THE ROUTLEDGE HANDBOOK OF ECOMEDIA STUDIES

Edited by Antonio López, Adrian Ivakhiv, Stephen Rust, Miriam Tola, Alenda Y. Chang and Kiu-wai Chu

Routledge
Taylor & Francis Group
London and New York

earthscan
from Routledge

11

COLLAPSE INFORMATICS AND THE ENVIRONMENTAL IMPACT OF INFORMATION AND COMMUNICATION TECHNOLOGIES

Laura U. Marks

This chapter gives an overview of the environmental impact of ICT, which comprise the interconnected webs of computing devices, networks, storage, and servers. Focusing on the important subcategory of ICT engineering research in sustainability, I argue that ICT's growth is unsustainable, even given the vaunted efficiency of the technologies, especially as it expands to developing countries. Reviewing some proposed best practices for making ICT use sustainable, I suggest that the movements of slow computing and collapse informatics offer a model for learning to live with decreased expectations.

ICT research occurs at the nexus of computer science, information systems, human-computer interaction, and economics. The majority of engineers working on ICT do not reflect a concern for the environment in their research but rather are driven to innovate solutions to make ICT more efficient. But as we shall see, efficiency usually translates to increased growth and a higher environmental footprint. I will focus on just one of the barriers to environmentally sustainable ICT: the rebound effect, whereby increased efficiency leads to greater demand.

Over the two years that I have immersed in the ICT engineering literature, I have come to empathize greatly with these hard-working engineers, much of whose research benefits telecoms and other corporations that extract profit from ICT services. Of those ICT engineers who do seek environmentally responsible solutions, some appear to end up, intentionally or willy-nilly, contributing to corporate greenwashing. Often this is because their analyses are limited in space and time: they study shorter term effects, or they exclude variables that are too hard to quantify. This greenish research creates a false sense of security that ICT's direct environmental effects, including resource extraction, carbon footprint, water use, and other pollution, can be mitigated and in any case are outweighed by ICT's good indirect environmental effects. I have the highest regard for those ICT engineers who, in the careful and precise language and methodologies of their discipline, do the more difficult work of studying the larger picture despite its many unknowns. They encourage us to convert the relativistic terms of efficiency and sustainability to the absolute terms of sufficiency and self-sustainability, as we will see later.

DOI: 10.4324/9781003176497-14

"We'll need a lot more energy"

When I first read "What Will the World Be Like in 20 Years?" in the *New York Times* of November 29 2021, I was so irritated by its glib contradictions that I flung the article across the room (luckily, I was reading the paper newspaper). Demographic studies indicate to the article's author, Andrew Ross Sorkin, that the majority of the world's population will live in cities, requiring more infrastructure. "We'll also need a lot more energy," he writes. Citing a 2017 US Energy Information Administration (EIA) report, Sorkin argues that the additional energy will come from renewable sources.

In fact, the EIA's long-term projection of world energy consumption is pretty gloomy. Its October 2021 update projects a 28% increase in world energy use by 2050 as populations and incomes rise. Almost every kind of energy consumption will rise: renewable, nuclear, natural gas, and petroleum. Crude oil and natural gas production will increase worldwide. The EIA projects coal consumption to slowly flatten worldwide, but this is not happening: China, India, and South Korea led the 2022 expansion of new coal plants, and Germany reopened coal plants after the Russian invasion of Ukraine (Global Energy Monitor 2023). The EIA's study shows that renewables will support *only* the increase; fossil fuels will maintain at a steady state. These predictions demolish any hope that global greenhouse gas (GHG) emissions will decrease to levels that make it possible to avoid catastrophic global heating.

Decarbonization Fallacies

ICT currently is estimated to use about 7% of the world's electricity and generate almost 4% of global GHG emissions (Belkhir & Elmeligi 2018, Bordage 2019). It is predicted to grab an ever-larger proportion of global electricity as numbers of data centers, network technologies, and devices continue to increase. As with the global trend, even if new electricity generation for data centers, networks, and devices comes from renewable sources, this is *in addition to*, not replacing, the existing fossil-fuel–powered electricity sources.

