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AFTER THE STACK OPAQUE

CLOUD GAMING INFRASTRUCTURE AND ENVIRONMENTAL OUTSOURCING METABOLISMS

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This paper discusses the environmental implications of cloud gaming and the sustainability strategies employed by infrastructure providers underpinning this gaming model. At present-day, such an analysis needs to recognise the increasing presence of other agents from the ICT sector in the gaming ecosystem in specific, and the digital entertainment economy at large. To understand the inherent infrastructural and environmental challenges to operationalise cloud gaming in this setting, the paper examines the intricate geo-distributed architecture required to offer the real-time experience of gaming through cloud-based services, while observing the growing concerns with the resource consumption associated with cloud platforms. As a result, the analysis unfurls the prevailing adoption of energy efficiency and carbon offsetting strategies by cloud infrastructure providers. Under environmental compensation methods, heat dissipation and water excess are not merely emblems of an accursed climatic share, but also valuable assets for trade. The paper highlights the significance of taking a step back to re-evaluate discourses on gaming and sustainability, to observe more closely how the environmental problems associated to the industry take shape under a cloud-based platform model.

Keywords: gaming-as-a-service, media infrastructure, cloud gaming, sustainability imagery, environmental media

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1. Introduction

The prevalence of cloud gaming within the jargon of the digital entertainment economy has witnessed a notable upsurge (Newzoo, 2021), as cultural industry observers see big tech conglomerates exhibiting substantial interest in fostering gaming as services (Cai, Chen and Leung, 2014), with titles being offered through platforms such as Microsoft xCloud, Amazon Luna, Nvidia GeForce Now, or the now already obsolete Google Stadia (Di Domenico et al., 2021). The attempt to provide on-demand content through platforms is said to be especially challenging in a technical sense, though, due to the intricate and highly specialised infrastructure required to foster the effective, real-time performance of games through streaming to large audiences (Willett, 2019). Concomitantly, the rapid escalation of cloud-based media services of different sorts has drawn attention to a series of ecological concerns (Brennan, 2019), from energy consumption to a surge in water usage. The latter issues are not specific to games, as they refer more widely to the data processing facilities that underpin the cloud model. Such a potential transition in the business model of the gaming industry, with the worldwide audience of players that would rely upon it, can significantly contribute to intensifying tensions over the subject. In this paper, we will discuss the interconnectedness between these two challenges, namely the infrastructural and the environmental, which lie at the heart of an operatively functional cloud platform model for gaming. The successful accomplishment of the former would largely add up pressures over the latter, making it necessary to establish wider debates on the topic.

As recent discussions on environmental sustainability in the Information and Communication Technology (ICT) sector point out (Freitag et al., 2021; Pasek, Hunter and Starosielski, 2023), there is an increasing concern with the use of carbon compensation strategies and energy efficiency discourses to justify business-as-usual approaches to development. The rationale behind this is that such incentives would stabilize growth as the primary driver of the sector, while disregarding potential collateral and deleterious environmental effects. Therefore, further in the analysis we outline some of the problematic sustainability strategies adopted by cloud infrastructure providers, pointing out how, at the present state, they may just render the environmental effects of outsourced media processing more opaque.

2. Entanglements: why (and how) infrastructure matters

In simple terms, and on a surface level, cloud gaming lets players experience games without needing to install them on their machine. Without demanding expensive hardware from players, games can be played via streaming, akin–at first glance–to the experience of film streaming services. On the surface, this operation may give the impression that the infrastructure underpinning cloud gaming would be somewhat equivalent to what is necessary to stream other media content, and that the gaming industry could easily operate the same business transition that led other media industries in the past to successfully establish themselves upon a service-based model.

However, this perception is not utterly accurate. In an operative level, gaming platforms make their content available in servers geographically distributed in decentralised data centres. The location of servers influences the routes from-where-to-where data circulates. If game servers are in a data centre far from the player, it takes more time for information to travel, potentially incurring more latency. Without a proper, functional infrastructure across different geographies, it is not reliable to scale cloud gaming services, as latency is particularly worrisome for playing most of the triple-A titles which drive the market, and which are based on consistent real-time interaction. As an employee from an Internet Exchange Point in Germany affirmed to us in a recent, but still unpublished interview, "to provide services from banking to gaming, latency is the currency of the data centre industry".

