# The Carbon Footprint of Streaming Media: Problems, Calculations, Solutions

*Laura U. Marks and Radek Przedpełski*

## The Carbon Footprint of Streaming Media: Introduction to the Problem

Coming up on 2020, the electricity consumed by information and communication technologies (ICT) was calculated variously to generate 1.4% (Malmodin and Lundén 2018), 3.3–3.6% (Belkhir and Elmeligi 2018) and 3.8% (Bordage 2019) of global greenhouse gas emissions.[1] ICT has surpassed the carbon footprint of the airline industry, which contributes 1.9% of global greenhouse emissions (Ritchie 2020). About one-third of that, or 1% of global greenhouse gas emissions, has been attributed to streaming video: video-on-demand platforms, YouTube,

[1] Not to mention ICT's significant water consumption and mining impact.

L. U. Marks (✉)
Simon Fraser University, Vancouver, BC, Canada
e-mail: laura_marks@sfu.ca

R. Przedpełski
Trinity College Dublin, Dublin, Republic of Ireland
e-mail: przedper@tcd.ie





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pornography, live streaming, videos embedded in social media, and games (The Shift Project 2019a, b; Marks et al. 2021). These emissions result from the electricity obtained from fossil fuels (currently 79% of worldwide energy sources: BP 2020), which is subsequently used to power a tentacular system made up of data travelling through data centres; metropolitan, long-haul and undersea data networks; and end-user devices (Table 1).

Then came the Covid-19 pandemic. The world's wired population was flung onto their couches. An eerie passivity prevailed. Like wolves in a pasture, predatory media platforms and the undervalued telecommunication companies that support them took advantage of the locked-down peoples to further addict them to streaming 'content.' In the first two and a half months of the pandemic, internet traffic spiked by 40%, according to the network research company Sandvine. Over 15% of that traffic was YouTube, and 11% was Netflix—this despite the fact that both those companies, as well as PlayStation, reduced resolution to standard definition in order to cope with demand (Sandvine 2021). Video conferencing also contributed to the spike, as meetings and social gatherings moved onto the so-called 'cloud.' Gaming too, in increasingly high definition, increased in this period, as did video calling and video-heavy social media. And, only slightly slowed by the pandemic, ICT's infrastructure of networks, data centres, and devices continued to expand worldwide in anticipation of market growth (Cisco 2020; Global Market Insights 2020; Research and Markets 2020). The pandemic ingrained streaming habits that will be very difficult to unlearn.

Future contributions of ICT to global warming are difficult to calculate, given the many unknown variables, but most ICT engineers agree that in just a few years, unprecedented demand for online data will outstrip even the most fantastically efficient technical capacities. By one estimate, ICT will constitute 15% of global electricity consumption by 2040 (Belkhir and Elmeligi 2018). This chapter does not address calculation-expensive applications like artificial intelligence, cryptocurrency, and the Internet of Things, but they compound the urgency to regulate the electricity consumption of ICT. Comparable to the simultaneous increase in the automotive market of SUVs and electric cars, ICT's efficiency gains are in many cases outweighed by its greater energy consumption, in what is known as the rebound effect. The danger here is that the ICT sector alone will be responsible for a worldwide failure to curb carbon emissions by the necessary degree to avoid catastrophic global warming. However, it is only a question of how soon, and by how much, this failure to curb will take place. Accordingly, media scholars

**Table 1** Spreadsheet by The Shift Project

| *Action* | *Time spent on the action (min)* | *Data size (byte, B)* | *Device used* | *Network used* | *Energy impact (kWh)* | *Hypothesis* |
|---|---|---|---|---|---|---|
| To send an email | 3 | 1E+06 | Smartphone | FAN Wired | 8E-04 | 1 MB email, 3 minutes |
| | | | | FAN WIFI | 5E-04 | |
| | | | | Mobile Network | 1E-03 | |
| | | | Laptop | FAN Wired | 1E-03 | |
| | | | | FAN WIFI | 1E-03 | |
| | | | | Mobile Network | 2E-03 | |
| To watch a video online | 10 | 2E+08 | Smartphone | FAN Wired | 9E-02 | 10 minutes video, 1080p quality |
| | | | | FAN WIFI | 4E-02 | |
| | | | | Mobile Network | 2E-01 | |
| | | | Laptop | FAN Wired | 9E-02 | |
| | | | | FAN WIFI | 4E-02 | |
| | | | | Mobile Network | 2E-01 | |

should be at the forefront of communicating this urgent message and lobbying companies and governments for change and regulation.

## A Brief Plateau

Readers may be asking: What about Moore's Law, according to which circuit complexity doubles every two years (Moore 1965)? Or what about Koomey's Law, which states that energy consumption per processing unit halves about every 1.5 years (Koomey et al. 2011)? What about the impressively increasing efficiencies of data centres (Shehabi et al. 2018) and networks that are meant to be counterbalancing this rising footprint? And the fact that mobile devices, on which many users stream their media, consume less energy than laptop and desktop computers? Aren't these all sufficient to curb the electricity demand of streaming media?

The simple answer is: no. Data centres, networks, and devices are ever more efficient, but given the exponential rise in demand—largely driven, we argue, by streaming media—the work they are required to do increases even faster, resulting in ever greater consumption of electricity. Moore's Law relies on the successful shrinking of metal-oxide semiconductors, but those semiconductors have shrunk to the point where they are beginning to leak electrons (Bohr 2007; Koomey et al. 2011; Kaeslin 2015). At some point this will bring Moore's Law to an end (Hintemann and Hinterholzer 2019). The efficiencies modelled by Jonathan Koomey are also finite.