Mega-ICT corporations could claim, as Apple and Google do, that their data centers are sustainable because they are powered by renewable energy. In fact, data center operators purchase renewable energy credits, which allow them to claim that they are using renewable energy while continuing to use energy from fossil fuels (Chernicoff 2016). Moreover, that renewable energy could have been used to power the local grid. Take the Irish example. In Ireland, the infrastructural site of Google, Facebook, Amazon, and soon TikTok, data centers are projected to account for 25% of national electricity demand by 2030. In 2021, the state-owned electricity company EirGrid warned that the country would be short of 1,850 megawatts of energy in 2024–2025. Ireland's environment minister stated that EirGrid would fall back on diesel generators, among other things, to make up the shortfall (O'Doherty & Hyland 2021). Thus, the renewable energy demands of big media corporations force other folks to rely on fossil fuels.

Dreams of Dematerialization

Most people, especially in wealthy parts of the world, rarely consider that ICT has an environmental impact. That is partly because most of the infrastructure is invisible to us, as my diagram shows (Figure 11.1). Data centers are usually invisible; most parts of networks are underground and undersea; device manufacture takes place in factories in China; copper and rare metals are mined

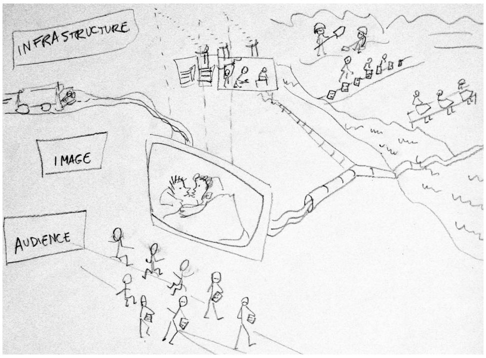

Figure 11.1 The infrastructure beyond the image

in Chile, Peru, China, the Democratic Republic of Congo, and elsewhere; dangerous disposal and the little recycling that occurs takes place most often in China, Brazil, and India.

ICT is generally thought to result in *dematerialization* or *virtualization*, the replacement of physical goods such as newspapers and DVDs with electronic media. Both terms are problematic. To call electronic media virtual grates on a Deleuzian like me, since electronic media are thoroughly actual. (Virtual describes, for example, a future world powered by renewable energy; or a future in which our planet becomes uninhabitable.) Nor are the products delivered by ICT immaterial. They use electricity, they are delivered on media composed of minerals, and they embody the labor of miners, assemblers, installers, and hardware and software engineers.

Moreover, ICT instates behaviors and expectations that have material effects. Streaming YouTube to a laptop or a large TV, instead of listening to the radio or your own CDs, or streaming audio music. "Reading" a video-heavy newspaper online instead of a paper newspaper. "Jumping on a Zoom" instead of talking on the phone. Streaming video for 35 hours a week instead of watching TV or going to the movies. Using AI-driven dictation software instead of typing. At first, these substitutions of one platform for another appear to result in a savings of energy and other resources. However, as behavior changes, they often end up consuming more energy. These are all examples of the rebound effects of ICT that result in increased demand on networks, data centers, and devices.

Infrastructure Anticipates Demand

ICT infrastructure is overbuilt to respond to anticipated demand. Preist et al. (2016) point out that in the dominant ideology of the "cornucopian paradigm," the internet is a limitless resource. Consumers expect internet services that are instantaneous, of huge variety, of high quality, and always available. Each one of these expectations has implications for data storage, network capacity, and energy consumption, setting up a feedback loop of increased capacity and increased demand. For example, the expectation for high-resolution audio, images, and video increases the demand on networks, servers, and storage. It also creates a demand for high-resolution devices. The resulting files are so large that users store more of the content they create on the cloud. Similarly, the expectation of instantaneous access to online content means that the infrastructure "must be sufficient to cater comfortably with peak demand, resulting in the need for more servers and network capacity than would otherwise be necessary" (2016, 1327).