However, even if reducing latency is important to the wider array of online activities, the infrastructural needs required for gaming are not directly comparable to that of other media services. Still, considering that cloud-streamed games rely on video traffic similar to other audiovisual media, and all game processing occurs on industrial supercomputers, why does the infrastructure present greater challenges when compared to streaming video content? It turns out that gaming demands differ in at least three factors (Ball, 2020). In the video streaming for movies: 1) The content is fully encoded, analysed, and compressed well before delivery; 2) Live streaming with precise timing is seldom necessary, as milliseconds typically have negligible perceptible impact; and 3) Since media files have a predetermined endpoint, the content remains consistent for all viewers and is notwithstanding predictable. On the other hand, in the data traffic for games, if a data packet is missing it requires cueing or skipping the missing video frame, which causes jittery. Buffering can be annoying when streaming a movie, but in a digital game it will make the player fail in its most fundamental operations.

Players acknowledge this through the phenomenological experience of gaming, of course, but theory on game interfaces can help shed light on further details of this problem. The continuous iteration between player actions and the images and sounds of gameplay establishes videogames as *operative media*. This "interface mises-en-scène" (Distelmeyer, 2022), with its visual, acoustic, and kinetic qualities, provides a familiar framework for non-specialised individuals to perform the high-level operation of digital media. Such interfacing condition conveys the ready-made possibilities of entertainment software, turning the human-computer relationship more functional. Interfaces, therefore, offer conducting and guiding principles for the actions of users, or players, interacting with the machine. If this command-response mise-en-scène is periodically impaired by infrastructural problems, the thorough experience of gaming through the cloud model is jeopardised. As most Triple-A games demand precise, synchronous movements, the interfacing disruptions caused by latency and jitter become ultimately intolerable.

The surface-level interfaces of monitors, loudspeakers and controller peripherals are, nevertheless, only gateways to much larger and intricate technical systems, and the failures in the interfacing operations provide us with a valuable opportunity to interrogate the larger infrastructures that underpin them. Latency brings infrastructure to the foreground, as a form of infrastructural inversion (Bowker and Star, 2000), showing why it is particularly challenging to implement gaming as a cloud-based service. Particularly in the case of the cloud gaming model, these operative problems run from the user interface down to the lower levels of critical infrastructure and all the way back. They re-articulate in the digital media ecology one of the most basic functions of the infrastructures for providing physical products and goods: transportation. To mitigate the risk of latency, which is ultimately an expression of geography over the contrivances of telematics, the closest bet for platforms is geo-distributing several game servers across countries and the globe, whether in privately owned or, as in most cases, leased data centres. This means expanding horizontally the density of data processing facilities, enabling the logistics of the cloud gaming model to multiply the available pathways and route the traffic more efficiently. Furthermore, for the gaming industry, maintaining engagement, and therefore, the processing, is naturally a key objective. The service-oriented business model itself shows how the sector seeks to create incentives for gaming modes where the gaming opportunities are seldom truly over (Ochsner et al., 2023).

Moreover, in terms of their technical and spatial implementation, the logic and logistics of cloud gaming data traffic function on the principle of outsourcing computational processing from personal devices to these geographically distributed server halls, which are equipped with substantially more potent hardware. Beyond the technical requirements of household computing apparatus, this model demands the provisioning of power to sustain entire on-premise or colocation data centres (inclusive of auxiliary utilities such as air conditioning and power generators). Considering its resource metabolism, this whole operation is an energy colossus that draws resources on a macro scale.

As outlined by researchers from the Lawrence Berkeley National Laboratory (Mills et al., 2019), to ensure that it can operate fully functionally, cloud-based gaming emerges as the most energy-intensive facet of internet-based gaming. In this sense, it is important to understand gaming activities in the cloud through a broader scope, aiming at the overarching environmental concerns intrinsic to the demands of its vast-scale infrastructure, which is poised to exacerbate as the demand for entertainment software continues to surge. In the present-day scenario, data centres collectively consume already an estimated 200-terawatt hours (TWh) of energy annually (Jones, 2018). That is to say that, if one were to treat the cloud as a country, it would rank as the sixth-largest global electricity-consuming nation-state[1] (Ensmenger, 2018). But that treatment would lead to a misrepresentation, as cloud applications are more often merging with state plans, and not just adding to them. Just as importantly, their environmental effects transcend matters of computing power, electricity consumption and carbon dioxide emissions, as cloud computing extends to a more complex and multifaceted interaction with Earth systems. For instance, in the United States,

[1] Just for the sake of illustration, we could also mention the environmental pressures posed by the computational workload of Artificial Intelligence applications. It is not simple to estimate a representative average of the electricity consumption of AI model training and consumer use, as they are largely variable according to the tasks and parameters used to run it, as well as the technical conditions of data processing. AI represents one of the most significant workloads in data centres and, according to a recent study (de Vries, 2023), based on the performance of AI servers shipped by market-leading company NVIDIA (which currently retains 90–95% of the market share for graphic processors used in data centres), estimates are that global AI demand could consume around 85–134 terawatt–hours (TWh) of electricity by 2027. If this scenario is confirmed, the estimation of water withdrawal for operating AI applications would amount to circa 4.2–6.6 billion cubic meters globally–roughly half of the total annual water withdrawal of the United Kingdom (Li et al., 2023).

data centres currently rank among the top ten water-consuming industrial sectors and are witnessing an upward trajectory (Siddik, Shehabi and Marston, 2021). Conventional cooling methods employed within relatively modest 1-megawatt data centres–that is, with an electricity demand equivalent to that of 1,000 households–can consume as much as 26 million litres of water annually (Mytton, 2021).

