

Scenes from the Regional Geographies of Cloud Infrastructure: Routing, Humming, Hydrating

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Abstract

Data centers are resource-intensive facilities, relying not only on computational hardware but also on ancillary systems such as air conditioning and backup generators to maintain the computing capacity required for delivering a broad range of global services. While substantial research has focused on internal operations of data centers, considerably less attention has been directed toward the external landscapes and environments where they are sited. This paper draws on fieldwork conducted in regions with high concentrations of data centers in Germany and Switzerland. Through on-site observation, mapping, photography, and soundscape recording, we re-interpret the regional settings where large-scale cloud infrastructure providers are located. This tentative study seeks to elicit counterintuitive insights into digitality and the often-overlooked relationships between computer-intensive infrastructures and their surrounding environments.

Keywords: cloud computing infrastructure, environmental aesthetics, regional geographies

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The Climate of Computer Processing

Over the past few decades, visual representations of climate change have proliferated, contributing to the collective imagination around the phenomenon. However, as recent climate-related disruptions illustrate, climate change imagery continues to focus largely on the dramatic consequences of extreme events. Press coverage of the 2024 floods in eastern Spain and southern Brazil, as well as the hurricanes in Florida, for instance, often relied on recurring narrative framings and familiar rhetorical tropes. Such accounts tend to foreground the aftermath of disaster through images of submerged rooftops, vehicles smashed and piled together, collapsed infrastructure, and similar scenes of destruction.

Critics argue that this disaster-centric focus, while indicative of the rising frequency of extreme events tied to climate instability, misses the quotidian and less immediate aspects of climate change (Hulme 2009)—the ‘slow violence’ (Nixon 2011) associated with ongoing environmental degradation, which steadily pushes the increase in global temperature averages. Addressing the complex realities and scales of climate change is not simply a matter of

producing more images, but of interrogating and diversifying the visual repertoires through which climate change becomes culturally intelligible and meaningful (Schneider 2023). It would be naïve to assume that single images can overturn historically sedimented iconographies. Bringing to the fore the temporal and multi-scalar tensions that conventional climate shock imagery tends to smooth over would require no less than fundamentally destabilizing both the milieu and the enduring constitution of these images in their long *durée*. More modestly, as a conceptual and political gesture, one could attempt to include images that, though not entirely absent, appear with less frequency in this established repertoire: among others, images of underobserved places, practices, and dynamics involved with the everydayness of climate change drivers. Moreover, tracing continuities, rather than focusing solely on the consequences, could refine the distinction between climate change as a geological constant and as an anthropogenic phenomenon—highlighting the historical environmental rifts driven by particular forms of human activity on Earth (Dunker & Chakrabarty 2021).

Even when it comes to portraying the main drivers of climate change, it would be valuable to represent them in a more diverse manner, reflecting the wide range of anthropogenic factors transforming ecosystems. Both intensive agricultural and highly industrialized societies are well-acquainted with environmental challenges, whether due to the effects of intensive farming on soil and the atmosphere or the pollution generated by factories and power plants. These processes certainly carry a significant, almost ghostly presence into the collective imagination of climate change—and justifiably so. However, images of digital infrastructures contributing to environmental problems are seldom seen. On the contrary, digital technologies are often imagined as a pathway toward a more sustainable future. Sustainable development agendas have indeed heavily relied on the potential of digitalization, with the digital transition of production-consumption systems often being associated with greener energy sources, particularly when compared to traditionally well-known carbon-intensive processes.

However, computer technology not only has a long environmental history (Ensmenger 2018), as it may also be more closely linked to legacy polluters driving anthropogenic environmental change than is often assumed. As ubiquitous actors in 20th and 21st century industrialized societies, oil industries played a significant role in the development of the semiconductor and computing sectors (Mody 2023). Therefore, it is puzzling that digital infrastructure has, until very recently, been largely absent from critical perspectives on climate change imagery. While this has changed in the recent decade, this long absence has been particularly delicate in the case of resource-intensive agents in the IT sector, such as data centers. Whether for storing, processing, and transferring massive amounts of data for commercial applications, delivering real-time content for social media, gaming, and video services, training large language models and other AI systems, running complex scientific models, or validating microtransactions, data centers are central stakeholders in the ecosystem of industrial-scale computing. To reduce latency and provide redundant signal routes, these facilities are increasingly geo-distributed across continents. Operationalizing this infrastructure—which supports temporary data processing, functional caching, and long-term archiving (Schubert, Bajka & Öz 2020)—entails significant environmental pressures, including energy, land, and water usage.

