4. Streaming against the Environment

Digital Infrastructures, Video Compression, and the Environmental Footprint of Video Streaming

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Abstract

Building on an infrastructural approach, this chapter investigates the environmental impact of video streaming. It clarifies some of the less obvious relationships between media infrastructures, video compression standards, and electronics supply chains and demonstrates how their interactions unfold material effects on the environment. Complicating recent critical research on data centers, we posit that existing models for calculating the ecological footprint of video streaming cannot capture its full extent and advocate for an interdisciplinary approach to data, computation, and infrastructure. This approach informs our argument that the development of new compression standards redistributes environmental responsibility in a way that benefits streaming providers and data centers at the expense of end users and hardware manufacturers.

Keywords: video streaming, video compression, infrastructural inversion, environmental footprint, data infrastructure

In 2020, while many were staying at home due to the COVID-19 pandemic, internet traffic rose to an unprecedented high. Studies reported momentary surges of web conferencing, gaming, and video streaming of up to 300% and a general increase of internet traffic by about 40% above the expected annual growth (Feldmann et al. 2021). Internet service providers had to take short-term measures and increase their capacity. The European Commission even asked streaming services and internet users to relieve the pressure on internet infrastructure (European Commission 2020), and Netflix and YouTube lowered their bandwidth demands to help prevent data overload.

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This bandwidth crisis foregrounds the physical realm of data traffic upon which digital culture rests. While diaphanous metaphors like "the cloud" or "streaming" evoke the impression of immateriality (Carruth 2014; Blanchette 2011), media theorists have long been pointing out that all data is bound to hardware (e.g., Kittler 1995). In this chapter, we take up on these insights and investigate the materiality of video streaming. We emphasize computational processes and their impact on the environment, thereby echoing Paul Edwards (2021), who views algorithms as a core element of digital infrastructures.

As part of our argument, we posit that existing models for calculating the greenhouse gas emission of video streaming cannot capture the full extent of its ecological footprint. To better understand the environmental effects of our digital media culture, it is important to develop approaches that bring together perspectives from various disciplines including media studies, critical data studies, science and technology studies, environmental studies, and information science. Such an interdisciplinary approach informs our argument that new compression standards benefit streaming providers and data centers at the expense of increased energy use on the users' side. This allows streaming services to gradually divert environmental responsibility to consumers and hardware manufacturers, even as they continue developing and advocating for increasingly energy-hungry video standards.

Following Lisa Parks and Nicole Starosielski (2015) and aligning methodologically with what science and technology studies call "infrastructural inversion" (Bowker et al. 2009, 98), we are taking on an infrastructural perspective to emphasize the materiality of video streaming and understand how the physical and sociotechnical arrangements of electronic devices, data centers, and other network facilities interconnect with other technical systems, computational processes, and technological standards.[1,2] Such an approach is not only suitable to render transparent technical systems visible, but it also explores the environmental impact of digital media culture. Previous research into the ecological footprint of digital media has focused, among other issues, on the extraction of raw materials and the enormous amount of waste that the rhetoric of immateriality usually conceals (e.g., Gabrys 2011; Maxwell and Miller 2012; Cubitt 2017), but our goal is to clarify

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[1] Such an inversion can be understood as a "figure-ground gestalt shift" (Star and Ruhleder 1996, 113) that aims to make infrastructures visible. In science and technology studies, this is one of the methods to study them. See Bowker et al. 2009, 98.

[2] The infrastructure of video streaming is what Paul Edwards calls a second-order system (2021, 317), because it relies on other telecommunication and electricity infrastructures.

some of the less obvious relationships between video compression standards, media infrastructures, and electronics supply chains and demonstrate how their interactions unfold material effects on the environment. More specifically, we posit that video compression algorithms play a crucial role in the ongoing shift of the environmental costs of streaming from data centers to end users. Conceptually, this claim ties in with Jonathan Sterne's (2012, 250) suggestion that research on data compression techniques can serve as a point of entry toward richer theories and histories of media. The consideration of tangible material elements (such as raw materials or electronic waste) is important, but we should also not lose sight of computational processes, whose environmental effects, as we argue, cannot be fully captured by tools like carbon footprint calculators. The situation in the Netherlands offers a particularly compelling example, because it demonstrates the complex position of data centers in the debate.