By connecting this secondary data to the materialities of media (Parikka, 2015; Luersen and Fuchs, 2021), one can say that the energy usage and management within the facilities running cloud-based computer applications are always dependable on the continuous interaction between computational and non-computational resources. Especially when following the techno-aesthetic standards of computer-demanding triple-A titles, gaming through the cloud necessarily entails the support of a comprehensive, planetary-scale computational infrastructure (Bratton, 2015) to furnish real-time gameplay experiences across global audiences. Even though its initial customer base continues to be based on class privilege and access (Hogan, 2021), the several investments in developing gaming-specific racks and utilities for geo-distributed data centres suggest that it is very likely that such an infrastructure is going to keep escalating both vertically and horizontally.

In recent years, several researchers have started to observe the nexus between gaming and climate change (Preisinger and Endl, 2023; Fizek et al., 2023; Abraham, 2022; Chang, 2019; Navarro-Remesal, 2019; Raessens, 2018; Woolbright, 2017). At the industry level, new organisations concerned with the environmental effects of gaming have emerged to channel environmental policies and advise best practices to game developers and publishers (Whittle et al., 2022; Patterson and Barratt, 2019). This is the case of the Playing for the Planet Alliance (P4P), backed by the United Nations Environment Programme, and the special interest group on climate of the International Game Developers Association (IGDA Climate SIG). Moreover, these initiatives can effectively encourage class action among developers and help establish climate councils in the industry.

Nevertheless, even if such initiatives are important, comparatively limited attention has been directed to scrutinising the environmental implications intrinsic to the infrastructure needed for gaming through the cloud. And there is a fundamental reason why this should not be neglected: if gaming services unfurl more aggressively towards the cloud, the major environmental pressures of gaming in the coming years may not be assessed by monitoring developers and publishers alone, but the more fundamental level of critical infrastructure provided by cloud assemblages. Estimations from life cycle assessments project that if the demand for cloud storage and processing keeps its current growth tendency, the electricity usage for communication technologies could contribute to circa 23% of the globally released greenhouse gas emissions by 2030 (Andrae and Edler, 2015). Data centres alone are expected to consume from 5 to 10% of the global electricity demand, in comparison to circa 1% as of today.

Therefore, it is necessary to point out this important gap in scholarly discourse and environmental advisory within the gaming industry. As models based on the outsourcing of computational demands unfurl, it is important to take a step back to underscore the telematic infrastructure supporting cloud gaming, which spans from the electricity grids sustaining data centres to the intricate mesh of cables and satellites interconnecting servers within a transcontinental overflow of networked devices. Networked synchronous media traffic, although portrayed with the use of seemingly ethereal metaphors, is inexorably tethered to terrestrial, atmospheric, and aquatic realms (Parikka, 2015; Peters, 2015; Starosielski, 2015). As a composite construct derived from Earth's elemental reserves, the cloud concentrates and distributes resources at once. Likewise, digital distribution platforms turn game production and consumption into a process that is "both inherently global and intensely localized" (Sotamaa and Švelch, 2021, p. 9). Hence, discussions on the sustainability of activities such as cloud gaming cannot focus solely on the micro level, such as stimulating game developers to adapt their studios to sustainability standards. Focusing on the support systems that underpin the practices of ambient supercomputing appears more promising. Measuring the footprint of game developing studios is important, but scratches only the surface of the problem. In our view, inquiring the infrastructure underpinning gaming platforms can provide a deeper understanding of the environmental implications of gaming, especially as the industry transitions toward a cloud service paradigm.

3. Growings crops, planting trees: on compensations

Currently gaming is roughly estimated to make up 7% of global network demand (Marsden, Hazas and Broadbend, 2020). Cloud gaming still refers to an indeterminate part of this signal traffic. As data centre providers do not discriminate, or at least do not disclose publicly, how each activity in the cloud is responsible for this consumption, providing an estimation of the cloud gaming share would be reckless. Notwithstanding, as a popular computer-intensive activity which is outsourced to data centres, gaming can be ascribed as a significant activity participating in this resource metabolism. As an ongoing, constantly renewed trend in the industry, it is important to document the development of gaming in the cloud as it unfolds, as these services have been gaining a lot of traction with the infrastructure provided by corporations such as Amazon, Alphabet, Microsoft, and so on. Even with the recent failures of projects such as Google Stadia, it is still important to keep track of the provision of infrastructure to support game streaming services as they develop.

