10

DISAGGREGATED FOOTPRINTS

An Infrastructural Literacy Approach to the Sustainable Internet

Nicole Starosielski, Hunter Vaughan, Anne Pasek, and Nicholas R. Silcox

As digital infrastructure has expanded over the past decade, researchers have drawn attention to the massive amount of energy it requires (Andrae and Edler, 2015; Varghese, 2020). Much of this discourse has focused on data centers, the energy-intensive warehouses of the internet. Perhaps predictably, less attention has been paid to measuring the network's least energy-intensive components or to comparative analysis of the network's many constituent parts. We still do not have a full picture, for example, of the relative carbon footprint of a network exchange, a terrestrial network, a last-mile connection, a satellite transmission, and a subsea cable link. This is in part an issue of data transparency and collection. However, it also reflects the fact that calculations of digital infrastructure's environmental impact have been largely driven by a desire to aggregate, to tie together various sections and sectors of internet infrastructure, and to assess harm at its broadest scale and scope.

Understanding where the biggest impacts can be made allows environmentalists to strategically advocate for technical and infrastructural change and could potentially play a crucial role in advancing the development and implementation of alternative energy futures. However, in this chapter, we advance a different—and as yet still marginal—approach to understanding digital infrastructure's impacts: a disaggregation of the internet's energy use, a focus on its localized and geographically specific parts, which can reveal the environmental specificity of critical digital infrastructure components. It is essential, we show, that both researchers and public stakeholders grasp the relative energy impact of data centers, subsea cables, and Internet of Things devices, among the multitude of other internet infrastructures.

Beyond understanding that data centers are energy-intensive, how can we assess them relative to one another and pose further questions regarding sector dynamics? How does our understanding of the environmental impact of digital infrastructure change when we consider different kinds of footprints—not only energy but also water or land footprints—in specific, local conditions? Knowing which part of the internet is more sustainable enables us to advocate more precisely for different models of internet organization—to design sustainability not only with a mindset of reduction or efficiency but also with a careful leveraging of pieces in relation to the whole. We describe this elsewhere as a turn to a *relational footprinting* rather than a complete accounting of the internet's carbon footprint (Pasek, Vaughan, and Starosielski, 2023). This isn't to say there is no value in a global approach, but rather there is much to be gained by supplementing such

DOI: 10.4324/9781003176497-13

approaches with attention to environmental variance and difference at the local level. Such specific critical understanding will not only advance a more holistic understanding of the network but also provide isolated and pragmatic targets for potential applied solutions and future best practices.

Crucial for this disaggregation of digital infrastructure, and the possibilities and advocacy for environmental change it opens, is an infrastructural literacy of ecomedia. Media scholars Lisa Parks (2009) and Shannon Mattern (2013) describe infrastructural literacy as the critical capacity to read, understand, and interact with the complex infrastructure systems in which we are enmeshed. In order to assess digital media's environmental dimensions, a basic literacy of the network—and its varied ecological effects—is necessary. For that reason, the first half of this chapter contains a breakdown of the parts of the internet's infrastructure and the environmental issues most pertinent to each. Evaluating the energy impact of a given set of digital media practices, whether executing a Google search, creating a TikTok video, or operating a server requires an infrastructural literacy in part because (1) different media practices activate different parts of our global digital infrastructure, and (2) individual platforms diverge in terms of policies of storage and organization. In the second section of this chapter, we discuss one relevant digital infrastructural trend—that of edge caching—and describe how this logistical technique dramatically reshapes the environmental effects of signal traffic. We discuss how applying a local ethos, such as edge caching, to the network could actually increase its environmental impact.

Data Centers: The Warehouses of the Internet

Data centers are the sites where computers (more specifically, racks and racks of servers) house the internet. What this means is that the content of websites, emails, and social media are all stored (at least within a cloud computing model) in a central location from which individuals can remotely access information. Within the landscape of data centers, there are a range of differentiations that affect environmental impact, most notably size and tenancy occupation, surrounding climate, and access to energy supply sources.