After briefly delineating the infrastructure of video streaming and addressing some recent controversies surrounding Dutch data centers, we discuss the complexity of calculating the CO_2 footprint of streaming and then focus on the environmental ramifications of compression standards, addressing in particular the notion of compression efficiency that drives the development of new video standards.[3] We show how streaming services' standards-making activities result in increased energy consumption by end devices. In effect, each new compression standard gradually shifts the responsibility for sustainable action away from data centers and streaming services and onto viewers and end users. Our argument touches upon the limitations of existing ways of calculating and conceptualizing environmental impact, and we hope to increase awareness of the role our media habits and media devices play in contributing to energy consumption.

The Infrastructure of Video Streaming

Infrastructures are socio-technical systems that provide critical services to our society (Edwards 2021, 314), with power grids, water supply, railroads, and telecommunication networks as archetypal examples. Infrastructures emerge from an interplay of technology and socio-political factors (such as social transformations, consumer demands, regulations, and policies) and comprise a variety of elements, including technologies, institutions,

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[3] For more information, see https://www.washingtonpost.com/climate-environment/2022/05/28/meta-data-center-zeewolde-netherlands.

financial schemes, built environments, work processes, etc.[4] Once they are built, infrastructures sink “into an invisible background”: they are “just there, ready-to-hand, completely transparent” (Star and Ruhleder 1996, 112), unless a breakdown, like a power outage or the collapse of a bridge, makes them visible.[5]

The infrastructure that facilitates video streaming is similarly invisible and taken for granted. However, an increasing interest in the physical, social, and political materiality of media distribution is rendering it more and more visible (e.g., Holt and Sanson 2013; Lobato 2019). Data centers have become a preferred object of study when investigating digital infrastructures, not least because they are the site of intersection for a range of pressing issues such as data mining, large-scale surveillance, geopolitics, and data sovereignty. Data centers have provoked discussions about the corporate use of public services (Hogan 2015; Brodie 2020) and stimulated reflections on land use and physical space (Johnson 2019; Vonderau 2019; Mayer 2020), on power sources and cooling systems (Hogan 2015; Velkova 2016) and on the energy demand of machine learning (Rohde et al. 2021; Tarnoff 2020).

Data centers’ environmental impact is ambiguous, particularly in the context of video streaming, as we will discuss in more detail below. On the one hand, data center operators in some regions, such as the Netherlands, are increasingly committing to carbon neutrality and energy efficiency (DDA 2020; Kamiya 2020). On the other hand, their corporate environmentalism has been criticized as a strategy to “reduce, refuse, and redistribute the relations between carbon and data,” which preempts ecological critique (Pasek 2019, 2). Research on, for example, failed plans for the reuse of data center–generated waste heat in the Netherlands (van Kessel 2021a) or Anna Pasek’s probe into Microsoft’s renewable energy purchases and system of carbon offsetting (Pasek 2019) have demonstrated this point convincingly. Focusing on video compression, we argue that video streaming services are similarly reshaping environmental relations by passing on responsibility to hardware manufacturers and end users. Laura Marks et al. (2021) advocate that in addition to data centers, end user devices must be included in calculations of the energy consumption and carbon footprint of video streaming. Somewhat counterintuitively, this is not always the case, as consumer

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[4] Brian Larkin points to the conceptual unruliness of infrastructures that are things and, at the same time, the relation between things (2013, 329). Scholars of science and technology studies emphasize this relationality as well, since the “work of one person is the infrastructure of another” (Bowker et al. 2009, 98); see also Star and Ruhleder (1996, 122–23).

[5] Repair and maintenance are similar moments that make infrastructures visible; see Henke and Sims (2020).

devices are often seen as outside the internet system boundary. We concur with this view, and in the following analysis of streaming infrastructure and compression algorithms, we provide further reasons as to why end devices are critical in these considerations.

Public and academic interest in streaming infrastructures has been growing in recent years, and the global chip shortage caused by the COVID-19 pandemic has prominently drawn attention to some of its lesser-known elements, such as semiconductor manufacturers. But the topography of streaming also comprises other elements that continue operating in relative obscurity and have yet to be addressed by critical humanities scholarship. To sketch the close entanglements between hardware, data, infrastructure, and standards, let us briefly recapitulate a part of the life cycle and supply chain of a chip, like the graphics processing unit that a smartphone or television might use to decompress video.