As such evolution is path-dependent, it is also important to think about what the arguments in favour of cloud gaming could be. Many advances are being made to improve the energy efficiency of cloud computing facilities, for instance, and energy specialists often have to recalculate the energy expenditure of the devices every year due to such improvements (Masanet et al., 2020). It is also true that fewer consoles being manufactured means fewer in landfills after they are outmoded and discarded. If there are also no discs to make, the environmental burden of transporting them to physical stores vanishes. As Benjamin Abraham argues (2022), this would be beneficial to mitigate the overall carbon cycle involved with digital gaming, as the emissions involved in the distribution of physical products are very high.

However, what can be observed more prominently at least since the COVID-19 pandemic is that the implementation of digital infrastructures has been growing at a much faster pace than the discontinuation of analogous offline, carbon-intensive logistical operations (Freitag et al., 2021). More often than not, online and cloud-based applications are used not as a substitute, but as a redundant infrastructure. In practice, this means that the steady growth of cloud-based gaming services and the infrastructure to support them is stacked upon prevailing models of manufacturing and shipping of game disks and downloadable gaming content. In this sense, the environmental pressures associated to established gaming infrastructures are accumulated instead of being mitigated.

While it is true that the energy efficiency of cloud computing facilities has demonstrated improvement trends, these advancements are contingent upon the cleanliness of local energy mixes and other parts of the remaining infrastructures. More importantly, they are completely path-dependent, what makes any estimation highly volatile to broader macroeconomic and political trends. A well-argued, optimistic view of such developments was conveyed by Jonathan Koomey, an experienced researcher in the field of energy and sustainability, who posed more than a decade ago that peak-output computing efficiency was doubling every 1.5 years (Koomey et al., 2011). From this data, Koomey inferred that the total energy consumption of ICT would constantly decrease over time in line with industry tendencies. Indeed, since 2010 the energy intensity of data centres has decreased by approximately 20% per year, leading the International Energy Agency (IEA) to project significant growth in the sector *coupled with* reduced energy demand (International Energy Agency, 2020). This was particularly noticeable in the data centres designed to accommodate higher volumes of data storage and processing, called hyperscale. These facilities require a lower energy consumption per unit of data–although processing *more data*. This condition suggests imagining a scenario in which the infrastructures to support cloud gaming are expanded without amplifying environmental pressures.

However, it is highly questionable whether this efficiency tendency in enough to guarantee the long-term sustainability of the sector. Energy efficiency, for instance, is constrained by the physical limitations of silicon semiconductors (Freitag et al., 2021), which eventually reach a point in which further miniaturisation compromises performance. As the ongoing improvements in energy efficiency are contingent on the densification of microchips, the more optimistic forecasts are difficult to meet. Nowadays we already see the predictions from more than a decade ago compromised, as the rate of peak-output energy efficiency slowed down, now taking 2.7 years, instead of 1.5, to double (Pasek, Vaughan and Starosielski, 2023).

Moreover, besides the uncertainty itself, another problematic aspect of the most optimistic discourses on energy efficiency is that, ultimately, they may just incentivise more growth without serious carbon mitigation commitments. It is not difficult to predict that computer-intensive activities of data centres, such as game processing, can serve to feed into the very same logic. When looking to reality on the ground, beyond the modelling of projections, one can see platforms already using this rhetoric to justify unsustainable growth, by using the heat produced by the increased consumption in data-processing facilities as an additional financial asset.

The constant refrigeration of data centres, for instance, is a systemic source of heat dissipation. Circa 40% of the energy consumed in data centres goes for air conditioning, as the facilities are normally recommended to maintain a temperature between 20 and 25 degrees Celsius to operate properly, keeping the process-intensive servers from overheating (Zhang, Li and Wang, 2023). Even personal computers, from old machines to consoles of different generations, have heat prevention systems that shut the device down when a certain internal temperature is reached, in order to protect the delicate hardware from heat overexposure, which could melt or damage the components irreversibly. More sophisticated computer systems have configurable automatic shutdown temperatures, while simpler home entertainment systems have a pre-established factory setting[2].