As computers heat the server halls, data centers require a robust and redundant system to regulate temperature and humidity, keeping room temperatures within an optimal range (typically between 18 and 27 degrees Celsius). Cooling systems alone tend to account for approximately 40% of a data center's total energy consumption (Rong et al. 2016), relying on

electricity, water, or, in some cases, diesel generators. Moreover, data centers dissipate most of their internal heat into the immediate environment where they are located. The cloud's temperature regulation process is normally also linked to water resources. For example, a small 1-megawatt data center utilizing water-based cooling can consume up to 26 million liters of water annually (Siddik et al. 2023). It is no coincidence that many new data center campuses continue to be constructed near rivers and canals, or in areas where logistical access to water sources is more convenient and cost-effective. Water-based cooling methods tend to consume less energy than dry cooling, while the latter simultaneously increases the stress over electricity-generating sources (including hydro power)—therefore water remains integral to the functioning of most facilities, directly or indirectly.

With digital technology assuming an almost species-like role in today's anthroposphere (Peters 2015), data centers act as *thermocultural mediators* (Starosielski 2016), managing micro-climatic interactions between culture and nature, computation and heat. Much of this activity remains imperceptible to users because of the technical and logistical affordances of the cloud, which outsources computing power to specially conditioned, geo-distributed facilities that nonetheless operate in plain sight. For this reason, this paper explores these physical dimensions of digital infrastructure as they manifest in different visible (and audible) forms.

Aligning with calls for a more diverse set of images in the visual repertoire of anthropogenic climate change in this case also means intertwining the imaginary of digital infrastructures with the regional ecosystems on which they depend. Examining the regional geographies in which these facilities are situated provides visibility to how the cloud interacts with urban, industrial, and rural landscapes—within different spatial, organizational, and logistical configurations. As such, the surroundings of data centers raise several questions of form: What do the places where the cloud processes information look (and sound) like? What common characteristics do these sites share? As a contribution to the existing literature, we ask how images and sounds might put into perspective the environmental entanglements of large-scale computing infrastructures. While producing images, we develop a conceptual discussion of how cloud infrastructures actively structure scalar affordances and shape regional environments, not just as abstract systems, but through material-cultural dynamics. We highlight three concrete modes—routing, humming, and hydrating—that render legible the entanglements of energy, data, and resource management across the regional geographies of the cloud.

Unsettling Visualities: Methodological Notes

Methodologically, this paper relies on three procedures: gathering statistical information on data centers, referred to as *data center demographics*; conducting fieldwork in areas surrounding data center campuses in Germany and Switzerland, which involved multiple visits around these sites; and visual and aural documentation. The collection of statistical data on commercial data centers entailed reviewing available corporate information about these facilities, information that—while public—is often self-reported by providers through PR documents and service websites. The volatility regarding the data sources introduces methodological challenges and concerns with generalizability. Overall, the analysis of self-disclosed sectoral reports indicates that metrics vary significantly within the sector, even when standardization measures are applied. To provide a concrete example: vis-à-vis certification by the International Organization for Standardization (ISO), the vast majority of commercial data centers in Frankfurt and Zurich—the largest markets in each country—report holding ISO

50001 certification, while ISO 14001 certificates are also relatively common. These standards concern, respectively, *energy management* and *environmental management*. While the energy certification can certainly have an impact on commitments towards more environmentally meaningful practices, its high adoption by companies can also be explained by operational reasons, considering that energy efficiency can substantially reduce the costs of operating a data center, being central to the business (and its scalability) in the long run. Perhaps more telling is that certifications related to *water efficiency* and *water footprint* (ISO 46001 and ISO 14046, respectively) are far less common in reports, and regulations generally take a regional approach, focusing primarily on direct water use. This means that the full life-cycle water footprint of data centers can fly under the radar, even when there is significant usage of water in associated energy generation or equipment manufacturing and supply chains. If one considers Big Tech for a moment, for instance, Apple has reported that 99% of their total water footprint can be attributed to scope 3 emissions—which refer to supply chain and the wider range of indirect factors (Li et al. 2023). These issues further complicate the global tracking of water consumption and the comprehensive reporting of water footprints in the tech sector. They do, however, make us wonder about how these regulatory aspects are articulated with corporate sustainability imagery.