Analysts in Germany (Hintemann and Hinterholzer 2019) and the United States (Shehabi et al. 2018) who have access to confidential information about data centres agree that data centre electricity consumption, after a rise until about 2008, plateaued or even dropped slightly for several years. This is partly explained by the move to larger, more efficient data centres, including hyperscale data centres, and to cloud services, which are more efficient because they respond to demand. 'Virtualisation' is maximizing overall system usage by using more than one operating system on a device (e.g. computer, server). Since the device needs a constant rate of cooling, virtualization is also energy efficient. Thus, even though electricity consumption increased, large data centres' power usage efficiency (PUE) fell to 1.75 and lower in Germany, 1.3 for new, large data centres that do not use older equipment (Hinterholzer and Hintemann 2019). Hyperscale data centres in the U.S. have an even lower PUE of 1.2 (Shehabi et al. 2018, 2018). However, even as efficient cloud computing is introduced in wealthy countries, traditional data centres are not dismantled (Hintemann and Hinterholzer 2019; Shehabi et al. 2018), and the manufacture and installation of upgraded infrastructures carries with it a massive—but often ignored—range and scale of Scope 3 emissions.

Among ICT engineers there is vigorous debate and barely concealed panic over whether and when the plateau in data-centre efficiency will come to an end. Most likely this will occur by 2025, if not earlier (Koomey and Nafziger 2015). Even the most sanguine engineers and industry spokespeople, those who seek to accommodate ever-rising market demand, are worried. Rarer are those engineers who call for truly sustainable, or self-sustaining, ICT that demands changes in public policy, industry practice, and consumer behaviour (e.g. Hilty 2015).

Why has so little attention been paid to the carbon footprint of streaming media, not only by the public but also by scholars? There are a few factors. Readers of this book are aware that what we call digital media can no longer be perceived as "virtual"—they are as actual as can be, and their travelling filaments exert a real, energetic and material impact on the Earth. However, a popular and scholarly understanding subsists that digital media are immaterial. Hence, most people believe that their streaming activity is neutral or even 'green.' Next, although ICT's electricity consumption is an urgent topic in engineering, very little of that literature reaches audiences outside the field. These communications, as we will explain, tend to be politicized.

When we tell people we're researching the carbon footprint of streaming video, they visibly recoil. Streaming media are exactly the sort of desired object that, though toxic, compels continued use, as it 'provides something of the continuity of the subject's sense of what it means to keep on living on and to look forward to being in the world' (Berlant 2010). A flow of videos on your phone, gaming online, online porn, video chats, and streaming movies, together with the gestures, habits, and sociabilities they engender, provide many people with continuity and reason to carry on. This is the case in wealthy regions and, with less resolution and reliability, many poor regions as well. Tech development and marketing, of course, profit from this subjective condition. Who wouldn't disavow the toxicity of what they can't live without?

The powerful brew of Moore's Law, undervalued electricity, the capitalist ideology of obsolescence, the hardy fantasy that the Internet is immaterial,[2] researchers' segregation and, as we will see, the pipe dream of energy efficiency, is a narcotic, under whose influence the hallucination appears feasible that billions of people can stream high-resolution movies for hours a day with no damage to the planet. With this chapter we aim to puncture tranquilizing notions that increasing technological efficiency will be able to absorb ever-higher rates of online media consumption.

Research in environmental sustainability tends overwhelmingly to focus on positive trends (Antal et al. 2020), rather than on unsustainable developments and rebound effects, and therefore to give a false sense that technical innovation walks hand-in-hand with sustainability. This is the case in environmentalist engineering, which can celebrate technical developments while neglecting or minimising the rebound effects of new efficiencies. In addition, we noticed that within the engineering literature, studies on optimising efficiency (for example by developing more efficient circuits, cooling, and network time use) are oriented toward a future in which worldwide ICT becomes more efficient.

However, laboratory experiments for future efficiency operate in a kind of magical realism mode, where ideal best-practice scenarios are taken as the norm on which projections are based, even though they are likely to be only partially, slowly, and unevenly adopted. There is a wide gap between ideal practices modelled in the lab and existing equipment. It is expensive to install new data centres and networks. These tend to be layered onto existing equipment rather than to replace them outright. Those inactive servers, also referred to as orphan or zombie servers, continue to consume electricity but do not provide services. They have been estimated to constitute 10–30% of servers in US data centres (Koomey and Taylor 2015) but also just 10%, which is still substantial (Shehabi et al. 2018); and to be responsible for 25% of ICT electricity use globally (Van Heddeghem et al. 2014). We note that the underestimation of inactive servers may be accurate for a wealthy country, like the United States, where institutions can afford a high turnover of equipment, but is less likely to apply to other countries.

Another reason why projections of efficiency are likely exaggerated is that they are modelled on practices in wealthy countries. The United States is far ahead of other countries in the use of hyperscale data centres. However, not all companies can afford to consolidate servers. Thus, these

[2] Among the many useful critiques of the ideology of media immateriality, see for example Blanchette (2011).

efficiency measures will be less applicable to less wealthy countries—though on the other hand, companies in newly IT-intensive countries like China and India will be in a position to begin with new, more efficient equipment (see e.g. Pereira 2020).[3] As a consequence, we fear that these expensive efficiencies will likely arrive too late to halt the alarming rise in ICT's proportion of global greenhouse gas emissions.

## ICT Carbon Footprint Calculations and Their Politics

As part of the Tackling the Carbon Footprint of Streaming Media project,* we surveyed 22 ICT carbon footprint calculators and nine calculators specifically for streaming video and identified issues with each of them. One problem is the definition of the system boundary. As well as data centres, networks, and devices, should the embodied energy (energy involved in manufacture) and disposal energy be included? What about the pollution associated with mining and disposal? Another problem we confronted is the wide variation in the estimated contribution of each of these to overall electricity usage. Studies also diverge as to whether to include the electricity expended in production of devices or only in their use. This is significant, especially in the case of small devices like mobile phones, 90% of whose electricity consumption occurs *before* they reach the consumer. And yet another is varying methods of data collection. The construction of mathematical models of the energy intensity of ICT, as well as models to predict changes in that intensity, is not beyond the understanding of a humanities scholar who remembers high-school math classes; but modelling is rife with opportunities for error.