As a scalable thermocultural technique, though, artificial cooling has much more radical effects in the case of supercomputing infrastructures available to operate 24/7. In order to keep their internal server halls at an ideal temperature, data centres need a lot of air conditioning, and end up generating a lot of excess heat. To take advantage of the excess heat produced, some data centres have used increased air temperature as a commercial asset, incorporating the transfer of heat into their sustainability portfolios in different ways: Amazon and other companies with proprietary data centres invest in projects to channel the heat produced in their server farms to heat their own offices (Oró and Salom, 2022), and Amazon reported to have drastically reduced the projected greenhouse gas emissions from their offices by these means. In partnership with local energy cooperatives, several projects are underway to transfer the heat generated inside Amazon Web Services (AWS) data centres to other commercial buildings (Amazon, 2021). Waste heat from data centres is increasingly traded with municipalities to provide domestic heating. The *thermopolitical strategy* (Velkova, 2021) of transferring the heat produced by intense computer processing in data centres to municipalities and businesses is repeated in Rotterdam, Basel, Mantsaala and Dublin, and in more and more cities around the world[3].

Another way to profit from the excess heat produced is to grow plants in greenhouses near data centres. Projects from data centre operators in Sweden

[2] This is a personal anecdote, but one of the most tangible examples we have of this type of system is our experience a couple of decades ago with an old PlayStation console, which used to work perfectly for several hours in winter, in the subtropical-temperate climate of southern Brazil, but during the hottest summer nights rarely operated for many hours straight without the frustration of shutting down unexpectedly. Unless, of course, the user could resort to artificial cooling of the room.

[3] The growing interest to incorporate energy sources in urban planning also generated compelling gamification methods to identify and report sources of waste heat in industrial infrastructures. See Wernbacher et al. (2022).

and Canada are expected to grow crops of leafy green in greenhouses warmed with the excess heat transferred from their server halls (Cáceres et al., 2022; Frenzel and Ruder, 2023). Another example of a combination between cultivation and the use of excess heat is the White Data Centre in Hokkaido. In addition to cultivating mushrooms and spinach, the company harnesses the heat generated by its data centre to rear eels, as the fish is valued in the Japanese seafood market. The company raises 300,000 eels a year for the gastronomy sector (Judge, 2022). The waste heat is used to warm water tanks to an adequate temperature for breeding the fish. Green Mountain, a data centre operator from Norway, also channels the heat from its data centres to warm the water they use to grow lobsters and trouts for restaurants (Judge, 2021; Swinhoe, 2021).

Other data centres prefer to take measures targeted at biodiversity, hosting beekeeping or tree planting programs to improve their sustainability indicators. Stack Infrastructure hosts circa 200,000 bees on the roof of its data centre in Milan (Swinhoe, 2022b). A CyrusOne data centre has installed *bee hotels* and so-called *bee-friendly landscapes* on its data campus in Dublin, the same city where Equinix grows orchards and raises pollinators (Swinhoe, 2022a), allegedly for the same environment-friendly reasons.

While at a first glance most of these examples might look like promising cases of efficiency derived from computer-intensive activities, one needs to hold their expectations about their viability as a pathway to reduce the environmental impacts of the industry. More than an ecological motivation, the rationale underpinning these initiatives points towards a financial strategy that nurtures continuous growth. Instead of being seen as an environmental burden, the heat from data centres becomes a strategic asset to be traded on energy markets, on carbon markets, on food markets, as well as on markets for voluntary environmental compensation. In the meantime, the cumulative heat generated, and the overall CO_2 emitted, some of the biggest environmental problems with data centres, are not properly addressed. As data centres establish themselves as the factories of Industry 4.0, such practices grant more productivity through the efficient use of the systemically supplied heat, which is incentivised to increase.

Aside from the involvement in the computer processing happening in proprietary and leased data centres, the gaming industry invests in other sorts of projects with rather similar problems. These include the several reforestation initiatives that are recommended and implemented by actors in the gaming industry. In recent years, discourse about forestry has begun to to abound in gaming industry conventions, as game developers seek strategies to offset the carbon dioxide emissions produced by their studios. One of the most widely adopted initiatives for this purpose is reforestation. In Germany, for instance, non-profitable organisations such as *GamesForest.Club* encourage industry actors to contribute to forest protection and reforestation enterprises as part of a carbon sequestration strategy. The goal of the initiative is to harness the influence of games and compassionate individuals within the industry to safeguard and rejuvenate nature (Games Forest, 2023). When accessing the website of the organisation, one starts to hear the playback of bird vocalisations and other compositional elements of an archetypal forest soundscape. Nevertheless, even if these initiatives convey persuasive enunciations and messages about an idyllic (albeit engineered) nature, there are arguments suggesting that carbon compensation strategies deliver more in terms of corporate rhetoric than of practical, eco-conscious achievements. Scholars in Earth System Governance advise that tree-planting might not be an adequate way to offset emissions (Blum and Lövbrand, 2019). Depending on the species, trees require a significant amount of time to grow and begin sequestering carbon from the atmosphere. In worst-case scenarios, which are not uncommon, forests may also become susceptible to wildfires during heat waves or as an outcome of active anthropogenic deforestation activities. This situation can cause forests to shift from carbon sinks to significant carbon emitters, suddenly reversing any previously alleged "compensation" for emissions. Additionally, numerous tree-planting initiatives have been issuing redundant certifications for different venues (Romm, 2023), complicating the efforts to accurately assess the potential positive impacts of these incentives.