A chip manufacturer—a company such as Mediatek or NVIDIA—designs the chip hardware. Chip manufacturers closely follow the development of video compression standards (in fact, they might actively take part in their creation, as NVIDIA does) and will design their chips to allow the processing of new and emerging video formats. Neither Mediatek nor NVIDIA physically produce any chips but outsource their fabrication to semiconductor foundries like TSMC in Taiwan. The chip might be bought and further handled by a hardware and consumer electronics manufacturer like MSI or Sony, who assembles it into larger components such as graphics cards, smartphones, or televisions, or by an integrator, who installs firmware on devices such as set-top boxes. Telecommunications and pay television companies offer such devices with their services, which often include partnerships with streaming providers such as Netflix. A company like Netflix, in turn, purchases computing power from data center operators like Amazon Web Services. Data centers then deliver video to end users through various forms of wired and wireless infrastructures, which are maintained by network operators. The Netflix app fetches video signals from the data center, which are processed by the chip and displayed on your screen.

All these actors maintain complex logistical relationships with each other, and many of them enter partnerships to develop new industry standards. These partnerships take the form of consortia such as the Alliance for Open Media, whose influence on the energy use of our electronics we address further below. The standards development process results in new video formats through which economic cooperations and rivalries are negotiated (Volmar 2020). At this point, what is important to us is that video compression standards, despite seeming like abstract documents that only deal with the computation of data as disconnected from issues of materiality, actually exert significant material effects on the environment.

As we show in the following section, grasping and calculating the full extent of these material effects is troublesome. The complexity of the streaming infrastructure and supply chains outlined above, as well as their relationship with, and dependency on, other technologies, complicates the assessment of video streaming's environmental impact. By focusing on video compression, we want to emphasize that streaming services like Netflix or YouTube are not only built on top of (landline and undersea) cable communications systems, cellular networks, and power grids. Video streaming is also enabled by standards, protocols, and compression algorithms and software—which all need to be factored in when taking on an environmental disposition.

Calculating the Environmental Impact of Video Streaming

Modeling the environmental footprint of video streaming is notoriously complex. It is difficult to quantify the pressure on landscape, water quality, and biodiversity that data centers, cable installations, cooling systems, and energy supply place on the environment. Even when it comes to carbon emissions and energy consumption, estimates of CO_2 emitted and kWh consumed per hour of video streaming differ by up to three orders of magnitude, depending on whom and when you ask (Aslan et al. 2018; Marks et al. 2021).[6]

A comparison of two recent sources illustrates the scope of the uncertainty. According to a white paper by the London-based Carbon Trust (2021), streaming one hour of video in Europe produces 55g of CO_2-equivalent emissions. Obringer et al. (2021) found a value of 441g for the same activity, more than eight times as much.[7] The large discrepancy between these studies, both of which claim to be using up-to-date data, can be partially explained by differences in the underlying assumptions, such as disparities in the proportion of sustainable electricity in a particular region's energy mix or emission factors. But these differences matter not only in a numerical sense. It is important to recognize that they are also used to underscore

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[6] Existing models have been criticized for a range of reasons: severely over- or underestimating variables like bitrates and wattage, overlooking parameters like device type and screen size, building upon obsolete data, mistakenly correlating data traffic with energy use, erroneously extrapolating energy use growth from storage capacity growth, or failing to account for energy efficiency gains (Kamiya 2020; Masanet et al. 2020; Carbon Trust 2021).

[7] The difference of 386g corresponds to the CO_2 emitted by driving 3.1 kilometers in a recently manufactured passenger car (European Environment Agency 2021).

specific attitudes toward climate action: Obringer et al. use their numbers to emphasize the need for regulatory intervention, whereas the Carbon Trust report concludes that “the carbon footprint of viewing one hour of video streaming is very small compared to other everyday activities” (2021, 8), implying that the video streaming industry does not merit immediate attention. It comes as no surprise that reactions in high-profile media outlets to scientific research have been just as contradictory, covering the entire spectrum from alarmist to appeasing (e.g., Daigle 2020; cf. Kaufman 2020).