Throughout the literature, the disparity between figures is enormous. We found a surprising degree of cherry-picking when it came to identifying data, modelling electricity consumption, and prediction. Like Maxime Efoui-Hess and colleagues at The Shift Project (henceforth, TSP), 'we quickly realized that much of the literature on the subject used figures from previous documents, very often without cross-referencing them with others, and without taking precautions regarding the limits of their validity' (The Shift Project 2019a: 12). As we researched more

[3] Reports on the market for hyperscale servers from companies like Cognitive Market Research and Markets and Research cost several thousands of dollars, so we will not be digging further into these figures in this chapter.

deeply, these issues turned out to reflect not only the regular turnover of scientific findings but also ideological agendas. We began to identify alliances, rifts, and tribes among the engineers studying this topic, even though all of them profess devotion to environmentalism and the role of ICT within it.

Earlier calculations of the carbon footprint of streaming media multiplied electricity intensity (in kilowatt-hours per gigabyte, kWh/GB) by number of users. Andrae and Edler (2015) and The Shift Project's (2019a) popularization of their calculation are the most influential examples. TSP developed an impressive and exhaustive calculator, first published in 2018 and updated in 2019 (TSP 2019a). It includes streaming media's boundary variables for the energy expended in mining copper and rare metals; production energy and use-phase energy for devices, networks, and data centres; and the $CO_2$ and other greenhouse gas emissions and environmental toxicity resulting from each of these. TSP concluded that streaming video contributes 1% of global greenhouse gas emissions.

Our report corroborated The Shift Project's estimate, albeit through different calculation methods, by triangulating their figures with those of other engineers who calculate streaming electricity consumption based on electricity intensity. Even though TSP does not give a calculation of electricity intensity (kWh/GB), our survey of streaming carbon footprint calculators effectively corroborates TSP's estimate. With one exception, all the calculators give comparable estimates of ICT's electricity intensity in kilowatt-hours per gigabyte, the standard for measuring the electricity consumption of online video.

Recently a consensus has developed that it is not feasible to separately parse out the contribution of streaming video to ICT. Power consumption of data centers, networks, and devices must be measured separately (e.g. Hinterholzer and Hintemann 2020; Andrae 2021). Some engineers (e.g. Malmodin 2021; Preist et al. 2019) argue that more data, as in streaming video and other data-intensive practices, does not necessarily result in more energy consumption. This is because networks and data centers are running 24/7, regardless of data use. It makes sense to calculate the electricity consumption of large actors like YouTube, and to calculate individual consumers' electricity footprint, including the production energy of their devices, but not to add up all individual consumers' hours of streaming. As network engineer Chris Preist explains, 'With current network technologies, if you send less data along it, in most cases it doesn't reduce the energy use. It's like an airplane: if you don't fly, the plane flies anyway, and so "not flying" only reduces emissions if it leads to less airplanes flying in the long term' (Burgess 2021).

That's not good news, though. ICT's infrastructure of networks and data centers was put in place for data-intensive applications like streaming and computation-intensive applications like AI and cybercurrency. The infrastructure is engineered to anticipate future use and spur consumer demand. The argument that streaming only slightly increases electricity consumption naturalizes the notion that infrastructure should be over-engineered, and it encourages additional high-data (and high-calculation) use that will require infrastructure to expand still more. The more we use them, the more the infrastructure will expand. *That* is why streaming is responsible for an increase in ICT's carbon footprint. Our goal can only be the equivalent of keeping more planes out of the sky: reducing the *expansion* of ICT.

## IEA Backlash

TSP's 2019 calculation made a splash in popular media, with coverage by the BBC, *The Guardian*, the *New York Post*, CBC, Gizmodo, and other news agencies. It quickly drew a rebuttal from George Kamiya, an analyst for the International Energy Agency (Kamiya 2020), which is oddly mean-spirited in tone. Kamiya could have simply criticised the science behind The Shift Project's model, and he does justifiably criticise assumptions and calculations in Andrae and Edler 2015 article, such as their over-estimation of bitrate. But otherwise, his article, available on the IEA website and widely popularised, deploys language, charts, and hyperlinks intended, as we will see, to downplay the carbon footprint of ICT and discredit The Shift Project in the eyes of a layperson.

First, Kamiya shifts the focus on Netflix, not all streaming video as TSP does, beginning with his title, 'Factcheck: What is the carbon footprint of streaming video on Netflix?'. Netflix is unusually energy efficient. As its content is hosted on content distribution networks near the end user, it does not have to travel through multiple networks (Lobato 2019: 95–97). Hence it is extremely misleading to subsume all streaming to the efficiency of Netflix. Second, Kamiya cites a 2014 study stating that streaming video's energy usage from data centers constitutes '<1% of the total video streaming energy use,' because streaming uses not data centers but *servers*, 'cloud-based IT equipment.'[4] This is simple word-play, perhaps exploiting the light and fluffy connotations of the term. Cloud servers *are* data centres, but they are more efficient because they respond to demand. Elsewhere Kamiya states that 'energy efficiency of data centres and networks is improving rapidly,' with an ungrammatical hyperlink, 'networks is improving rapidly,' to an article about the electricity efficiency of the Internet (Aslan et al. 2017). However, that article excludes data centres from the Internet's system boundary.

The article's mean-spirited character really comes to the fore when Kamiya takes advantage of the spoken error a member of TSP made in an interview—'megabits' instead of 'megabytes.' Based on this verbal error, Kamiya multiplied all TSP's calculations by eight—even though the bitrate error only affects calculations for devices—and produced a chart that makes them look ridiculous. Months later Kamiya published a chart with the corrected figure (Fig. 1).

