has a cost per unit of usage (energy).

Determining the best way to play with minimal impact is difficult. We took our example game of *Metro Exodus* which can be downloaded on Steam, or streamed on Stadia. According to crowd-sourced data from over 300 players [18], the game takes an average of 14 hours and 11 minutes to complete. Given the download size of 72 GiB on Steam, this means an average of 5 GiB per hour if the user plays just one full play through (and no new patches are downloaded). This is far less than playing the game on Stadia at 4K, which according to our previous measurements would use around 18.65 GiB per hour for a total of 264 GiB. Playing in 720p results in approximately 64 GiB, slightly less than the actual download size of the game. This could indicate that if a player were to complete the game fully and in 4K, it would be more sustainable from a network perspective to download the game. However, if the player was expecting to play fewer hours or wanted to try the game, streaming might be a better option.

An environmentally-conscious user wanting to be more sustainable in their game playing could use a graph similar to figure 1 to help make their decision. (But note that a downloaded game played on a high-power device such as a desktop gaming PC can cancel some of the gains of avoiding streaming, as discussed below.) A combination of these approaches could also be taken, where a game is downloaded once a user expects to continue playing beyond a certain number of hours. This approach is less relevant for other streamed content such as video, where the size of the data stream is similar to the video download size.

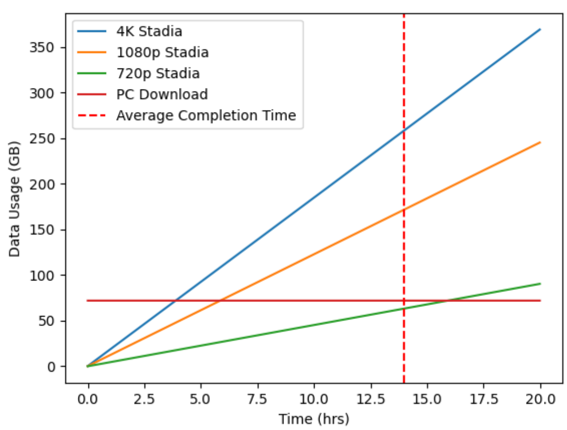

Figure 1: How game play time affects data volume for *Metro Exodus* on Stadia.

6 GAME STREAMING INTO THE FUTURE

Based on data from Ofcom [35], we create a model that tries to determine the UK network usage attributed to gaming (outside of gaming-related downloads). We do this by taking the UK population figures and the projected figures from ONS [12] to determine an estimate for the number of people age 16+ in the UK. This figure is normally around 81% of the total UK population [13]. Ofcom data from 2018 showed around 38% of adults fell into the 'any gaming on any device' category [38]. This assessment included the devices this group used for gaming, but did not specify how much time was used on these devices. To account for this, we take the average time spent gaming per week in the UK in 2018 (7.15 hours) [29] and divide this by the time per person based on the presence of the device being used by each person, rather than an expectation of the actual time. Of the 1476 adults in the weighted sample [29], 559 of them undertook at least one kind of gaming, with these adults also specifying which devices they used: 1015 different devices are declared.

In Figure 2, the presence of these devices is shown, followed by the percentage of data these devices used based on our findings. We assume mobile and tablet devices to produce similar levels of network traffic, given the shared app marketplaces. We also assume the same relationship for desktop and console devices. The following three bars of the chart show different percentages (5%, 15% and 30%) of uptake for cloud gaming, where mobile, console, desktop and tablet users move to cloud and increase the presence of these supporting devices. The low figure of 720p (or mobile Stadia) is used (10Mbps). As the figure demonstrates, it only takes a relatively small uptake for cloud gaming traffic to dominate the overall traffic profile. As mentioned previously, this does not account for gaming-related downloads on the network.