Reliable data about the environmental impacts of video streaming are not only difficult to obtain; they also become obsolete very quickly. Changing consumption patterns, fluctuations in power production and demand, and the rapid succession of new technologies confound existing models and necessitate continuous adjustments in the calculations. This can be exemplified by the energy consumption of Dutch data centers. Statistics indicate that global internet traffic has tripled, and data center workloads have doubled since 2015. But thanks to improvements in energy efficiency, data centers’ energy use has remained constant (Kamiya 2020). Some data center operators have also achieved remarkable improvements in decarbonization. The Dutch Data Center Association reported that 86% of its data centers operate on renewable sources, even reaching 99% in the Amsterdam region where three quarters of the nation’s operators are located (DDA 2020).[8]

While these numbers are laudable, they hide other environmental frictions. For one, data centers rely on the common grid, and their energy consumption places a large burden on an electrical infrastructure already at its limit in regions like Amsterdam.[9] Furthermore, there are fears that the staggering amount of cooling water that Dutch data centers consume could jeopardize water supplies (van Kessel 2021b). This is a major risk factor in a country where groundwater quality is deteriorating and water shortages are increasingly common (van Engelenburg et al. 2021). Furthermore, ambitious plans to reuse data centers’ residual heat to warm homes and offices frequently fizzle out. Data centers tend to opt to be physically close to electricity sources and cable landing points. Such locations are often unsuitable for heat networks.[10] And thus, while waste heat reuse is often

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[8] Dutch data centers purchase their green energy via certificates, an industrial practice that Pasek (2019) criticizes as negating the environmental impact while driving up the grid demand and therefore failing to reduce carbon emission.

[9] Data centers constitute 4.2% of the country’s entire electricity usage, according to 2019 estimates from the DDA and Statistics Netherlands.

[10] In addition, the relatively low-temperature heat that data centers generate also makes them uninteresting for many heat networks.

touted as one of data centers' great contributions to a more sustainable resource economy, hyperscale centers such as the one built by Google in the port of Eemshaven simply dissipate heat into thin air (van Kessel 2021a).

These environmental and infrastructural complexities pose methodological hurdles. Proper impact assessment not only needs to be multilateral by considering greenhouse gas emissions and energy consumption as well as water and land use, as Obringer et al. (2021) have argued. It also needs to handle temporal intricacies that necessitate constant adjustments to the data, and it must deal with spatial challenges, such as national and regional differences. Calculating for collateral impact on other, underlying infrastructures—electricity or water supply, for instance— demands the consideration of even more comprehensive factors. Ultimately, these complications only underscore the necessity of interdisciplinary research and of relational thinking regarding the character of digital infrastructures beyond what is usually considered to be "the media" or "the internet."

But alongside questions of infrastructure on the macro scale, microscale computational processes also contribute significantly to the total environmental effects of video streaming, as we show in the following.

The Material Effects of Video Compression

Compared to sound or still images, video requires an enormous amount of data to look reasonably good. Such large amounts of data are impractical to store and distribute, because storage space and network bandwidth is limited. Shrinking these data means they can be delivered to end users much more easily. Lossy compression—that is, compression in which some of the original information is removed permanently—ensures that a video recording you made with your phone is 30 rather than 3000 MB big. The algorithms that achieve this are a vital element of streaming infrastructure.

Scientific discourses on video compression frequently feature two divergent notions of efficiency. A brief discussion of these terms is useful in articulating the role of compression in what Allison Carruth (2014) calls "the micropolitics of energy." Together, the concepts of *computational* efficiency and *compression* efficiency can help us interrogate the chain of relationships that connects calculations inside a processor to large network and electricity infrastructures, and to an even larger political economy of video streaming and global hardware supply chains.

The basic principle of lossy video compression is that much of the visual information in a moving image can be discarded without becoming noticeable to humans. Specialized algorithms are used to identify and then eliminate these redundant data. On the most elementary level, this process boils down to adding and multiplying numbers. Algorithmically, any given compression method might be realized with more or fewer operations in (more or less) efficient ways. An algorithm that solves a problem with fewer operations is said to be more computationally efficient. A good example of this is a mathematical tool known as the discrete cosine transform (DCT). The DCT and its derivatives are used to reduce the amount of data in practically every major digital audiovisual format, from JPEG images and online video to DVD, Blu-ray disks, and digital TV broadcasting standards. The DCT can be computed in many ways, some of which are faster than others. Algorithms can be sped up with various mathematical shortcuts that exploit the structure of the processed data, take advantage of certain properties of trigonometric functions, or utilize knowledge of the processing hardware—for example, how much longer a specific electronic circuit needs to multiply two numbers as opposed to adding them.