After trashing TSP and citing the American ICT engineers who are most sanguine that the energy usage ICT is under control, Kamiya takes a more thoughtful tone, echoing the concerns of these same engineers that energy efficiency will soon run its course. By the end of the article, the IEA analyst is reiterating Efoui-Hess' recommendations to conserve bandwidth. But by that point most readers will have already stopped reading. TSP responded graciously to Kamiya's critique (2020-06_Did-TSP-overestimate-the-carbon-footprint-of-online-video_EN), politely considering each of his points in turn. Yet, a search on DuckDuckGo for 'The Shift Project' and 'streaming video' shows that IEA's strategies have succeeded in muddying the waters, because Kamiya's article shows up, in multiple iterations, right at the top.

So why is the International Energy Agency, the planet's most influential voice on energy policy, so determined to demolish this little French think tank? Why does it need to reassure the public that the energy consumption of ICT is not a concern? The organization advises governments and the private sector on energy policy, but it also represents the interests of energy producers worldwide. Clad in soothing graphics featuring a lot of blue and green, its public media emphasise that ICT companies are

[4] That study (Shehabi et al. 2014), comparing the environmental impact of DVDs and streaming, warned that the rebound effects of streaming in greater numbers of hours and higher resolution would overtake the initial environmental benefit of streaming.

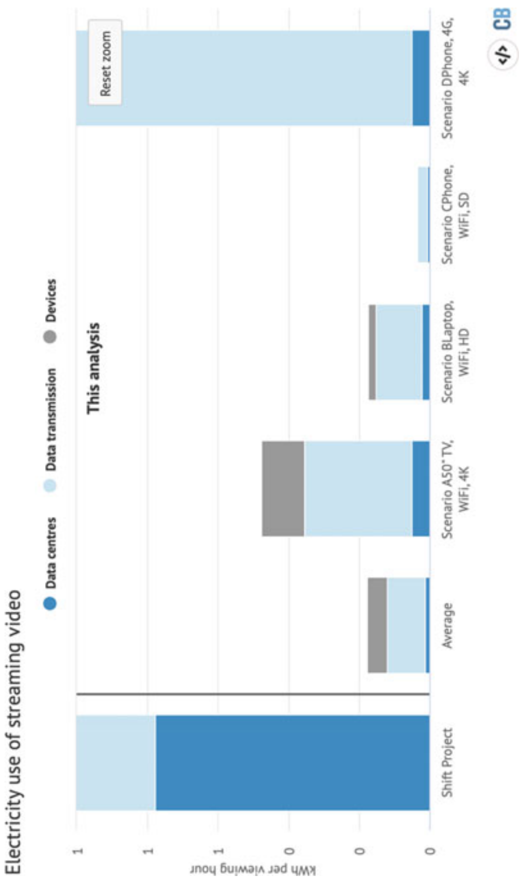


**Fig. 1** Chart by George Kamiya

investing in renewable energy—but hold back the fact that these renewables are usually complementing, not replacing, energy sources powered by cheap fossil fuel, as the demand on ICT continues to rise. The IEA's estimation of the worldwide energy consumption of data centres at 194 TWh in 2017 is very low compared to almost all reputable estimates, for example from GreenIT.fr, World Borderstep Institute, and Greenpeace (TSP 2019a). As the environmental research organization Oil Change International explains, the IEA's model of continued fossil fuel extraction, gradual conversion to renewable energy, and reliance on unproven technologies like carbon capture is designed to intoxicate investors. In fact, "Emissions under the IEA's alternative 'Sustainable Development Scenario' (SDS) would exhaust the 1.5-degree Celsius carbon budget by 2023 and the 2-degree budget by 2040" (Muttitt 2018: 4).

In 2021 the IEA announced a more radical schedule to wean the planet off fossil fuels, 'Net Zero by 2050' (International Energy Agency 2021). This appears to be good news. But the agency's timeline is slow—for example, halting sales of new internal combustion engine passenger cars by 2035, and phasing out all unabated coal and oil power plants by 2040—and it continues to rely on technological innovation currently in the laboratory stage to maintain the existing high level of consumption, rather than advocate an absolute decrease in energy consumption.

## Efficiency Fever Dreams

Koomey and Nafziger's article (2015) cited above, cheerily titled 'Moore's Law Might Be Slowing Down, But Not Energy Efficiency,' first appeared in print with the gloomier title 'Efficiency's Brief Reprieve' as noted in the article. Efficiency is demonstrated by the ratio "useful output per input." The efficiency of computing has increased impressively since the first mainframe computers, but, in an illustration of the Jevons paradox, ICT's consumption of energy and material resources has increased even more. Energy efficiency is the capacity to do more with less energy, and the ICT industry is working overtime to make all system elements more efficient. Unfortunately, the goal is not that data centres, networks, and devices do the same amount of labour for less energy, but that they can do more labour, in response to accelerating demand, for the same amount of energy.

The Jevons paradox leads us to question the purposes for which so much money and sweat has gone into Internet energy efficiency. Do people really need cheap bandwidth? In whose interest is the software bloat that forces smartphones into obsolescence after a couple of years? Is it really necessary to store multiple copies of video files, by far the bulkiest occupants of data centres worldwide?[5] In our research we have noticed that both scientists and industry model worldwide growing Internet bandwidth needs on the predictions of network company Cisco. These predictions are fantastical—for example, ultra-high definition virtual reality is seen as a major contributor to the 'significant demand for bandwidth and video in the connected home of the future' (Cisco 2020: 16). Yet, as we noted above, they have a sickening way of becoming factual, because the ICT industry strategies are based on their predictions, through planned obsolescence, market saturation, and corporate demands for government investment in new technologies. For the planet's connected population—whose numbers are rising as Internet and smartphone "market penetration" reaches people of the global South (Cisco 2020)—bandwidth-hungry behaviours like video calling, movie streaming, and multi-player online gaming have become habitual, and push their energy-modest antecedents into oblivion.