In the data center market, achieving these certifications is also important for a company's public image, as most stakeholders contracting with computing centers seek to establish a good reputation by ensuring they work with firms that comply with recognized certification standards. While confirming that certifications are relevant, sustainability scholars also affirm that their impact should not be overestimated, as certificates often reflect goals set by the companies themselves. While certifications imply a formal commitment and auditing, the stated aims are not always achieved, even when seriously pursued, and critics argue that they may eventually even lead to deleterious effects (Boiral 2007). Overreliance on certifications may hinder more thoughtful, well-paced developments in the sector, since standards based on non-binding frameworks can encourage mere ceremonial compliance—imbuing companies with a greener public image even when actual progress is unobservable. Certifications are typically highlighted in self-reported fact sheets and sustainability brochures, elevated as central elements in the visual presentation of data centers as green infrastructures. More importantly, this focus highlights the endeavours of individual firms but obscures that the deeper environmental problems in the sector stem primarily from its systemic growth and overall spread. In other words, by presenting sustainability as a matter of site-specific performance and voluntary compliance, certification frameworks may divert attention from the cumulative effects of an industry whose environmental burdens arise not only from how individual facilities operate, but also from how rapidly and extensively the sector continues to expand as a whole.

Qualitative research on data centers can help foreground spatial aspects that self-reported data otherwise flattens, inviting more contextualized, relational understandings. We focus on a regional scope, mixing sensory ethnographic fieldwork with visual and aural documentation (Canevacci 2018, Pink 2015) across five cities and their surroundings in Germany and Switzerland (namely, Frankfurt, Munich, Berlin, Zurich and Basel). Ethnographic approaches have been employed consistently in research on data centers. Steven Gonzalez Monserrate (2022) has offered compelling accounts of environmental aspects of computation through *in situ* fieldwork. Monserrate's approach ranges from interacting with technicians



Figure 1: Microsoft Data Center, Middenmeer

Source: 'Acid Clouds' project by Niels Schrader, photography by Roel Backaert

working in data centers, focusing on the experiences of the 'caretakers' of infrastructural operations and the facilities' internal environments, to collecting stories from residents living near cloud computing centers in different U.S. cities. Asta Vonderau (2019) has conducted extensive interviews with managers and engineers, politicians, and consultants involved in the planning of data centers in Sweden. Her approach offers significant insights into the policy and strategic dimensions of these infrastructures, underscoring how institutional and governmental discourse shapes dominant narratives around data centers as clean and future-oriented technologies.

Contemplating how computing infrastructures coalesce with regional landscapes can supplement the insights derived from these insider perspectives, underscoring aesthetic tropes arising from the rapid upscaling of the sector and how it reconfigures spaces. While such an approach has numerous historical precursors in urban studies (Powell 2018), its employment in the study of digital infrastructures is underrepresented, and may help unfurl 'more-than-digital' (Klausner 2022) aspects that other analyses might overlook. Therefore, as noted by Ingrid Burrington (2016) in her exploration of the urban internet infrastructure in New York, visual fieldwork does not necessarily aim to show anything that is hidden, but to provide a different framing to the mundane, with which we normally suppose great familiarity.