Rebound Effects

As efficiency of technologies increases and costs decrease, demand for these technologies rises. This is the rebound effect, also known as the Jevons paradox: more efficient technologies encourage greater use of a resource, reducing or eliminating savings. Direct environmental effects of ICT include resource extraction and water use and the pollution resulting from fossil-fuel sources for electricity, i.e. ICT's carbon footprint. More difficult to measure are the indirect effects of ICT. Things like smart buildings, substituting travel with videoconferencing, and substituting tangible goods with electronic media (online newspapers, streaming music, streaming movies, distance learning) are thought to decrease environmental damage. But these initially energy-saving activities lead to new behaviors that quickly become normalized: rebound effects (Gossart 2015). In a market dynamic of obsolescence, rebound is cyclical, as new software drives renewal of hardware, which leads to more intensive use, which leads to new software (Belkhir & Hilty 2021). Inexpensive electricity—cheaper in the United States than in Nigeria or the UK—further drives demand (Ejembi & Bhatti 2015).

Many engineers argue that there are too many variables and unknowns to determine ICT's indirect environmental effects (Horner et al. 2016). Industry boosters and lobbyists prefer reports like that of Accenture and the Global e-Sustainability Initiative (GeSI) in 2015, which suggested that while the ICT sector causes only 2% of global GHG emissions through direct effects, ICT applications could prevent up to 20% of annual GHG emissions in 2030 through positive indirect effects (GeSI and Accenture 2015). But in a study based on an extensive literature review, the majority of researchers found that rebound effects are too high to prevent a sufficient absolute reduction in energy demand (Lange et al. 2020).

Surveys of ICT's indirect effects suggest that the more carefully you model, the more likely you will be to find that they are deleterious. The approach GeSI used is ICT-enabled modeling, a rough calculation based on estimating how ICT may decrease baseline emissions, for example in telecommuting. Bieser and Hilty, surveying 54 environmental impact assessments, note that ICT-enabled modeling almost always demonstrates favorable indirect effects of ICT. A more inclusive model is life cycle analysis, which models "all exchange of energy and matter between the product system and its environment" (Bieser & Hilty 2018, 12). At maximum, life cycle analysis takes into account the environmental effects of resource extraction, production, use, and disposal of a given product system (Global Energy Monitor 2023).

For researchers, a disheartening example of the digital rebound effect is that, because of online journals and databases, the numbers of academic journal articles have multiplied dizzyingly, diluting the quality of research and making it near impossible to assimilate new knowledge (Gossart 2015, 443). In my recent research, the overconsumption of streaming video is a carbon-intensive rebound effect of inexpensive high-bandwidth transmission (Marks 2021, Marks & Przedpełski 2022).

Rebound in Global Perspective

A question for ethical ICT design is, "If this service were to be used by all the world's population, what would the overall environmental impact of the infrastructure be?" (Preist et al. 2016, 1332). In well-infrastructured parts of the world, the global pandemic cemented unsustainable media practices. People streamed more hours of video per day; shared more videos on social media; played more online games, in increasingly high resolution; kept the videoconference platform open all day for working from home and attending webinars; and bought more stuff online.

Such users could protest that since they are no longer traveling by air and they drive less, their carbon footprint is smaller than it was before the pandemic. But the rebound effect teaches us that soon enough people will be traveling more *and* maintaining the high-bandwidth activities. On top of that, wealthy regions' high-bandwidth habits create a model for the expansion of ICT in less wealthy countries.

We have to blame the wealthy countries for establishing unsustainable and frankly ridiculous standards of consumption. Wealthy countries energy consumption is now quietly flatlining only because light and heavy industry moved to countries where labor is cheaper and energy is more likely to be unrenewable. I hesitate to use the term "developing" for countries whose GDPs are currently lower than wealthy countries, because (1) the current model of economic development is the cause of catastrophic global warming and (2) low-income countries offer many models of sustainable development, which wealthier countries ought to follow, as I suggest below.