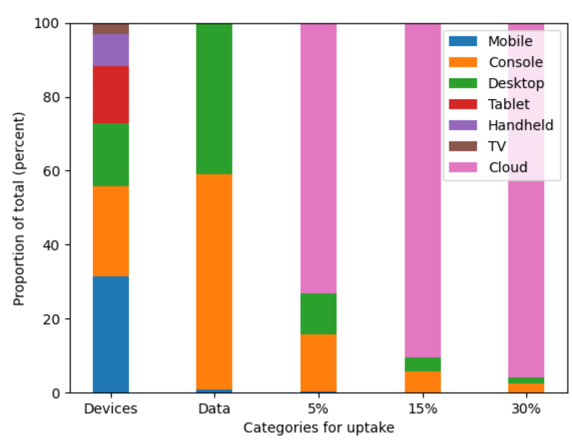

Figure 2: Device presence and data usage in a theoretical uptake

Our model uses these population figures, the average weekly time spent, the assumed hourly presence [29] and our own measurement data shown in this paper, to produce an estimate for the weekly amount of gaming traffic in the UK. The conservative estimate of 1% of gamers moving to streamed services per year is used to demonstrate how data usage might be developing currently.

Table 5: Weekly data usage for gaming in the UK population (PB) using 1080p resolution

	2018 (0%)	2020 (2%)	2030 (12%)
Mobile	0.2	0.3	0.5
Desktop	12.6	13.9	23.4
Cloud	0	50.5	574.6
Others	9.5	10.5	16.9
Total	22.3	75.2	615.3

As shown in Table 5, even a relatively small group (12% of current mobile, desktop, console and tablet users) transitioning to cloud platforms has the potential to create over 615 petabytes of data (compared to perhaps 22 PB in 2018). This level of service growth could contribute heavily to a substantial growth in overall network traffic traversing the Internet, creating huge amounts of data demand in just ten years. These figures would be significantly greater still if 4K game streaming is used; a very possible reality given the increase of network speeds predicted for the coming years [5]. We also note that the 2030 figures assume no growth in UK population, the number of people gaming, or the number of hours people spend playing games.

7 GLOBAL SCENARIOS IN 2030

Another consideration to be made is the total carbon cost of facilitating gaming. For this, we propose future scenarios which could create a different isolation of carbon costs in various areas. Our assumptions rely on current data and estimates from life cycle assessment, which will undoubtedly change as new games consoles, technologies and releases are likely in the next ten years. Nonetheless, this data still presents a useful starting point for discussion. We draw on Bates et al. [2] and Teehan and Kandlikar [45] to create estimates for the embodied emissions in the production of the gaming devices by their weight (27 kg CO_2e per kilogram).

For the number of global gamers and devices, we use statistics from Statista [14–17, 19] and use the estimated growth figures, along with the global growth of gamers in the world from Newzoo [33].

Scenario 1: Streaming Stays Niche

Here, modes of delivery for gaming remain similar to what they are today. This means that streamed gaming will become a niche market, rather than growing to be the norm. The resulting energy demand would remain in line with the current for in creating the hardware of gaming, with production of hardware being dependent on the continued rising amount of people gaming, which is currently 6.4% [33]. Based on the Xbox One and PS4 being released 7-8 years after their previous generation, and the successors to these consoles following the same pattern (coming next year in 2021), we assume a life cycle equivalent to this span. There are often different versions of these consoles released that bridge the gap between generations, but these are included in our measures as a single group. In 2019, the PS4 had reached an install base of 100 million [46], whilst in 2018, the Xbox One had 39.1 million [21]. Furthermore, in 2019, Steam claims a monthly unique user base of 90 million [11]. Using the year on year value of growth, we assume 400 million consoles and PCs will be produced specifically for gaming by 2030. For calculating the CO_2e, we use the weight of the PS4 console of 2.7 kg. Included in our figures is our estimated energy usage of running the devices (“direct energy”): Console 90 W, Desktop 200 W, Laptop 90 W, Mobile 4 W, Lightweight 5 W.

To convert data traffic volumes to electricity we assume a factor of 200 Wh/GiB, following Widdicks et al. [48, p. 5364]. To then estimate the consequent carbon emissions, we use the intensity of the UK National Grid, which in 2019 was an average of CO_2 241 g/kWh [20]. We keep this as a constant, though we acknowledge that this figure could be lower in the future, and varies regionally based on the mix of energy sources. As shown, the majority of emissions in 2030 would remain embodied in the production and life cycle of devices associated with gaming, with the network being as relatively lightweight for gaming as it is today. To estimate for downloads, we use data from Cisco [6] and Sandvine[39] to predict the amount of traffic attributable to gaming, then apply the same method of converting to CO_2e.