One distinction that shapes data centers' environmental impact is between the hyperscalers, the companies that have been able to build out massive data centers (e.g., Google, Facebook, and Amazon), and the much smaller data center players. Perhaps surprisingly, when it comes to the environment, bigger is often better. At scale, and in the development of massive new builds, it has been easier for companies such as Google to adopt increased efficiency measures and new technologies, and these companies have helped to drive sustainable development in the data center world. In contrast, a smaller data center or an older facility might fare much less well in an environmental assessment. Yet at the same time, the hyperscalers—in the acquisition and appropriation of additional land, energy, and water resources—still have a massive impact on the communities they inhabit.

Location also shapes data centers' overall environmental impact. Because of the need to maintain consistent temperatures, and because existing technologies are largely built for moderate climate (what Jen Rose Smith, 2020, calls "temperate normativity"), this means that data centers in cooler, often Northern climates typically use less electricity than comparable infrastructure built in tropical regions. Local energy grids also matter, since the mix of renewable versus carbon-intensive fossil fuel electrical generation varies dramatically from region to region (and even during times of day or the year). A data center powered primarily by wind, solar, or legacy nuclear and hydro will have a much smaller climate impact than one powered by coal, oil, or gas. This advantages and disadvantages certain areas of the world (and regions within a country) in terms of environmental performance.

Since its explosive growth in the 2010s, the data center industry has significantly advanced in its attempts to address sustainability compared to other sectors of network infrastructure development. The energy intensity of these infrastructures is a central economic and public relations concern for industry players, both in terms of operational cost and a growing trend of green finance that has incentivized this push. These efforts still have their limits, however: latency and national data sovereignty concerns, among others, mean that hyperscale data centers are not the best solution to every infrastructural problem.

Last Mile: The Driveways of the Internet

Alongside data centers, one of the most energy-intensive segments of internet infrastructure is last-mile infrastructure. By this, we mean the technologies and hardware that route traffic from internet exchange points (IXPs) to individual homes and businesses, as well as the routers, computers, screens, and periphery devices through which users interact. This equipment is generally less energy efficient than network traffic infrastructures, resulting in higher energy draw. While there has been improvement in overall energy efficiency per device with increasing regulatory standards over the past decade, the number of devices and consumption outpaces energy efficiency standards, a phenomenon known as Jevons Paradox. Despite variance in study data, there is broad agreement that last-mile infrastructures and end-user devices contribute a significant amount of the overall energy usage and carbon emissions of digital infrastructure networks. Some studies estimate that 47% of all ICT emissions can be attributed to last-mile infrastructures and end-user devices (Accenture Strategy, 2015). Others suggest that amount is greater than half (Malmodin et al., 2014). There is some evidence to suggest that this number might be lower, but still a significant portion of all ICT emissions (Ferreboeuf, 2019: 20). In addition to being energy-inefficient, last-mile infrastructure and end-user devices make up a significant portion of e-waste, expanding their environmental impact (Maxwell and Miller, 2012).

There have been efforts to make these devices and infrastructure more efficient, as well as the development of applications that monitor and report energy usage to consumers. There have also been some recent efforts to address consumer behaviors. Scholars have argued for the political and social possibility of an ethics of repair and accepting obsolescence in place of embracing the new (Mattern, 2018; Maxwell and Miller, 2012). Yet this focus on consumer behavior also risks redirecting the culpability of the environmental impact of digital infrastructure onto consumers themselves (Ericsson, 2020).

Internet Exchanges: The Transit Hubs of the Internet

A third key component of internet infrastructure is the internet exchange, the place where traffic is shifted between different kinds of networks. If data centers are warehouses and last-mile infrastructures are driveways, network exchanges are transit hubs, the train stations, and the airports for the data center metropolis. The energy use in these sites tends to be lower. While data centers are fairly mobile and can be established in preferable locations (taking into account environmental concerns ranging from the presence of renewable grids or cooler climates), network exchanges tend to be geographically situated as they are tied into and mediate between long-standing fixed lines. This sector of the network is often underexplored in terms of sustainability, partly because of its geographic situatedness, as well as lower energy consumption generally.