Nevertheless, in developing countries' ICT infrastructure will expand even faster and consumers will be encouraged to expect the high bandwidth, high turnover of devices, etc. that are touted as the norm in wealthy countries. As a country's income grows, installing new ICT infrastructure leads to an increase in electricity consumption (Saidi et al. 2017, 801). In 2020, the network corporation Cisco (2020) projected a 42% increase in IP traffic in the Middle East and Africa (Belkhir & Elmeligi 2018, Ihayere et al. 2021). Cisco's projections tend to become factual because the ICT industry strategizes based on their predictions through planned obsolescence, market saturation, and corporate demands for government investment in new technologies.

Development cannot be sustainable if all countries seek to achieve the bloated infrastructure of wealthy countries. Rather than increase ICT capacity worldwide to be equivalent to that in wealthy countries—what Radek Przedpełski and I call bandwidth imperialism—it is more appropriate for the ICT capacity of low-income countries to serve as a model for the rest of the world (Marks & Przedpełski 2021).

ICT's environmental impact in developing countries is difficult to project, given disagreements about the relative impacts of direct, indirect, and rebound effects, alongside the ways ICT drives economic development. For example, one study finds that ICT initially increases CO_2 emissions in developing countries but later on can moderate them, for example in the use of smart electric grids (Danish et al. 2018, Park et al. 2018). It focuses on what Goldman Sachs identified in 2015 as the N11 or next 11 countries that could potentially become some of the world's largest economies: Bangladesh, Egypt, Indonesia, Iran, Mexico, Nigeria, Pakistan, the Philippines, Turkey, South Korea, and Vietnam. The authors recommend that government policy in these countries should focus on energy-efficient infrastructure and clean energy. But given that, as of 2019, all the N11 countries rely largely or overwhelmingly on fossil fuels for electricity generation[1]—indeed, that's one of the reasons why they're in this category—it is beyond unlikely that they will hasten to move quickly to renewable energy.

Prospects

Given this global context, prospects for mitigating the increasing carbon footprint of ICT are fairly dismal, but I will enumerate some of them, from individual to institutional to governmental levels.[2]

Like recycling, actions at the personal level can seem puny and ineffectual, but they add up. And like recycling, they're subject to larger forces of economy and regulation. So doing things like streaming less and in lower resolution, compressing videos before you upload them, minimizing subscriptions, avoiding cloud storage, and keeping your device for as long as possible have a cumulative effect. Oh, and don't buy cryptocurrency. You might ask, if our local grid is powered by renewable energy, can we stream without compunction? The answer is no. First of all, it's difficult to determine whether the servers and networks that support your streaming get their electricity from renewable sources. Second, even if they did, in all likelihood your devices were produced with energy from fossil fuels. Third, excessive use of ICT pushes global demand for consumption and resulting expansion of infrastructure.

At the medium scale, it is in the interest of media corporations and service providers to conserve energy and reduce digital waste. Streaming platforms can default to low resolution and not offer high resolution without users' consent (The Shift Project 2019, Obringer et al. 2021). YouTube can use audio-only detection, which would turn off the video when it is detected to be playing in the background (Preist et al. 2016). Google can delete less popular videos from all but a few central servers (Cubitt 2017). Service providers can sell longer subscription plans at discounted rates to encourage customers to keep their phone for longer (Belkhir & Elmeligi 2018). They should also charge per unit of data, rather than at a flat rate (Reinsdorf et al. 2018). ICT corporations should include rebound effects in self-assessments.

Ultimately, mitigating the carbon footprint of ICT can only be resolved by governmental and international regulation. For example, governments can impose a real carbon tax on streaming platforms, telecoms, and network managers, who would pass these costs on to consumers. They can regulate cryptocurrency, AI, and other highly electricity-intensive applications (Montevecchi et al. 2020).