The savings among different algorithms can be minuscule in a relative sense. For instance, the 2D Arai-Agui-Nakajima DCT algorithm from 1988 requires 464 additions, the Feig Fast DCT (1990) requires 462, and the Generalized Chen Transform (1994) requires 608 additions but no multiplications (Kuhr 2001). But these algorithms are run thousands of times for every single frame of video that flickers across our screens. With trillions of calculations performed daily on the scale of visual culture, a difference of two additions per block of data translates into enormous savings in computation time. In this way, the microtemporalities of compression scale up to tangible and environmentally significant fluctuations on the level of infrastructure in the form of increased or decreased electricity demand.

Aside from computational efficiency, the interrelated notion of *compression* efficiency is equally environmentally significant. Compression efficiency refers to how much smaller an algorithm can make a video file at a given image quality. Streaming services have an incentive to strive for the highest possible compression efficiency, because smaller video files can be delivered to end devices faster and counteract what Neta Alexander (2017, 8) has called "digital dams"—the experiences of network latency, delay, and buffering.

New compression algorithms are constantly being developed, and the process of standardizing, implementing, and promoting them carries significant vested interests. Companies like Netflix are continuously optimizing compression efficiency, re-encoding their catalogs as more efficient techniques emerge, and performing adjustments to encoding parameters to decrease file sizes and increase perceived image quality.[11] As with computational efficiency, there are numerous strategies for increasing compression efficiency. For example, if the encoding algorithm is taught to "understand" the notion of film editing, it can recognize cuts in moving images and operate with individual shots, thus compressing motion more efficiently. The result is a video file with a smaller size, which means less buffering and data consumption.

However, from an environmental disposition, the salient point is that more "efficient" compression schemes are also more complex and therefore consume more energy (Lin, Liu, and Liao 2010; Sharrab and Sarhan 2013; Ejembi and Bhatti 2014; Monteiro et al. 2015; Uitto 2016; Kränzler, Herglotz, and Kaup 2020). The encoding device draws more electricity in order to compress data more heavily. When the file is decompressed during playback, the decoding also generally requires more power from a television set and drains the batteries of a mobile device faster. These batteries then need to be recharged more often and their capacity diminishes more rapidly, decreasing the device's lifespan and accelerating the rate at which electronic waste is produced. The speed of video streaming is paid with environmental costs that ultimately contribute to the warming of the planet. This is "the materiality of media heat" (Starosielski 2014) at work—the concrete effect of video compression on the physical world.

Data centers play a comparatively minor role with respect to compression and the accompanying energy consumption, despite their environmental costs mentioned above. Data centers and content distribution networks encode and store the video files that eventually get delivered to end users, but the computational work of decompression is performed by the billions of devices at the end of the delivery chain. This is one of the reasons why end-user devices are responsible for about half of the energy consumption of all digital services (DDA 2020; Malmodin and Lundén 2018).[12] Our television sets, laptops, smartphones, gaming consoles, and set-top boxes consume the largest proportion of electricity required to view video. And with each more complex generation of video compression standards, they consume progressively more than the rest of streaming infrastructure.

The streaming industry capitalizes on the growing processing power of these devices. By leveraging computationally demanding compression algorithms, streaming providers ensure that the data centers and cable

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[11] For concrete examples, see Sole et al. (2018) and Mavlankar et al. (2020).

[12] Some recent research claims that data centers account for less than 1% of video streaming's total emissions and energy (Carbon Trust 2021).

and cellular networks they rely on handle ever smaller file sizes. But the highly compressed files are more energy-intensive to decode and, consequently, magnify the end users' overall share in energy demand.[13] Simply put, streaming providers, network operators, and data centers all benefit from the increased speed and lower bandwidth demands of a smaller file, but the users have to compensate by expending more energy to compute the equations needed to play that file back.