Due to stringent security standards, external access to photograph data centers from their inside is rarely granted. Yet, as data services become increasingly ubiquitous and the reliance on platforms enabled by continuous computing availability grows, data centers are increasingly recognized as underpinning critical infrastructure sectors (Velkova & Plantin 2023), making claims about secrecy and security more salient (Lyon & Wood 2020). As a rule of



Figure 2: Equinix AM4 Data Center, Amsterdam

Source: 'Acid Clouds' project by Niels Schrader, photography by Roel Backaert

thumb in corporate business, data centers curate how they are visually portrayed and which images of their interiors are shown. In order to provide a public visibility of the industry's infrastructure, since 2023, the Data Center Association in Germany instituted a yearly public visiting event, the *Tag der offenen Rechenzentren* (TdoRZ) (Open Data Centers Day), when the general public can have guided tours through the facilities. As put by Alexander R. E. Taylor (2021: 90), curated tours and visits fall within the logic of the "data security safari": while purpose-specific data centers may seek to remain invisible, commercial computing centers rely on publicity to attract new customers, making a cohesive corporate image essential. This visibility strategy often depicts data as permanently threatened, with computing centers promising to technically and physically protect their clients' data from any exogenous threats, avoiding also power outages and malfunction. Similarly, the strategy to portray data centers as drivers of a sustainable digital transformation often entails highlighting the modernist functional architectures of these facilities: from the straight geometric shapes and stainless-steel detailing of exteriors to the sterile corridors and blinking lights of server halls, they project an aesthetics of control and optimization. A focus on the investments in renewable energy occludes the environmental aspects tangled up with both the overall global growth and the regional expansion of data center campuses. Therefore, against the backdrop of the limited access and the curated visuality of the facilities, aesthetically surveying the external environments of data centers can offer alternative lenses to understand how industrial computing entangles with environmental factors.

This is the case with the methodologies employed by researchers invested in the visual and sensory aspects of cloud infrastructure. Among different artists exploring the visuality of data centers, we highlight the contributions of Niels Schrader and Roel Backaert (Figures

1 and 2), who have been systematically photographing data centers across the Netherlands, having documented more than 100 facilities since 2018. Their approach provides a visual, physical, and geographical sense to cloud computing infrastructures through a particular style of frontal photography with long exposure, shot during nighttime (Backaert & Schrader 2025, 177), imbuing the facilities with distinctive colourful patterns, lights, and reflections. With this, their visual research provides a particularly outer way of seeing data centers, in a stage in which they are becoming more proverbial and, therefore, opaque in urban and rural environments. Ultimately, their work shows that producing alternative imagery of these infrastructures can also be a way to engage critically and creatively with emerging (and very concrete) capital-driven spaces of real estate.

Scale: Problems with Estimations

Consulting firms project data center investments to grow globally at a compound annual rate of 22% over the next five years, reaching a cumulative total of \$7.9 trillion by 2030 (McKinsey 2025). While the inherently speculative nature of investment forecasting warrants caution and a degree of skepticism, particularly where vast real estate capital is implicated, a brief review of recent developments helps to contextualize the question of scale in the sector. As of 2021, approximately 8,000 commercial data centers were operational worldwide, with numerous additional campuses planned or under construction (USITC 2021). Currently, estimates suggest that there are about 11,000 such facilities (Visual Capitalist 2025). The United States holds a significant lead in the absolute number of data centers per country. However, cloud infrastructures are undergoing mitoses, forming distinct—though often-times overlapping—computational stacks across continents. This expansion aims to broaden access to optimized computational services and platforms on a global scale, requiring decentralization through geographically distributed servers in specialized facilities. Key strategies supporting this geo-distribution include the establishment of content delivery networks (CDNs) and edge data centers, which reduce latency and enhance reliability by carrying data processing closer to end users.

CITY (FLAP-D)	DATA CENTRES PER YEAR (DCM)			
	2014	2019	2024	2026
Frankfurt	45	49	118	139
London	67	77	137	222
Amsterdam	36	44	74	81
Paris	48	49	85	126
Dublin	14	20	69	110

Figure 3: Data Center Demographics

Source: Compiled by the Authors based on Data Center Map Figures

The largest data center hubs in Europe, often referred to by the acronym FLAP-D (Frankfurt, London, Amsterdam, Paris and Dublin), illustrate this pattern (Figure 3). According to Data Center Map (DCM), an industry index founded in 2007 to catalog computing center services, there are currently 678 commercial data centers operating in the FLAP-D region (Data Center Map 2026). When we began writing this paper, in August 2024, there were 461, compared to only 210 in 2014.¹

¹ Figures were extracted from the DCM database, which has been regularly updated since 2007. Given that the database primarily serves commercial data management needs, it is important to bear in mind that several data centers (i.e. governmental, military, university-based, and other non-commercial facilities) are excluded from these estimations. These figures are meant to illustrate rather than to provide precise estimates.