Self-Sustainability and Computing within Limits

The ICT industry itself is influential and can model energy-saving practices that can become the basis of government regulation. The fields of sustainable computing and sustainable ICT engineering have burgeoned in the last several years, with dedicated journals and conferences. Engineers can come up with remarkably divergent analyses under the rubric of sustainability. Sometimes terms such as "sustainability" and "circular economy" are just greenwashing. As Lorenz M. Hilty and Bernard Aebischer, leaders in the field of sustainable IT, point out, sustainability is a relative term, as it refers to sustainable use in terms of a given context (Hilty & Aebischer 2015). Preferable are *sustainable development* and *self-sustaining systems*. "Networking technology should follow the principles of Appropriate Technology […]: be designed to be a) simple, b) locally reproducible, c) composed of local materials / resources, d) easily repairable, e) affordable, and f) easily recyclable" (Raghavan & Ma 2011). One group, Computing within 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.
>
> (87)

Embracing Collapse Informatics

When resources collapse, as in the declining periods of past civilizations, making do with less becomes a necessary art. Lambert et al. (2015) explore post-peak oil scenarios in which low-power networking is no longer optional but instead becomes a necessity due to an energy-intermittent future. This would also apply to other energy-constrained situations, such as disaster recovery or off-grid installations in developing countries. (e.g., Tomlinson et al. 2013, Lambert et al. 2015). The authors introduce the concept of "graceful decline."

Collapse informatics (a term introduced by Tomlinson et al. 2013) models what I believe is the only truly sustainable model of ICT. It necessitates making do with less electricity and therefore lower bandwidth and intermittent access. It amplifies the value of tinkering and DIY practices that people have always used in the absence of access to new technologies. It shifts the direction of emulation away from over-infrastructured regions and toward lightly infrastructured regions where people have devised ways to make do.

Models for collapse informatics thrive in informal media economies (Lobato & Thomas 2015). Tinkering, hacking, and making may begin as a response to deprivation, but once the tinkerer develops expertise, they can be elegant, effortless, and empowering (Larkin 2013, Marks 2017). Collapse informatics posits that everyone but the over-infrastructured elite will have to embrace oppositional technophilia, Ron Eglash's term for minority groups' practices of hacking received technologies (Eglash 2009).

Young people in highly infrastructured parts of the world have grown up taking high-speed access for granted. My colleague Yani Kong surveyed students and instructors at our university about their attitudes toward the use of streaming media in online teaching (Kong 2022). They argued that the best ways to decrease the carbon footprint of online teaching are to turn off video in videoconferences and decrease the resolution of streaming movies. Most of the instructors were open to, or actively preferred, decreasing the resolution of videos, especially lecture and demonstration videos. In contrast, the majority of students insisted on a high-resolution learning experience. "4K or bust, baby!", one student wrote. However, young people are also innovators of elegant media objects that require very little bandwidth: GIFs and memes (Figure 11.2). Both are tiny, intensive files—infinitesimal movies in the case of GIFs—that are perceived briefly but create a lingering affective and cognitive impact. Kong and Predpełski devised some memes to communicate their findings instantaneously, such as these.

A design question for the collapse-informatics scenario is, "Can a restricted version of the service be imagined, and what would its value and infrastructural burden be?" (Preist et al. 2016, 1332). The annual Small File Media Festival that I founded in 2020, which imagines a restricted version of the streaming-video service, models a paradigm for collapse-informatics art and entertainment. We invite media works of no larger than 1.44 megabytes per minute, a constraint that

Figure 11.2 Coughing cat meme

stimulates makers to radical experiments in content, style, and compression esthetics. Hundreds of media artists from all over the world have risen to our challenge, competing for prizes such as Lowest Bitrate, Best Cat Video, Best Postapocalyptic, and Best Haptic Renunciation. As the title of that last prize suggests, small-file movies are intensive, pulling viewers toward the screen and stimulating their imaginations, rather than push out in high resolution toward a viewer who remains passive. Small-file movies are often very short, giving viewers more time to relish their enjoyment.