Together with intensifying calls for environmentally aware consumption, such as the EU's Green Deal or the UN's Sustainable Development Goals, streaming users are increasingly being prompted to assume responsibility for their rising energy use. Simultaneously, the burden of sustainable action gradually seems to be moving away from streaming providers. While vaunting a largely decarbonized or carbon-offset electricity supply on their own end (e.g., Netflix 2020), streaming services can point the finger to hardware manufacturers and divert attention to the need for more energy-efficient technology (e.g., Carbon Trust 2021, 70). Ultimately, this reaffirms Julia Velkova's conclusion that "data centre operators [and streaming services] do not offset the environmental problems that the industry generates, but rather reshape the discourse around it" (2016, 8).

Such deflections may make it seem as though streaming services and hardware manufacturers were operating in different industries. In truth, they are closely interconnected, as large streaming providers invest considerable effort into the development of new compression standards, and new standards frequently necessitate new hardware. The case of AV1, a recent compression codec geared toward ultra-high resolution video, is useful to demonstrate the relationship between standards-making, infrastructure, and electronics supply chains. AV1 was created by the Alliance for Open Media (AOM), an industry consortium developing new, more "efficient" compression standards whose members include, among other tech giants, Amazon and Netflix. Netflix, YouTube, and other major video platforms began streaming videos in AV1 in 2020. Like most high-complexity codecs, AV1 is very energy-inefficient and impractical to decode with software and thus requires specialized hardware with a suitable chip. Google, another

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[13] There are some established and emerging strategies that counteract compression standards' growing hunger for energy, such as fast algorithms, efficient display technology, code optimizations, low-complexity enhancements to existing codecs, or coding practices that consider the energy cost of decompression already during encoding (Herglotz, Heindel, and Kaup 2019; Corrêa et al. 2018). But these measures are unlikely to offset the energy needed to power increasingly bright screens with exponentially swelling resolutions, frame rates, and bit depths, as well as the surge in the sheer number of screen devices.

member of AOM, has reportedly mandated that all new television sets with the Android operating system support the codec (Rahman 2021), further underscoring how mutually intertwined software and hardware are. The new compression standard thus not only transforms how audiovisual data is processed on a computational level. It also reinforces the consumptive cycle of material extraction, electronics production, obsolescence, and waste. Despite their public commitments to sustainability, tech companies and streaming providers thereby contribute to an ultimately unsustainable electronics supply chain (c.f. Gabrys 2011; Maxwell and Miller 2012; Cubitt 2017).

Conclusion

From an infrastructural approach, it becomes clear that inquiries into the environmental effects of video streaming fall short if terms like "Netflix" or "data center" are considered self-contained entities. Digital infrastructures are highly relational; they consist of a multitude of interacting elements. As second order systems, they are based on already existing infrastructures, and they are unruly. To comprehend the infrastructure of video streaming and its environmental impact, we therefore need to take a wide range of elements and relations at varying scales into account: cable networks, compression algorithms, telecom companies, pay television operators, browser and operating system developers, industry consortia, and national energy policies, but also more obscure actors such as chip vendors, set-top box firmware integrators, and others.

Naturally, the complexity of such an assessment demands interdisciplinary research. This chapter has indicated how media studies and science and technology studies can productively inform critical inquiries into data. As humanities scholars, we can contribute by, for example, keeping track of trends in the media industry, observing the development and standardization of new forms of compression, and calling critical attention to discourses and practices that transfer, manipulate, and redistribute environmental responsibilities.

Currently, the compression standards development process at AOM is primarily driven by cost considerations and the media companies' aversion to the complex and costly licensing structures that the MPEG standards family was encumbered with. While open-source standards are a positive development, sustainability—not cost—should be the principal value and fundamental driving force in standards-making and governance.

And despite our criticism of corporate strategies in this chapter, we want to stress that our own behavior as scholars and consumers matters and has a significant impact as well. Not only can we make sure to use electricity from renewable resources, but we can also stream less, reject "single-use films" (Veléz-Serna 2021), demand more energy-efficient standards and electronic devices, or, even better, resist the manufactured impulse to purchase ever larger and brighter screens.[14]

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[14] Laura Marks et al. (2020) recently published a list of suggestions on how media scholars can mitigate their carbon footprint, and Anna Pasek (2020) has some recommendations for low-carbon academia.

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