According to the same source, Germany reportedly had 170 service-oriented data centers in 2014, distributed across 31 cities, compared to 471 operational facilities across 69 cities in 2026. Twelve years ago, Switzerland counted 59 such data centers in 16 cities, while in 2026 it counts 113 facilities distributed across 25 areas. In 2023, Europe saw the largest global expansion in cloud regions, adding eight hyperscale data center clusters serving exclusively major cloud providers such as Amazon Web Services, Microsoft Azure, and Google Cloud (TeleGeography 2024), which are not included in the DCM estimates.

While this accelerated growth rate at global and regional scales is usually celebrated by the IT industry, there are increasing concerns about energy security even within the sector, as severe and frequent power outages can harm reputations, disrupt customer bases, and cause financial losses. More critically, this rapid expansion may exacerbate pressing environmental issues. Recent estimates suggest that data centers account for 1-3% of global energy consumption, with projections indicating that by 2030, they could consume between 3% and 13% of the world's available energy (Freitag et al. 2021). At the same time, energy forecasting research suggests that a transition to cleaner energy sources may partially offset this increase (Masanet et al. 2020), leading to a notable debate over whether the overall carbon emissions associated with computation are rising incrementally or expanding at an alarming rate. This uncertainty is intensified by volatility in energy efficiency trends, data traffic rates, and energy markets. Additionally, the adoption of different measurement standards and reliance on self-reported data from industry stakeholders further complicates the issue (Pasek et al. 2023). This uncertainty may also undermine public trust, hindering the expectations for meaningful environmental action at the societal level.

In a different vein, here we aim to explore the continuities between digital infrastructures and environments through the previously outlined approach. We narrate this exploration through the series of vignettes below. The three vignettes are intended to provide situated impressions of data center infrastructure, highlighting how regional material entanglements coalesce with the affordances of cloud computing. While adopting a regional approach, the analysis does not diminish at all the importance of attempts to establish global estimations. Rather, it seeks to underscore the value of a relational dialogue between perspectives operating at different scales. Therefore, the vignettes offer exploratory insights through the interplay between these impressions and provisional data on global data flows, visualizing patterns and continuities as a way of contributing to an alternative imaginary of the cloud. By attending to what is made visible or audible and what remains opaque, one can calibrate to the multi-scalar dimension of the problem at stake and advance this methodological discussion.

Routing: Logistical Landscapes

When researching the localities we planned to visit, we mapped out potential routes and examined publicly available aerial images of the surrounding areas, zooming in and out of the districts where data centers are located. Air conditioning units and cooling towers, typically arranged in geometric modules on top of the facilities, are best seen from above. They

As a methodological note, it is important to mention that DCM only presents present-day data, therefore the information about previous years was retrieved using the Wayback Machine application of the Internet Archive (archive.org), accessed on February 2, 2026.



Figure 4: Airplane Takeoff Next to Data Center

Source: Image by the Authors

give rise to a sense of apophenia—the tendency to attribute familiar shapes to unrelated visual stimuli, such as clouds or shadows—when one observes satellite images of large computing campuses. From this aerial perspective, they resemble modular blocks of electronic components, integrated circuit boards, microprocessors, or other computer parts, sparsely scattered throughout the urban fabric or across rural settings.

From street level, the view is far less whimsical. When searching for specific data centers in technological parks, it can sometimes be difficult to differentiate between them. Buildings are often windowless rectangular blocks guarded behind fences and surveillance cameras distributed around the constructed area. When located within industrial perimeters, their gray and cobalt tones blend seamlessly with the coated steel and aluminum façade cladding of the surrounding architecture. The opposite occurs when looking for computing campuses in the countryside: they stand out even from a distance. In this sense, the location of the facilities is conducive to two distinct aesthetics: camouflage or salience.