An ICT Contribution to the Commons

Ultimately, as the more critical ICT engineers emphasize, rebound effects indicate destructive contradictions in a growth-based economic system (Gossart 2015, 445). As Hilty points out, the rebound effect is a self-fulfilling prophecy. For example, 5G is predicted to be seven times more efficient in 2030. But capacity is planned for *eight* times current capacity, in order for the companies to be financially successful, leading to a net increase in electricity consumption (Belkhir & Hilty 2021).

Between the lines of self-sufficiency in ICT engineers' proposals shimmers an ICT contribution to the Commons. If the capitalist compulsions for proprietary product competition, obsolescence, and immediate consumer gratification are subtracted, 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 corporations.

Notes

1 Most of the N11 countries get over 90% of their electricity-generating energy from fossil fuels. The others are Nigeria: 77% fossil fuels, 23% hydro; Turkey: 63% fossil fuels, 25% hydro; South Korea: 70% fossil fuels, 27% nuclear; and Vietnam: 60% fossil fuels, 39% hydro. Sources: globalpetrolprices.com/energy_mix.php; ourworldindata.org; iea.org.

2 See the complete recommendations at https://www.sfu.ca/sca/projects---activities/streaming-carbon-footprint.

Further Reading

Hilty, Lorenz M., and Bernard Aebischer, eds. 2015. *ICT Innovations for Sustainability*. Dordrecht: Springer.

Marks, Laura U., and Radek Przedpełski. 2022. "The Carbon Footprint of Streaming Media: Problems, Calculations, Solutions." In *Film and Television Production in the Era of Climate Change: Environmental Practice, Policy, and Scholarship*, eds. Pietari Kaapa and Hunter Vaughan. Basingstoke: Palgrave Macmillan.

Nardi, Bonnie, et al. 2018. "Computing Within Limits." *Communications of the ACM [Association for Computing Machinery]* 61:10 (October), 86–93.

Patrignani, Norberto, and Diane Whitehouse. 2018. *Slow Tech and ICT: A Responsible, Sustainable and Ethical Approach*. Cham: Springer International Publishing.

Preist, Chris, Daniel Schien, and Eli Blevis. 2016. "Understanding and Mitigating the Effects of Device and Cloud Service Design Decisions on the Environmental Footprint of Digital Infrastructure." In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems*. Santa Clara: ACM [Association for Computing Machinery], 1324–1337.

References

Belkhir, Lofti, and Ahmed Elmeligi. 2018. "Assessing ICT Global Emissions Footprint: Trends to 2040 and Recommendations." *Journal of Cleaner Production* 177, 448–63. https://www.sciencedirect.com/science/article/pii/S095965261733233X

Belkhir, Lotfi, and Lorenz M. Hilty. 2021, August 12. Remarks on the Panel "Engineering Heroes." The Small File Media Festival. https://vimeo.com/595550014

Bieser, Jan C.T., and Lorenz M. Hilty. 2018. "Assessing Indirect Environmental Effects of Information and Communication Technology (ICT): A Systematic Literature Review." *Sustainability* 10:8, 2662. https://doi.org/10.3390/su10082662

Bordage, Frédéric. 2019. "The Environmental Footprint of the Digital World." Report for GreenIT.fr. https://www.greenit.fr/wp-content/uploads/2019/11/GREENIT_EENM_etude_EN_accessible.pdf

Chernicoff, David. 2016. "How Data Centers Pay for Renewable Energy." Data Center Dynamics. https://www.datacenterdynamics.com/en/analysis/how-data-centers-pay-for-renewable-energy/

Cisco. 2020. "Cisco Annual Internet Report (2018–2023)." Technical report. https://www.cisco.com/c/en/us/solutions/collateral/executive-perspectives/annual-internet-report/white-paper-c11-741490.html

Cubitt, S. 2017. *Finite Media: Environmental Implications of Digital Technologies*. Durham, NC: Duke University Press.