While IXPs are not energy-intensive, there have still been some efforts to increase their energy efficiency and sustainability. For example, some companies that manage IXPs have turned to renewable energy sources to power their facilities. This can be particularly advantageous for IXPs because they are so tightly tied to existing infrastructural geographies, and companies can adopt energy sources that are uniquely suited to the weather and climate conditions of the particular place in which they operate (Orghia, 2017). This can lower costs for companies, and for some, it can be a way of producing an energy surplus. Some companies have also invested in sustainable design of their buildings, further reducing their overall environmental impact (Equinix Initiatives, 2021).

The motivating factor for IXP location has rarely been ecological. Rather, IXP construction tends to follow a desire to keep the internet local and to provide higher quality internet access, especially in communities in which access is limited, as well as to increase the speed of data and information sharing within a local network (Internet Society, 2014). Given this reality, if local energy grids are primarily powered by fossil fuels, the decision to localize traffic through IXPs thus requires a trade-off between internet access, the cultural and business priority of maximum internet speeds, and emission of carbon. Thus, the more sustainable option in some cases might be to send data traffic to distant data centers that have more consistent access to renewable energy or more efficient standards overall. What are the implications of sending traffic to overseas data centers, even if this is more environment-friendly, instead of prioritizing local infrastructures? Thinking about IXPs and localization opens these critical questions about the geographical distribution of internet infrastructure.

Fiber-Optic Cables: The Highways of the Internet

Lastly, an oft overlooked aspect of the internet infrastructure is the long-haul fiber optic cable system through which network traffic is funneled underground and underwater. Satellites carry some transoceanic communication, but this is relatively small. In addition to being overlooked culturally, subsea cables are often overlooked in evaluations of the carbon and environmental impacts of the global internet infrastructure. This is, in part, because the emissions generated by subsea cables are so low that they are regarded as comparable to a rounding error in global calculations. Given the low-carbon footprint of subsea cables and the more general invisibility of the industry, there has been very little research dedicated specifically to cable infrastructure and its climate impacts. For example, in the subsea telecommunications industry, which constructs the transoceanic links that carry almost 100% of data traffic across the oceans, there has been almost no industry-wide carbon data exchange, collaboration around sustainability work, or discourse about the relative sustainability impacts of different cable landing stations or cables. In part because of its low-carbon footprint and its extensive focus on mitigating any potential marine environmental impacts, sustainability work has generally slipped through the cracks.

Since 2021, our team has been building the *Sustainable Subsea Networks* research project to document the energy use of this sector of the internet and develop mitigation strategies for its infrastructure. We have found many individual companies engaged in green practices, but on the whole, this has not been a sector-wide endeavor. To facilitate these green efforts, we have begun to generate basic environmental communication strategies (including the creation of a column on sustainability in the industry magazine and the generation of a sustainability map). Analyzing the internet's infrastructure in terms of its component parts, and understanding the specificity of different parts, reveals a multitude of places throughout the network where new strategies for making the system more sustainable, beyond degrowth and efficiency, are possible.

Case Study: Netflix and the Environmental Impact of Edge Caching

Given the pressing need to address climate change, much research on the energy use of the internet has been motivated by a desire to find the sites with the most significant impact, hone in on them, and develop solutions for reduction. Or, to aggregate and assemble the many different sites of energy use in order to demonstrate the magnitude of real or potential harm and to use this data to call for transformation. Such approaches bring with them several potential paths forward. Working at scale, aggregative approaches are particularly good at setting baselines for policy and regulation, for speaking to all parts of a network, and for connecting local actions into a greater whole. Yet they also carry the risk of eclipsing the specificity of different kinds of digital media practice and the infrastructures and places that support those practices. A big picture view does not as readily lend itself to solutions that involve reorganizing traffic, systems, and social practices, nor can strategies derived from their conclusions be easily implemented across the sector all at once.

Let us consider a specific case that illustrates the possibilities of disaggregation and the need for infrastructural literacy. Over the last decade, driven in part by the perceived need of consumers to receive streaming media content quickly, a new model of digital infrastructure organization developed: edge caching. In short, edge caching means that the content is stored in many edges in the global network, accessible in geographically proximate sites that are called cache servers, rather than distributed from a single central server. Edge caches are like smaller, regional airports, holding content that need not necessarily pass through and from major hub centers. A related development, “fog computing,” relocates not simply content but computing capacity to the edges of the network. This reduces the time it takes to receive data and increases the speed at which one can consume data, which is important for a variety of time-sensitive activities from gaming and streaming video to stock trading. The motivations that have animated network development and new forms of network infrastructure prompt engineers to ask: how close can we get to the users? How quickly can we get them content? How can we predict what it is that they will want so that way we can keep it nearby?