Meanwhile, data centre and network security is predicated on redundancy, the doubling of power supplies (traditionally by diesel generators and battery packs), networks, and other equipment that runs in standby mode to prevent momentary blackouts or system failures (Schomaker et al. 2015). These dramatically amplify electricity consumption. In most cases it is not an emergency to lose service. Only the marketing of instantaneity makes it seem so. Overpreparedness for worst-case scenarios—where the worst case is not, for example, the failure of the data center in a nuclear power plant, but the failure to deliver high-resolution streaming movies without lag time—is one of the foundations of ICT's disproportionate carbon footprint. As Tung-hui Hu suggests, infrastructure 'converts an imagined crisis in the future into present capacity' (2017: 83). Energy efficiency, then, is the ICT sector's defensive response to demands by telecoms and video streaming services (and AI and cryptocurrency) to underwrite the cost of their energy-greedy products.

[5] See also Cubitt (2017).

A soothing mantra that the energy demand of ICT can be managed through energy efficiency, renewable energy, and improved cooling of data centres is maintained by the International Energy Agency, the more sanguine engineers, and the Brussels-based Global e-Sustainability Initiative (GeSI and Accenture 2015). Sociologist-engineer team Janine Morley, Kelly Widdicks, and Mike Hazas (2018) interrupt this pleasant dream to make the unpopular point that 'the very idea to limit data demand, in any form, goes against the dominant paradigm in which digital services and government policies, alike, are designed' (136). They criticise a 2017 policy goal announced by the UK's Department for Digital, Culture, Media & Sport that 95% of UK households should have ultra-fast Internet of over 24 Mbps by 2020. After Selby et al. (2016), Morley and colleagues call policies like this 'invisible energy policies' (136), as they take no account of the energy demand and resulting carbon emissions of universal high-speed Internet. Sharing these authors' view, we critique the ideology of net neutrality and find that the anodyne reassurances of the IEA, other Industry organizations, and some ICT engineers barely mask an anxious solicitude to accommodate rising demand at any cost.

Similarly, as Kris DeDecker (2018) of the solar-powered website *Low-Tech Magazine* points out, 'The problem with energy efficiency … is that it establishes and reproduces ways of life that are not sustainable in the long run' (np). Organizations like the International Energy Agency treat energy efficiency like credit, which can be borrowed to offset ever greater energy consumption. He points out that energy efficiency policy ignores low-energy alternatives because efficiency is relative—'this electric dryer is more efficient than that one,' rather than 'this electric dryer is more efficient than hanging your clothes on a clothesline.' This comparison calls to mind the pleasures of hanging our clothes to dry: in mild exercise of reaching and fastening, the gradual transition from damp to dry; awareness of the circulation of air; if you're hanging them outside, the garments flapping in the breeze, the fresh scent of ozone on the fabric. Living with simple, appropriate technologies can help to ease people away from our formative dependency on toxic objects of desire.

Lorenz M. Hilty, one of the leading voices in computing sustainability, argues that computing needs to be not efficient but self-sufficient: using renewable energy, slowing the obsolescence cycle, and following the principles of appropriate technology. As he suggests, 'Contrary to the current "anytime culture", people living in a self-sufficient region would have to adapt their lifestyles to the pace of the renewable energy supply' (2015: 3). Hilty's aspirational scenario omits the competition among software providers that is one of the drivers of obsolescence: 'If the few basic functionalities that are needed in all types of application software would be more strictly and more universally defined, the innovation cycles for an infrastructure-type data center would slow down, and with them the hardware flow through the data center' (ibid.: 2; cf. also the quasi-socialistic Hilty and Pouri 2019). Another appealing scaled-down solution for the end of Moore's Law is approximate or inexact computing, a host of methods to reduces the energy and computational time required for tasks that not need accurate but 'good enough' results, such as machine learning and big data analytics (Barua and Mondal 2019).

Between the lines of Hilty and colleagues' proposals shimmers an ICT contribution to the Commons: if the capitalist compulsions for proprietary product competition, obsolescence, and immediate consumer gratification are subtracted—and, we would add, the customer-service-driven compulsion for redundancy—then indeed ICT can be sustainable. However, such a prospect to halt ICT's contribution to global warming is as unlikely as it is crucial, given that the vast majority of Internet traffic is powered by and serves shareholder-capitalist corporations.

What if the content flowing through data centres, networks, and devices could also be trimmed down to a 'few basic functionalities,' instead of forcing ICT to unsustainably contort itself to meet the crush of demand? If Netflix on a 4K TV is the electric dryer, what is the clothesline? So far, our suggested solutions to the unsustainable carbon footprint of streaming media have leaned toward, on the one hand, regulation and, on the other, radical anti-capitalist disruption. While both of these approaches have their place in the seemingly doomed attempt to achieve the goals of the Paris Climate Accord, medium-scale solutions, such as moderating our use of energy-intensive technologies, may have an incrementally larger effect.