Scenario 2: Streaming-as-Norm

Our second scenario assumes that streaming almost completely overtakes conventional gaming methods. This means consoles and PCs are no longer manufactured specifically to meet specifications for gaming, so the main devices used are lightweight ones such as mobiles, tablets and some small laptops. We also include lightweight devices dedicated to streaming, such as the Chromecast, as “thin client” (TC). Users play games at 720p on mobile and 1080p on the streaming devices, and all this traffic is tallied into the category called ‘Streaming’. This future assumes a yearly shift of 10% of users from conventional gaming over to streaming until in 2030, when 90% of gaming is done using streamed methods. This creates a much higher impact on the amount of CO_2e that gaming is responsible for. This scenario is extreme and naturally requires increased worldwide Internet connectivity, but we feel it is useful to provoke discussion.

Table 6: Carbon equivalent of gaming 2020-2030 in millions of tonnes CO_2e. 'TC' is thin client. 'DL' and 'Streaming' respectively refer to traffic attributable to game downloading and game streaming, regardless of client (Console, PC, Mobile, or TC).

	Manufacturing and direct energy					Network and data centre						Scenario
	Console	PC	Mobile	TC	Total	Console	PC	Mobile	Streaming	DL	Total	Total
S1	115.3	230.6	84	0.13	430	21.4	28.3	0.5	0	1016	1066.2	1496.2
S2	40.7	104.3	47.9	8.1	201.1	5.2	9.9	0.3	2797.7	157.9	2971	3172.1
S3	69.9	252.7	30.8	2.9	256.2	15.8	22.6	0.4	894.4	753.8	1687	1943.2

Scenario 3: A Hybrid Future

The final scenario in 2030 is a hybrid future, where 30% of people who play games move away from conventional gaming and do all of their gaming on streaming platforms. This is a combination of our previous two scenarios, with the results for all three scenarios shown in table 6. The scenario illustrates how easily the carbon cost of bandwidth can eclipse the carbon cost of manufacturing and running larger gaming devices. A note is that with this system design, the burden on the network for single player games is increased, where it was previously relatively low.

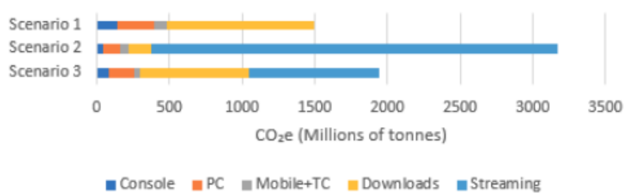

Figure 3: An overview of the emissions for each scenario

We should note the figures in this section are cumulative for the next decade, spanning 2020–2030, as some gamers move from conventional to streamed gaming. For a picture of how things stand after the transition, here we give the per-annum totals for 2030 in millions of tonnes CO_2e for Scenarios 1, 2 and 3 respectively: 432.4, 570, and 467.

8 CONCLUSION

In this paper we have explored the data demand of new cloud gaming services and proposed how it might expand in the coming years. There is much work to do in this field, in order to properly inform debates about public and corporate policy, as well as informing the general public. Perhaps foremost, we need better life cycle assessment of digital streaming services, and game streaming services in particular. Life cycle assessment is the basis for understanding the impacts of purchased devices and their data traffic. We need better estimates about which devices are purchased with gaming as an intended purpose; and the time-use of different devices and types of game.

The estimates we created show how easily the impact of a previously small category can grow much larger, even with a comparatively low shift in gaming practices. We reported measurements on two different game streaming services, for a number of games, different resolutions, and for mobile-based game streaming. We illustrated how a user concerned about the impacts of their data traffic might begin to identify less data-intensive ways of playing particular games (e.g. playing *Metro Exodus* in 720p on Stadia is only slightly less data-intensive than downloading the game). We showed that even a small shift to game streaming (using non-4K) could potentially result in a large increase in game data traffic (again noting that we set aside game downloads and patches from our analysis, since little information is available about their global data volumes). Finally, we provided rough calculations for the greenhouse gas emissions of gaming over the next decade. Compared to gaming as it stands today, the alternate futures represent significant increases in emissions: in the Hybrid scenario some gamers move over to streaming resulting in a 29.9% increase, and in the Streaming-as-Norm scenario, emissions may increase by 112%.

We would stress that our assumptions about game streaming bandwidth have been conservative, with mobiles running at 720p, and other platforms 1080p. If streaming at 4K resolution becomes widespread, then it may well be game over.

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