One of the most well publicized versions of this movement to the edge has been Netflix’s Open Connect, which involves Netflix partnering with Internet Service Providers (ISPs) in order to maximize efficiency and quality of streamed content. Working with over a thousand ISPs worldwide, Netflix utilizes a proprietary system of “embedded deployments” to localize data through what they call a “cooperative approach to content delivery.” Ultimately, it means that the content provider and the internet provider work together in order to anticipate localized content needs and map, distribute, and maintain data accordingly. The Open Connect project is global with “14,000 Open Connect Appliances spread across 142 countries” which has made it possible for Netflix to store and access data locally from most places where streaming happens. This “cooperative model” of data storage and transfer has reduced costs for Netflix and increased efficiency while “increasing quality for consumers” (Netflix, 2021). However, it is not clear that this model has been effective in reducing the carbon footprint of Netflix. Netflix self-reports their use of “Amazon Web Services and the Open Connect content delivery network” accounted for 5% of the 1.1-million metric tons the company produced in 2020, or nearly 600,000 tons of carbon. Notably, this analysis excludes emissions from internet transmission or user-end electronic devices (Stewart 2021).

This is of particular importance given the exponential increase in online video streaming over the last decade (Kamiya, 2020), which has greatly outpaced environmental regulation of ICT and puts added strain on existing sustainability practices in the industry. Both academic (Marks, Makonin, Rodriguez-Silva, and Przedpełski, 2021) and popular studies (Bedingfield, 2021; Kessler, 2017) have addressed the environmental impacts of digital streaming, primarily as an aggregate question of carbon footprinting: a certain amount of carbon per GB, or as the industry's share of overall global GHG emissions. Their conclusions are alarming, suggesting that edge caching and the user demand it supports and grows, pose substantial threats to the prospects of a greener internet.

Yet the question of digital streaming impacts might well be better understood—and made more available for intervention—by looking at its disparate elements and segmented design. One can evaluate the merits of edge caching versus centralization from various perspectives: Who controls the content? Under what regulations is that content controlled? Where can disruption occur? How fast are these systems? Are users subjected to increased forms of harm or surveillance in the movement to the edge? As yet, no one has calculated the relative environmental impact of different models of connection, whether edge caching, centralized delivery, or fog computing. We only have sketches of the network as a whole, and as it currently exists.

Here the analogy between internet infrastructure and the wider transportation system fails us. While we use the features of transportation systems to help make the dense layers of digital infrastructure intelligible—warehouses, transit hubs, highways—such transpositions also introduce potential misunderstandings. If we assumed that the length or duration of transmission is relative to environmental impact, we would easily adopt a localist perspective: like our food and commodity goods, local data would be lighter on the earth than a global import. However, while the transportation of goods via highway is a fuel- and power-intensive activity compared to leaving them stockpiled in a warehouse (provided this warehouse isn't climate-controlled), the opposite is true for digital signals. Long-haul transmission of information along digital highways is much more energy-efficient than local storage. Subsea routing is actually much less energy-intensive, relatively speaking, than storing data in perpetuity. In turn, the environmentalist ethos of situating things locally does not easily translate to digital networks. It is for these reasons that we need a clear disaggregation of the internet's energy use: a relational footprinting that locates usage in relation to national grids, energy policies, and the geography and displacements that govern movement across the internet (Pasek, Starosielski, and Vaughan, 2023). Greening the internet is both a decision about how much bandwidth one takes up and a matter of producing less or lower bandwidth content (Marks, Makonin, Rodriguez-Silva, and Przedpełski, 2022), but also a question of speed and network organization. Rather than only growing or shrinking the internet overall, we might also build different networks, taking advantage of geographic difference to move content along greener pathways, from greater distances. In turn, this might be an internet with content appearing slower, buffering for longer, and inaccessible at certain times and places. Recent critical creative projects such as Low-tech Magazine (https://solar.lowtechmagazine.com/about.html) and Solar Protocol (Brain, Nathanson, and Piantella, 2022) explore the role of sustainable design and solar-powered tech. Both projects center the idea of finite, limited energy resources as the political, esthetic, and technical motivations of design. They embrace intermittency, resiliency, and principles of degrowth as productive pathways through which to imagine low-carbon futures and reconsider our current understandings of the internet. These projects are less useful as specific blueprints—rather, they are useful examples that open up "new imaginaries of what web [and computing] systems designed within limits can be like" (Abbing, 2021).