Anthropologists Harriet Bulkeley et al. (2016) argue that climate politics carry out at a lived yet trans-individual scale that is material, embodied, and affective, at the nexus of *devices, desire and dissent*. In the case of streaming media, devices encompass playback media, networks, and data centres as well as policies, data plans, and the movies themselves. Desire, in the authors' Foucauldian perspective, constitutes socially framed forms of subjectivity: here, it might be "the 'gratified viewer' or 'the conscious viewer.' Dissent, unlike resistance, "captures … the more mundane, incremental, and provisional ways in which power is contested" (9) and may be expressed by devices and desires as much as human individuals or organizations. We can detect dissent in the slow loading of a movie on an overtaxed network, the fractiousness of engineers' debate about efficiency, and the smoke rising from an Oregon data centre from which US-made streaming content transmits to British Columbia. We concur with the authors' perspective that 'in order to act freely, the individual must first be shaped, guided, and molded into someone capable of responsibly exercising that freedom'; this is how dissent is informed. Nevertheless, we like to temper that moral imperative in a Spinozan fashion, by considering that it is joyful and pleasurable to form healthy assemblages. Doing so, small-file media and their human and nonhuman partners operate nimbly at the intersection of devices, desire and dissent.

Marx did not live to see the movies, and thus he did not anticipate the degree to which screen technologies mediate consumers' affective enchantment with newly invented needs[6] *for those very technologies*.[7] Although high-speed streaming media are less than a decade old, people of the connected world would rather go hungry than give up their streams. If we believe Cisco's predictions, these people are clamouring to be similarly enfranchised—although the ecologically sensible practice would be for those in wealthy regions to imitate the low bandwidth practices of the 'data-poor' (a term of Leidig and Teeuw 2015; see Marks and Przedpełski 2021). We heartily endorse Efoui-Hess and TSP colleagues' call (2019b) for consumers to stream less, stream at lower resolutions, watch physical media, and other alternatives to high-resolution streaming. We respect their suggestion that harmful video content should be moderated and that platforms' addictive designs, such as autoplay and recommendations, regulated. Their term 'digital sobriety' calls out the hangover-inducing indulgence of binge-watching. However, shaming consumers may backfire. We would like to share TSP's Epicurean call for moderation, while suggesting that moderation comes with its own pleasures.

[6] See Shaviro (2010), Ross (2011), and Beller (2018).

[7] Marx would see the high-definition video we stream, as with other commodities we consume, as "definite quantities of *congealed labour-time*" (1990: 130). See Cubitt (2017: 154–158). In this case, however, we are talking about nonhuman labour and the labour of the environment that has to absorb toxic emissions.

Small-file media, traveling lightly across networks and loading instantly with low-bandwidth connections, dissent from high-resolution expectations. They are embodied, intensive, haptic. They change the body of the streaming media consumer accordingly, inviting a leaning forward, an absorption, an engagement not only with the content but also with its planet-spanning technical support. Small-file media create a different kind of assemblage with their viewers whose affects are not lugubrious but pleasurable. After Berlant (2010) and Bulkeley and colleagues (2016), we need to acknowledge peoples' grief when contemplating losing instantaneous high-resolution streaming, and we hope that small-file media can be a soft handkerchief to catch their tears.

## Solutions: Small File Aesthetics and Politics

Moving from critical study to applicable solutions, this section addresses another of our research questions in more detail: "*How can we reduce the carbon footprint of streaming media through sustainable media art production*?" Streaming has given audiences (at least in wealthy regions) unprecedented access to niche, international, and archival works, and this means of distribution is indeed a boon for filmmakers. During the COVID-19 pandemic, filmmakers who preferred that their work be screened physically had to put up with less satisfying streaming versions, and understandably encouraged viewers to stream at maximum resolution. As we noted above, we are extremely concerned that these practices will become the post-pandemic 'new normal.' In addition, a brief overview of developments in mainstream contemporary art at the time of the pandemic indicates fantasies that high resolution, streaming media, the mixed reality spectrum, artificial intelligence, and machine learning act as the art media of the future. Such tech-driven deliria align with Cisco's predatory "prediction" of market demands.

Symptomatically, a recent TED talk held in August 2020 by AI artist Refik Anadol was called "Art in the Age of Machine Intelligence"—in a nod to Walter Benjamin's seminal 1935 essay "The Work of Art in the Age of Mechanical Reproduction"—as a way to describe the artist's enormous immersive visualisations of vast image data sets transformed via corporate AI and machine learning algorithms (sourced from Google) and quantum computers into 'data sculptures' (see Anadol 2020). In another context, renowned performance artist Marina Abramović has declared

VR (see Kane 2019) as a viable alternative to a live performance. Her 2018 VR piece *Rising*—available on the (notoriously malfunctioning) Acute Art X mobile app platform, which allows for the piece to be either streamed or downloaded—thematises the melting of polar ice caps, explicitly asking the audience to take steps combating the environmental crisis. And yet at the same time, the work glosses over the environmental impact that streaming or downloading the work generates. Here we can also mention the laughable, yet obscene, deployment of blockchain to produce unique works of digital art that sell, in some cases, for millions of dollars (as in a work by the artist Beeple in March 2021) and that, due to blockchain's current method of performing millions of calculations each time a new piece of information is added to the chain, generates a carbon footprint infinitely higher than that of a painting (Mora et al. 2018).

What can we do to replace the streaming and other unsustainable media that are overheating the planet? How can we inscribe the artistic image with environmental politics without overt didacticism? The annual Small File Media Festival founded by Laura Marks and hosted by Simon Fraser University since 2020 entices audiences and makers to forgo the desire for high-definition video and embrace low resolution and other small-file solutions as experimental and joyous media. The design of the festival forms part of an activist pedagogy aimed at raising awareness of environmental issues and changing existing behavioural patterns in an enjoyable way. The project's transdisciplinary crosspollination between art and engineering is evident in the inclusion of pages on the festival's website on both *aesthetic* and *technical* solutions for producing small-file media, highlighting the way art's aesthetic dimension is inseparable from its technical aspect. These solutions include using compression programs and algorithms such as Handbrake, ffmpeg, and H264 (while noting that compression too consumes electricity), lowering the frame rate, and combining still images with a rich soundtrack. Such necessary coupling of the aesthetic and the technical aspects resonates with recent approaches in philosophy and media theory, which see artistic and artisanal production from the point of view of philosophy of technology (see Sauvagnargues 2016; Hui 2017, 2020). In the same way, digital media and online streaming cannot be decoupled from their material support in Earth's environmental and human resources. Exposing the environmental impact of streaming media through small-file media making affirms therefore the critical aspect of aesthetic production postulated by Rancière, for whom "artistic practices are 'ways of doing and making' that intervene in the general distribution of ways of doing and making as well as in the relationships they maintain to modes of being and forms of visibility" (2013: 8).