Of course, investments from the gaming industry in the breeding of bees and reforestation (and, naturally, in securing that forests also keep standing) are more than welcome, but it is misleading to think of them as intrinsically beneficial environmental initiatives, especially from the perspective of carbon offsetting. More importantly, by using heat as a financial asset, as in the other cases shown during the paper, the ICT sector is focusing on the benefits of energy efficiency. The argument is that efficiency gains will *compensate* for the growth in consumption driven by cloud-based services, such as cloud gaming. However, if we look deeper into the history of the energy sector, there are reasons to be sceptical. A similar argument was made in relation to coal-dependent industries already during the first Industrial Revolution. Industrialists argued that by investing in greater energy efficiency, the increase in productivity could happen with less collateral environmental damage, allowing the industry to grow faster without polluting more (Clark and Foster, 2001). In 1865, economist William Jevons wrote *"The Coal Question"*, a book in which he questions the longevity of economies based on coal usage. Jevons observes, in particular, how the steam engine improved energy efficiency compared to previous designs, making it possible to produce more with fewer resources. However, Jevons also noticed that as efficiency increased, the cost of energy fell, which led to an increase in consumption. This phenomenon is nowadays called the *Jevons Paradox*. In summary, it highlights that improvements in resource efficiency can lead to a potential *rebound effect*. By stimulating economy-wise growth, efficiency can lead to higher overall resource consumption. This challenges the assumption that efficiency alone would lead to environmental benefits and reduced use of resources.

While Jevons developed his argument within the framework of non-renewable energy, which is not at all a negligible aspect, the significance of his argument still resonates strongly today. While the preference for renewable energy sources over fossil fuels is self-evident, and hastening the energy transition remains paramount, it is nonetheless concerning to rely solely on this strategy, ignoring potential collateral effects. The prevailing discourse within the ICT sector often emphasises efficiency as the main driver of solutions to environmental challenges, and this extends to sectors like data centres and gaming. As we move further away from the goals of the Paris agreement (that is, to reduce greenhouse gas emissions by 45% by 2030, compared to 2010 levels) (United Nations Environment Programme, 2023), relying on energy efficiency and compensation strategies is not enough, and these trends often extend further business-as-usual approaches. The current financial architecture systemically incentivises the proliferation of heat dissipation infrastructures.

If the games industry is serious about promoting more sustainable practices, it will have to move beyond reliance on compensatory measures. This does not affect only the strategy for cloud gaming, but also hardware choice, support for repairing and recycling, and end-of-life services–exceeding the criteria of TCO Gold certification, which promotes sustainability standards in ICT products. Sustainability analysts at the ICT sector suggest that to act in a truly environmentally responsible way, all stakeholders should be enacting policies on a much larger scale, while adopting a radically different management rationale, such as putting a price on carbon emissions or a global constraint on consumption (Freitag et al., 2021), which would push for more innovation in resource usage alternatives. This is a big challenge, of course, because taking the suggested pathway requires adaptation and potential reductions, meaning a broader restructuring of the sector and the whole resource metabolism.

On a conceptual level, this paper modestly aims to contribute to the discussion by suggesting that some improvement can be achieved by taking a step back to acknowledge the impossibility of mitigating planetary-scale problems without a more comprehensive, macrosystemic approach. To address environmental issues at their proper scale, it is necessary to examine the entangled infrastructure that underpins the gaming ecology of both today and the future.

4. Challenges to assessing the future and the reality of gaming's environmental entanglements: infrastructure and opacity

There is much work to do on the infrastructure level. Game studios have been collaborative in participating in intersectoral research initiatives, but the same cannot always be said about other actors in the ecosystem of cloud gaming.