Conclusion

In November 2021, Extinction Rebellion launched an anti-data center protest in Ireland. Standing outside of the Data Centres Ireland annual conference at the Royal Dublin Society, people gathered

Figure 10.1 Extinction Rebellion anti-data center protest

to protest the development and expansion of data centers in Ireland, a country that is at once a significant hub for internet traffic and particularly at risk for the impacts of climate change and rising sea levels. Protesters held signs that said simply "Ban New Data Centers" and, in echoing some of the sentiments of this paper, "System Change, not Climate Change" (see Figure 10.1). This is the kind of protest and public action that facts and figures about the environmental impact of the internet can help to motivate. The question remains: what is it that we want less of when we protest against emissions? Or rather, what does it mean to create "system change" with respect to internet infrastructure? Is it data centers that we need less of? Network exchanges? Subsea cables? No matter the answer, it is clear to us that infrastructural literacy is a precondition for creating more ecologically sound media.

Further Reading

Chang, Alenda, and Jeff Watson. 2022. "Steam Clouds and Game Streams: Unboxing the 'Future' of Gaming." In *The SAGE Handbook of the Digital Media Economy*, edited by Terry Flew, Jennifer Holt, and Julian Thomas, 240–59. London: Sage.

Freitag, Charlotte, Mike Berners-Lee, Kelly Widdicks, Bran Knowles, Gordon S. Blair, and Adrian Friday. 2021. "The Real Climate and Transformative Impact of ICT: A Critique of Estimates, Trends, and Regulations." *Patterns* 2 (9): 100340. https://doi.org/10.1016/j.patter.2021.100340.

Mattern, Shannon. 2018. "Scaffolding, Hard and Soft: Media Infrastructures as Critical and Generative Structures." In *The Routledge Companion to Media Studies and Digital Humanities*, edited by Jentery Sayers, 318–26. New York and London: Routledge.

Parks, Lisa. 2015. "Stuff You Can Kick: Toward a Theory of Media Infrastructures." In *Between Humanities and the Digital*, edited by Patrik Svensson and David Theo Goldberg, 355–73. Cambridge: MIT Press.

Pasek, Anne. 2019. “Managing Carbon and Data Flows: Fungible Forms of Mediation in the Cloud.” *Culture Machine* 18 (April). http://culturemachine.net/vol-18-the-nature-of-data-centers/managing-carbon/.

References

Abbing, Roel Roscam. 2021. “‘This Is a Solar-Powered Website, Which Means It Sometimes Goes Offline’: A Design Inquiry into Degrowth and ICT.” *Seventh Workshop on Computing within Limits*. https://computingwithinlimits.org/2021/papers/limits21-abbing.pdf.

Accenture Strategy. 2015. “#SMARTer2030: ICT Solutions for 21st Century Challenges.” Brussels, Belgium. https://smarter2030.gesi.org/downloads/Full_report.pdf.

Andrae, Anders S. G., and Tomas Edler. 2015. “On Global Electricity Usage of Communication Technology: Trends to 2030.” *Challenges* 6 (1): 117–57. https://doi.org/10.3390/challe6010117.

Bedingfield, Will. 2021. “We Finally Know How Bad for the Environment Your Netflix Habit Is.” *WIRED*, March 15. https://www.wired.co.uk/article/netflix-carbon-footprint.

Brain, Tega, Alex Nathanson, and Benedetta Piantella. 2022. “Solar Protocol: Exploring Energy-Centered Design.” In *Eighth Workshop on Computing within Limits 2022*, 7. https://computingwithinlimits.org/2022/papers/limits22-final-Brain.pdf.