The festival brief resonates with the rationale of the Knowledge Synthesis Grant, which identifies that living within the Earth's carrying capacity is 'one of humanity's most important challenges,' while acknowledging that 'human demands may be exceeding the absorptive and productive capacity of global ecosystems, with evidence indicating that pressures on several ecosystem services are near a tipping point' (Social Sciences and Humanities Research Council 2020). At a time when vast ecologies of data networks cross cities, continents and the earth's atmosphere, while a limitless innovation and connectivity is prescribed for environmental and social ills, the small-file media format is poised to question the prevalent ideology of exponential growth uncritically aligned with corporate interests by drawing attention to the finiteness of earth's resources: the earth's carrying capacity. The small-file format lends support to informatics scholars Nardi et al.'s (2018) proposed research framework of 'computing within limits' (LIMITS). As in Hilty and colleagues' critique of ICT engineering, Nardi et al. (2018: 86) point out that computing research is predicated on a specific vision of the future that entails an ever-increasing production and consumption while ignoring the planetary limits. The new research optics contests the inevitability of a future based on a 'growth-based worldview' (ibid.). Instead, 'LIMITS is concerned with the material impacts of computation itself, but, more broadly and more importantly, it engages a deeper, transformative shift in computing research and practice to one that would use computing to contribute to the overall process of transitioning to a future in which the well-being of humans and other species is the primary objective' (2018: 87).

Through its constraint-based brief encouraging digital media creativity within certain inescapable parameters, its compact online format ensuring minimal environmental impact and safety during the COVID-19 pandemic, and its carefully curated content, the Small File Media Festival resonates with the three key principles of computing within limits, reaffirming the signature transdisciplinary TCFSM perspective entangling art, science and technology. The principles are: (1) *Question growth*; (2) *Consider models of scarcity*; and (3) *Reduce energy and material consumption* (90–92). The first principle problematises the idea of endless growth which underpins the world's current capitalist economic system, calling for responsible, LIMITs-compliant innovation. The second recognises that current climate-related catastrophic events are not isolated incidents but outcomes of global environmental changes resulting from human economic activity, calling for recognition of scenarios of scarcity as viable potential futures. In turn, reduction of energy and material consumption entails an awareness of ICT's share in utilisation of the planet's dwindling resources, necessitating an accounting for resource use. At the same time, this must acknowledge the dynamics of the Jevons paradox, whereby more efficient technologies are not necessarily tantamount to a drop in absolute consumption because they may actually encourage greater resource use.

How does the Small File Media Festival implement those goals on the level of media production? First of all, by soliciting small-file artworks and requesting that the artists provide information on processing (encoding or transcoding) time, the festival focused on the work's actual materiality. In this it goes beyond the post-conceptual tradition at play in the contemporary art world that emphasises the virtual concept behind the artwork, as expressed in the artist's statement; something that resurfaces in mainstream computer-driven artworks such as those by Anadol, Abramović, and Beeple. At the same time, the festival's makers' forums, delivered by videoconference and facilitated in 2020 by festival team members and media practitioners Sophia Biedka and Joey Malbon, empowered the artists who submitted their works to the festival to share their creative and technological choices, creating a platform of outreach linking artists, curators, and interested audiences. The recordings of the forums are encoded into the small-file format and made available as a free resource on the festival website.

Secondly, the small-file works submitted to the 2020 festival inspired the curatorial team to develop nine different thematic strands. These strands in part stemmed from the brief and in part emerged in a dynamic dialogue with the artworks. The nine programs—'All It Takes,' 'Sensuous Pixels,' 'Missing,' 'Danse Macabre,' 'Feeling the Earth's Pulse,' 'Universe In your Pocket,' 'Mind Candy,' 'Seriously Small Files,' and 'Steamy Bits'—furnish inspiration for articulating a corresponding model of multi-levelled material and affective engagement in environmental activism through small-file media. Inspired by their respective curatorial strands, the model comprises nine interconnected calls to action, which enter into dialogue with Nardi et al.'s (2018) key principles of LIMITS research. We describe some of these below:

(1) *Present alternative future scenarios to growth!* Turning away from a globalised, unified and Western-centric futurism that disregards the past, small-file media, within the space of their tiny formats, explore different models of the future, and temporality in general, where the past is not discarded but becomes an illuminating, future-oriented thread woven into the present. This can be seen in Hân Phạm's *Once Upon a Time* (Vancouver, 2020, 5:17, 5.67 MB, 14:000 processing time) where a tiny bedroom blends into a pixelated lo-fi sequence of vivid new and old-time cine-images of the streets of Saigon. Phạm's pieces echo Quantum Black Futurism's evocation of a motto from Amiri Baraka (1995: 255): 'the future is always here in the past.' Small-file media become a medium of storytelling, a migrant image which reclaims for itself a space where temporal dimensions collapse and influence one another in unpredictable ways.