An illustrative practical example can shed light on the delicate intricacies of the current situation. As part of a recent research project, we have contacted via email 25 large-to-hyperscale data centre operators providing cloud services in Germany, Austria, and Switzerland. The intention was to inquire about the possibility of visiting the facilities to interview managers and workers to discuss aspects of sustainability related to their businesses, as well as to photograph the physical facilities that process gaming data. Although not all gaming platforms disclose transparently which data centres are leased to host their servers[4], one can have a general idea of the companies that have the apt facilities to provide such services. As we mentioned earlier, cloud gaming is a highly computing-demanding and therefore resource-demanding activity, engaging all layers of the computational stack, from the physical hardware and network infrastructure to the software and user interface. Thus, facilities need to provide not only a stable and reliable high-speed connection but also a very robust non-computational infrastructure of air conditioners, generators, and software systems. As not all data centres at all are capable of processing computing-costly games, the ones that can do it tend to advertise it openly on their website.

[4] Contracts of confidentiality very often prevent private enterprises in the sector from revealing the activities their customers develop within the leased facilities.

Based on this publicly available information, we have contacted cloud infrastructure providers inquiring whether they would be open to receiving our visit. Before doing this, though, we asked individually to each of them whether they could confirm whether they provided any kind of gaming-related services. Most operators never responded to any of the attempts to establish contact. Some of the few answers we had in these private correspondences are rather curious, nevertheless. The most common response provided was that there was not any interest in taking part on the research, with no further reason given. Some companies alleged that unfortunately it was not possible for "external personnel" to visit their data centres for "several, but private reasons". Some companies phrased their replies stressing that they "could not" fulfil our request to visit the facilities in person. Another data centre administrator straightforwardly mentioned that the company "didn't want" to support the request. A less laconic response was given by another provider, which operates a colocation data centre in Frankfurt. The alleged reason was that the company had no insight into what activities their customers developed in the servers hosted in their data centres, as they simply provide the core infrastructure to them, and are by no means involved with the content of these activities.

This may sound surprising, but in fact it could be expected as a fair response from colocation data centre operators, which only rent the space in their facilities to the server owners. And here things start to get more delicate. Such a secrecy regime, although understandable from a cybersecurity standpoint, is also very problematic, not only from the perspective of our failed attempts to start a research collaboration. It is comprehensible that companies that deal with confidential private and state-level data take secrecy as a matter of principle. The main contradiction, nevertheless, is that in the current situation, when cloud infrastructure is merging with resource-intensive software services that escalate to a planetary dimension, the auditability of such support systems becomes more and more a matter of commonly shared, public concern.

From this vantage point, the case of cloud gaming encapsulates a paradoxical scenario. It reflects a society striving to adapt individual and collective action by identifying sustainable management strategies, while at the same time exacerbating environmental pressures through digital interconnectedness and virtual environments.

As Lisa Parks (2014) notoriously put it, engineers often refer to infrastructure as *stuff you can kick*–robust physical apparatus that are dispersed and assembled to compose a system for the distribution of materials of value. But the environmental entanglements of infrastructure may show us the other way around: infrastructures can also kick you (and us all) back. As cloud infrastructures interact broadly with the earthly metabolism through the technical management of water, air, and temperature (Jue, 2020; Furuhata, 2019; Vonderau, 2019; Starosielski, 2016; Velkova, 2021), the pressure in scale impelled by cloud platforms cannot be understood by monitoring studios alone, nor its accountability can be delegated to the voluntary disclosure by companies. As global-scale infrastructures, cloud services are not only meant to provide social goods to the public in a sustainable way, but should also be available for public scrutiny. Due to issues of privacy and secrecy involving data centre operations, researchers and civil society at large have problems with understanding, let alone auditing them, in a way that is more reliable than accessing self-disclaimed reports. The challenge starts with the difficulty in assessing the facilities to conduct research (Vonderau, 2019). In this sense, questions on gaming and environment-wise polity also arise: how are cloud-based gaming services meant to serve the public in the face of planetary environmental upheavals? Are cloud gaming platforms publicly auditable in the first place?

Notwithstanding, these questions may sound naïve without a wider comprehension of the cloud's stack infrastructure that stretches beyond regional regulatory frameworks. Considering present-day developments, cloud infrastructures have been working on a very different techno-political spectrum. As Yannis Varoufakis (2023) asserts, the proliferation of cloud platforms is not merely a technological advancement but a pivotal driver of a predominantly self-contained rental economy, in a global level. This transformation gives birth to what Varoufakis terms *cloud capital*, a concept that is emblematic of the cloud colocation paradigm, wherein access to and control over digital infrastructure increasingly rely on power dynamics centred on ownership, concentration, resource extraction, and rental. As such, platforms and colocation providers control the access and terms of use of services, managing the servers, networks, and data centres that form the backbone of gaming practices. Moreover, as only a few large cloud infrastructure providers dominate the market, monetising the data traffic generated from users, they wield grand influence over platform economics and the management of resources in the digital realm.