Equinix Initiatives. 2021. “Map of Initiatives.” *Equinix Sustainability*, September 20. https://sustainability.equinix.com/map-of-initiatives/.

Ericsson. 2020. “A Quick Guide to Your Digital Carbon Footprint: Deconstructing Information and Communication Technology’s Carbon Emissions.” Ericsson. https://www.ericsson.com/en/reports-and-papers/industrylab/reports/a-quick-guide-to-your-digital-carbon-footprint.

Ferreboeuf, Hugues. 2019. “Lean ICT: Towards Digital Sobriety. Paris, France: The Shift Project.” https://theshiftproject.org/wp-content/uploads/2019/03/Lean-ICT-Report_The-Shift-Project_2019.pdf.

Internet Society. 2014. “The Internet Exchange Point Toolkit & Best Practices Guide.” 25 February. https://www.internetsociety.org/resources/doc/2014/ixptoolkitguide/.

Kamiya, George. 2020. “The Carbon Footprint of Streaming Video: Fact-Checking the Headlines – Analysis.” *International Energy Agency*, December 11. https://www.iea.org/commentaries/the-carbon-footprint-of-streaming-video-fact-checking-the-headlines.

Kessler, Matt. 2017. “The Environmental Cost of Internet Porn.” *The Atlantic*, December 13. https://www.theatlantic.com/technology/archive/2017/12/the-environmental-cost-of-internet-porn/548210/.

Malmodin, Jens, Dag Lundén, Åsa Moberg, Greger Andersson, and Mikael Nilsson. 2014. “Life Cycle Assessment of ICT.” *Journal of Industrial Ecology* 18 (6). https://doi.org/10.1111/jiec.12145.

Marks, Laura U., Stephen Makonin, Alejandro Rodriguez-Silva, and Radek Przedpelski. 2022. “Calculating the Carbon Footprint of Streaming Media: Beyond the Myth of Efficiency.” In *Eighth Workshop on Computing within Limits 2022*, 7. https://computingwithinlimits.org/2022/papers/limits22-final-Makonin.pdf.

Mattern, Shannon. 2013. “Infrastructural Tourism.” *Places*, July 1. https://doi.org/10.22269/130701.

Maxwell, Richard, and Toby Miller. 2012. *Greening the Media*. New York: Oxford University Press.

Netflix. 2021. “A Cooperative Approach to Content Delivery.” *Netflix*. https://openconnect.netflix.com/Open-Connect-Briefing-Paper.pdf.

Orghia, Michael. 2017. “Sustainability in Armenia: ARMIX Adopts Solar Power.” *Internet Society blog*, June 9. https://www.internetsociety.org/blog/2017/06/sustainability-in-armenia-armix-adopts-solar-power/.

Parks, Lisa. 2009. “Around the Antenna Tree: The Politics of Infrastructural Visibility.” *Flow*, March 6. https://www.flowjournal.org/2009/03/around-the-antenna-tree-the-politics-of-infrastructural-visibilitylisa-parks-uc-santa-barbara/.

Pasek, Anne, Hunter Vaughan, and Nicole Starosielski. 2023. “The World Wide Web of Carbon: Toward a Relational Footprinting of Information and Communications Technology’s Climate Impacts.” *Big Data & Society* 10 (1): 205395172311589. https://doi.org/10.1177/20539517231158994.

Smith, Jen Rose. 2020. “‘Exceeding Beringia’: Upending Universal Human Events and Wayward Transits in Arctic Spaces.” *Environment and Planning D: Society and Space* 39 (1): 158–75. https://doi.org/10.1177/0263775820950745.

Stewart, Emma. 2021. “Net Zero + Nature: Our Commitment to the Environment.” *Netflix*, March 30. https://about.netflix.com/en/news/net-zero-nature-our-climate-commitment.

Varghese, Sanjana. 2020. “Is Streaming Music Growing Your Carbon Footprint?” *Al Jazeera English*, February 28. https://www.aljazeera.com/economy/2020/2/28/emissions-possible-streaming-music-swells-carbon-footprints.