Danish, Noheed Khan, Muhammad Awais Baloch, Shah Saud, and Tehreem Fatima. 2018. "The Effect of ICT on CO_2 Emissions in Emerging Economies: Does the Level of Income Matter?" *Environmental Science and Pollution Research* 25, 22850–60. https://doi.org/10.1007/s11356-018-2379-2

Eglash, Ron. 2009. "Oppositional Technophilia." *Social Epistemology: A Journal of Knowledge, Culture and Policy*, 23:1, 79–86. https://doi.org/10.1080/02691720902741407

Ejembi, Oche, and Saleem K. Bhatti. 2015. "Client-Side Energy Costs of Video Streaming." *IEEE International Conference on Data Science and Data Intensive Systems*, 252–59.

GeSI (Global e-Sustainability Initiative) and Accenture. 2015. "#SMARTer2030: ICT Solutions for 21st Century Challenges." https://smarter2030.gesi.org/downloads/Full_report.pdf

Global Energy Monitor. "Global Coal Plant Tracker." Consulted January 20, 2023. https://globalenergymonitor.org/projects/global-coal-plant-tracker/

Gossart, Cédric. 2015. "Rebound Effects and ICT: A Review of the Literature." In *ICT Innovations for Sustainability*, eds. Lorenz M. Hilty and Bernard Aebischer. Dordrecht: Springer, 20435–48.

Hilty, Lorenz M., and Bernard Aebischer. 2015. "ICT for Sustainability: An Emerging Research Field." In *ICT Innovations for Sustainability*, eds. Lorenz M. Hilty and Bernard Aebischer. Dordrecht: Springer, 3–36. https://doi.org/10.1007/978-3-319-09228-7_1

Horner, Nathaniel C., Arman Shehabi, and Iñes L. Azevedo. 2016. "Known Unknowns: Indirect Energy Effects of Information and Communication Technology." *Environmental Research Letters* 11:10. https://iopscience.iop.org/article/10.1088/1748-9326/11/10/103001

Ihayere, O., P. Alege, G. Obindah, J. Ejemeyovwi, and P. Daramola. 2021. "Information Communication Technology Access and Use Towards Energy Consumption in Selected Sub Saharan Africa." *International Journal of Energy Economics and Policy* 11:1, 471–82. https://iopscience.iop.org/article/10.1088/1755-1315/665/1/012039

Kong, Yani. 2022. "Examining the Carbon Footprint of Streaming Media in Online Teaching and Learning". Summary at https://www.sfu.ca/sustainability/commitments-initiatives/living-lab.html

Lambert, Sofie, Margot Deruyck, Ward Van Heddeghem, Bart Lannoo, Wout Joseph, Didier Colle, Mario Pickavet, and Piet Demeester. 2015. "Post-Peak ICT: Graceful Degradation for Communication Networks in an Energy Constrained Future." *IEEE Communications Magazine* 53 (11): 166–74. https://doi.org/10.1109/MCOM.2015.7321987.

Lange, Steffen, Johanna Pohl, and Tilman Santarius. 2020. "Digitalization and Energy Consumption. Does ICT Reduce Energy Demand?" *Ecological Economics* 176. https://doi.org/10.1016/j.ecolecon.2020.106760

Larkin, Brian. 2013. "The Politics and Poetics of Infrastructure." *Annual Review of Anthropology* 42, 327–43. https://doi.org/10.1146/annurev-anthro-092412-155522

Lobato, Ramon. and Julian Thomas. 2015. *The Informal Media Economy*. Malden: Polity.

Marks, Laura U. 2017. "Poor Images, Ad Hoc Archives, Artists' Rights: The Scrappy Beauties of Handmade Digital Culture." International Journal of Communication 11, 3899–916.