Considering this, it is relevant to reassess this infrastructure and the services that rely upon the cloud from a perspective of the environmental risks involved in the wider geo-distribution of its architecture. In Paul Virilio's worn out expression, "to invent the train is to invent derailment; to invent the ship is to invent the shipwreck" (Virilio and Der Derian, 1998). Accidents are inherent to all technical systems, and each new technology nourishes its own specific and novel kind of accident, Virilio would advise. Cloud infrastructure is not at all new, however. The idea of data processing as a ubiquitous utility distributed from centralised computing units is as old as computer science itself, being traceable back to the development of the UNIX system in the 1970s, which synchronized computers across networks (Bratton, 2015). The main difference from then to nowadays, though, is that the horizontality of the network gave way to the conversion of several activities, and sometimes entire sectors, to a model based on proprietary platform services. Such services are largely available, yet also largely opaque.

One could say, still with Virilio, that the larger the infrastructure, the larger the accident. While in general infrastructures are understood as support systems that allow human agents to extrapolate certain physical limitations, providing societies with mid to long-term stability, the very same infrastructures may also create unforeseeable systemic vulnerabilities (Edwards, 2003). This may happen because of the inseparable metabolic connections that exist between technology and nature, through which the embeddedness between organic and inorganic systems (Schneider, 2018) comes to the fore, backlashing from fuel consumption, intensive video rendering, or computer heat dissipation–from smaller events to the point of anthropogenic global climate change.

In a more hopeful note, Gabriele Schabacher (2022) observes that although we usually focus on their more immediate and tragic dimension, disasters also have an epistemic significance: they can provide us with *infrastructural learning* about emerging sociotechnical systems. With this term, Schabacher emphasises the importance of understanding infrastructures not just as technical systems, but also as dynamic entities shaped by social, economic, and political factors. Accidents are diagnostic: amid their looming presence, infrastructural learning can be a pathway to the continuous adaptation that is necessary to effectively manage and govern the sociotechnical support structures of a world that is rapidly changing due to anthropogenic action, global interconnectedness, and resource-intensive planetary-scale systems. As argued in preliminary work (Luersen, 2023), this is even more reason to reframe the analysis of the environmental entanglements of cloud platforms from a perspective of their infrastructures: thinking along these lines, one can evaluate the challenges and the very failures to establish cloud gaming infrastructure so far as valuable cautionary tales for the future development of entertainment software. More so, one can think of the actual and potential environmental pressures outlined in the previous sections as analytical onsets, epistemological vantage points that can nurture future developments in the face of emerging gaming platforms.

5. Final considerations

The development of gaming towards a cloud service model raises questions on how to evaluate the environmental pressures associated to the gaming industry. Significant concerns involve, for instance, the energy and water consumption of data centres, which are increasingly utilised to process the intensive data traffic of games, let alone the widespread deployment of machine learning algorithms and artificial intelligence models. In this scenario, we discuss the need to address the infrastructure and ecological issues of cloud gaming platforms, emphasising the importance of further approaching the extent to which the gaming industry intersects with developments in the data centre sector. In this context, we highlight concerns related to questionable sustainability strategies adopted by cloud computing infrastructure providers, pointing out gaps in the understanding of the environmental problems associated to the support systems of media distribution services.

Throughout the analysis, we point out that the environmental problems associated to gaming are, likewise, increasingly intersecting with power dynamics centred on ownership, concentration, and resource extraction in the development of cloud infrastructure. The influence exerted by on-premise and colocation data centres over access and service conditions places a few major cloud computing facility providers in a position of substantial influence and control over platform economies and resource management.

We emphasise the significance of intersectoral research involving cloud infrastructure providers, as we understand that it can help identifying the new synergies between activities which are, otherwise, normally understood as constitutively separate. Initially, this may not contribute to mitigating adverse impacts of cloud gaming infrastructures, but it can help preventing that unsustainable innovation in the information technology ecosystem takes place inadvertently. As one can infer by observing how energy efficiency measures and carbon offset strategies are rhetorically used as synonyms of sustainable practices, the current developments often contribute to maintaining business as usual, outsourcing environmental pressures while increasing consumption.

As global-scale problems could hardly be mitigated without a macro approach, in the first place it is important to map and re-evaluate the wider ecology of machines and environments where digital gaming is processed, considering the complex techno-economic support system in which data centres and cloud gaming platforms overlap. In order to do this, however, it is necessary to acknowledge the significance of scrutinising both the existing gaming infrastructures and those currently in development with a broader ecosystemic view, and a higher degree of autonomy.

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