(2) *Create affective and haptic modes of encounter!* This aspect corresponds to a strand of small-file movies which explore the sensuous qualities and the tactile, visceral sensation afforded by the medium itself. As Marks (1998) points out, haptic visuality reconfigures the eye as an organ of touch and 'encourages a bodily relationship between the viewer and the video image. Thus it is not proper to speak of the *object* of a haptic look so much as to speak of a dynamic subjectivity between looker and image' (332). One way that small-file media create affective and haptic modes of engagement is by exploring the properties of the pixel and the sensations produced by its colour modulations, wave-like movements, and Tetris-like distributions. Derek Kwan's *Bombay Beach* (2020, 2:30, 4.9 MB, 2′30″ processing time) creates a tactile film where a frame filled with seething seafoam resonates with a blooming of rectilinear pixel groups. Colloids—these threshold formations between solid, liquid and gas—are revealed as a form of pixelation, and the pixel is revealed as a form of nature's informatics.

(3) *Disrupt perceptual and behavioural clichés!* Small-file movies set out to diagnose fossilised habits and ideologies naturalised as truth, such as the popular crutch of Moore's Law. Works in this category lodge themselves in gaps in seamless internet connectivity and their associated loss of image quality, in instances when the narrative arc stumbles and stutters, in moments of communication breakdown and social alienation. For example, Quin Martin's

*Extras* (Vancouver, 2009, 2:41, 4.8 MB, 1:33 processing time) is a low-frame rate Lynchian neo-noir story where two inept detectives investigate the case of double homicide: the murder of a woman and the loss of pixel quality. Shot at a nondescript diner, the movie features a conversation between the two characters discussing the case at hand. Their amateur idiosyncratic delivery, paired with the low resolution of the filmic image, creates a sense of artificiality and exposes both the narrative clichés at play in detective movies and the viewer's appetite for high resolution. This low-key, understated film uses disruption as a powerful strategy that culminates in the characters' metatextual (and humorous) realisation that the case photos they are discussing 'are from a different TV show.'

(4) *Accelerate imagination by juxtapositions of imagery and themes!* Small-file movies harness the conditions of capitalist image-saturated societies and their viral flows of imagery to create dazzlingly imaginative intermedia recombinations capable of addressing the contradictions and complexities, as well as the looming fears and concerns, of the pestilent Covid-19 era. Hany Rashed's *My Instagram* (Cairo, 2019, 0:35, 6 MB, 15:00 processing time) is a tiny piece of Instagram pop art collage—fun and ghastly at the same time—which sees a figure scream from a Cairo apartment block while a pixelly skeleton performs a danse macabre.

(5) *Bring the cosmos to your doorstep!* These at once robustly materialist and spiritual pieces transform the small-file medium into a meditation pondering the mystery of how the format's extreme compression of digital information and human experiences can at the same time expand into an expression of more-than-human infinity. This aspect of small-file media pedagogy is evident in a string of movies at the 2020 festival where a small object, impression, or quotidian experience can be affirmed as a part of the earth that affords an opening to the cosmos. A wonderful example of this is furnished by Azadeh Emadi's *Entangled Orb* (Glasgow, 2020, 5:07, 4.8 MB, 8:00 processing time) where a string of impressionist macro images of the everyday experiences pulsating with primary colours, such as a captivating, trembling frame featuring a magnified flutter of the eyelash, become vast universes and distant galaxies.

## Conclusions

Our call for work for the Second Annual Small File Media Festival (2021) took a merry, punkish tone. 'The SFMF makes HD, 4K, and 5G look unnecessary! Unsexy! So pre-pandemic! …. Small-file movies are not faithful, they're promiscuous! <3.' We are saying this as the influential new media organization Ars Electronica (2021) proudly launches its *8K Future Project* advertised as '7680 × 4320 pixels, ultra-high definition and hyper-realistic moments', asking. 'What unprecedented possibilities can 8K technology integrate into everyday media use?' Our endeavour to construct a new desire, the desire for the small, assembles with a newly reflective understanding of devices and a newly celebratory matter of dissent. Of course, very few people will fully embrace our playful challenge. Small-file media operate as a provocation, an affective reset, a rogue and tender materialism.

In 2021 we are marketing the festival to online communities of genre fans—sports, pornography, ASMR videos, meditation videos, cooking shows, even Netflix-type series with our 22 MB 'bingeworthy' category—and inviting them to experience small-file versions of their favourite media. Porn lovers (for example) may not switch to small-file porn, but they may enjoy the joke—porn can be just as effective even if you can't see it very well (Marks 2020)—and perhaps download our best practices, or even invest in some DVDs. Consumers of meditation videos may be attracted to a reconfigured subjectivity—calm, present, and carbon–neutral—and find that a highly haptic or audio-only stream that does less harm to the planet really makes them feel better.

Small-file media have an emergent politics that assembles audiences, media of all sorts, telecoms, network hops, compression algorithms, carbon dioxide, mourning, exhilaration, and numerous other entities into a nimble, polymorphous coalition. We intend this coalition to shape a more mindful media culture that rejects the assumption that larger, faster, and ubiquitous media are better and to curb the dangerously expanding carbon footprint of ICT.

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Makonin at Vancouver's Simon Fraser University (SFU), and joined by engineer Alejandro Rodriguez-Silva and media scholar Radek Przedpełski. As part of the project, the group surveyed the engineering and industry literature, evaluated the disconcertingly disparate measurements of the ICT sector's carbon footprint, and prepared a report for lay audiences. Full report: https://www.sfu.ca/sca/projects---activities/streaming-carbon-footprint.html. Evidence brief: https://www.sshrc-crsh.gc.ca/society-societe/community-communite/ifca-iac/evidence_briefs-donnees_probantes/earth_carrying_capacity-capacite_limite_terre/marks_makonin_przedpelski_rodriguez-silva-eng.aspx.

In order to publicise the project's findings and to promote sustainable experimental media production, Marks founded the annual Small File Media Festival hosted by SFU's School for the Contemporary Arts. This online festival (https://smallfile.ca/), which took place in 2020 and 2021, invited artists to submit movies of no more than 5 megabytes in size and 5 minutes in duration.

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