Marks, Laura U. 2021, August 3. "A Survey of ICT Engineering Research Confirms Streaming Media's Carbon Footprint." *Media + Environment.* https://mediaenviron.org/post/1116-a-survey-of-ict-engineering-research-confirms-streaming-media-s-carbon-footprint-by-laura-u-marks

Marks, Laura U. and Radek Przedpełski. 2021. "Bandwidth Imperialism and Small-File Media." In *Post-45, Special Issue on "New Filmic Geographies*," ed. Suzanne Enzerink. https://post45.org/2021/04/bandwidth-imperialism-and-small-file-media/

Marks, Laura U. and Radek Przedpełski. 2022. "The Carbon Footprint of Streaming Media: Problems, Calculations, Solutions." In *Film and Television Production in the Era of Climate Change: Environmental Practice, Policy and Scholarship*, eds. Pietari Kaapa and Hunter Vaughan, 207–234. Cham: Palgrave Macmillan.

Montevecchi, Francesca, et al. 2020. *Energy-Efficient Cloud Computing Technologies and Policies for an Eco-Friendly Cloud Market*. Vienna: Borderstep Institute and European Commission Directorate-General for Communications Networks, Content and Technology.

Obringer, Renée, Benjamin Rachunok, Debora Maia-Silva, Maryam Arbabzadeh, Roshanak Nateghi, and Kaveh Madani. 2021. "The Overlooked Environmental Footprint of Increasing Internet Use." *Resources, Conservation & Recycling* 167. https://www.sciencedirect.com/science/article/pii/S0921344920307072?via%3Dihub

O'Doherty, Caroline and Paul Hyland. 2021, September 29. "Fossil Fuel Burning Plants to be Used in Emergency, Says Ryan as EirGrid Warns of Major Electricity Outages." *Independent.ie*. https://www.independent.ie/irish-news/fossil-fuel-burning-plants-to-be-used-in-emergency-says-ryan-as-eirgrid-warns-of-major-electricity-outages-40899079.html

Park, Yongmoon, Fanchen Meng, and Muhammad Awais Baloch. 2018. "The Effect of ICT, Financial Development, Growth, and Trade Openness on CO_2 Emissions: An Empirical Analysis." *Environmental Science and Pollution Research* 25, 30708–19. https://doi.org/10.1007/s11356-018-3108-6

Preist, C., Daniel Schien, and Eli Blevis. 2016. "Understanding and Mitigating the Effects of Deviceand Cloud Service Design Decisions on the Environmental Footprint of Digital Infrastructure." In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems*. Santa Clara: ACM [Association for Computing Machinery], 1324–1337.

Raghavan, Barath and Justin Ma. 2011, August 19. "Networking in the Long Emergency". *GreenNet'11*. https://doi.org/10.1145/2018536.2018545

Reinsdorf, Marshall, Gabriel Quirós, and STA Group. 2018. "Measuring the Digital Economy". Washington, DC: International Monetary Fund. https://www.imf.org/en/Publications/Policy-Papers/Issues/2018/04/03/022818-measuring-the-digital-economy

Saidi, K., Hassen Toumi, and Saida Zaidi. 2017. "Impact of Information Communication Technology and Economic Growth on the Electricity Consumption: Empirical Evidence from 67 Countries." *Journal of the Knowledge Economy* 8, 789–803. https://doi.org/10.1007/s13132-015-0276-1

The Shift Project. 2019. "Climate Crisis: The Unsustainable Use of Online Video. The Practical Case Study of Online Video." https://theshiftproject.org/en/article/unsustainable-use-online-video/

Tomlinson, Bill, Eli Blevis, Bonnie Nardi, Donald J. Patterson, M. Six Silberman, and Yue Pan. 2013. "Collapse Informatics and Practice: Theory, Method, and Design." *ACM Transactions on Computer-Human Interaction* 20 (4): 1–26. https://doi.org/10.1145/2493431.