More numerous data centers are situated at exurban perimeters, near factories, warehouses, and shipping centers, optimally connected to freeways, harbors, airports and power plants (Figures 4, 5, and 6). From these peripheral nodes, data centers plug into local internet service providers and regional internet exchange points, linking to the broader network of computers anywhere else.

The regional settings of the cloud suggest that the location of computer-intensive facilities converges with conventional transportation corridors and networks. There are noticeable connections between current data traffic operators and established logistical and operational hubs. This is the case, for instance, of a recent data center campus in the district of Fechenheim, in Frankfurt am Main. Covering an area of 400,000 m³ of enclosed space, sits the former Neckermann headquarters. Cable rolls, cranes, heavy machinery, and construction equipment in the whole area can be seen from a distance. A signature steel-frame project from the architect Egon Eiermann, the main building used to host *Neckermann Mail Order House*, one of the largest mail-order retailers in West Germany from the 1950s to the 1980s.



Figure 5: Logistical Services behind a Data Center

Source: Image by the Authors

In the 1960s, TIME Magazine (1960) reported that, at its peak, the company processed nearly 40,000 orders per day, requested by customers from the 400-page catalogs distributed across and beyond the Federal Republic.

Given the infrastructural demands of its logistical center, the retail corporation was strategically positioned near the Frankfurt East Harbor (Osthafen), and through its established distribution system it became one of the largest logistical sites in Europe. In 2012, after years of financial decline and struggles to adapt to the digital retail landscape, Neckermann filed for bankruptcy. Its Frankfurt headquarters was acquired in 2020 by Interxion, a Dutch cloud colocation provider that was later acquired by the real estate investment trust Digital Realty, which operates as part of a global network of over 300 data centers (DCD 2019). Designed to be a park with multiple facilities, the full build-out is expected to be completed in 2028, including eleven data centers with 200 MW of power capacity.

Therefore, Fechenheim stands as a liminal site in contemporary logistics, where regional geographies, networks, and supply chains materialize the capital articulations of digital and pre-digital infrastructures. The campus construction site foregrounds the becoming of a residual logistical premise and its iconic modernist architecture into a major European data center hub. Media historians have been pointing out the significant historical-geographical continuities between the support systems of digitality and legacy industrial infrastructures (Pickren 2018). Networks, after all, tend to follow other networks, forming an infrastructural palimpsest. The spatial qualities of the cloud can be better expressed as *transient spaces*: beyond the monolithic passivity often associated with the external appearance of data centers (which are often misconceived as passive data storage stations), the cloud is conducive to continuous processes of centralization and decentralization. Although industrial computing



Figure 6: Parcel Center Behind Data Center

Source: Image by the Authors

does not produce tangible goods in a traditional sense, its operation is predicated on the storage, processing, and transmission of data as a circulation-valued commodity. Cloud infrastructure moves data, and consequently capital, from areas dense with users (whether human or non-human) to regions equipped with specially conditioned computer server halls. While at first glance it may seem that data traffic merely follows traditional patterns, a closer examination reveals how shifts in communication infrastructure and digital platforms reassign particular financial roles to these routing networks. Given that computing and data transfer capacity are established as assets for service-based operations, the regional settings of the cloud unfurl how, in a time of high computational demand, data centers establish themselves as a new kind of industrial powerhouse, including some of the environmental pressures normally associated with traditional industries.

This becomes more intriguing when considering the post-material epistemological assumptions that over the last five decades shaped the idea of digitalization as a process of dematerialization (Ensmenger 2018). The digital transformation has been expected to lead to less materialistic lifestyles, with societies transitioning from industrial modernity to an information-centered form of organization (Bell 1973). Detached from its material constraints, the digital economy was described as 'weightless' (Coyle 1999), a notion that still reverberates today. As a concept, *digitality* emerges from within this complex and ambiguous amalgamation of myth and matter (Distelmeyer 2022). However, critically exploring the regional geographies of cloud computing shows how the continuities between traditional logistical hubs and new technological centers are not arbitrary, since the storage, processing, and transmission of information re-enacts established networks of intensive resource consumption, sometimes literally stacking up over them.



Figure 7: Data Center in Industrial District with City Skyline in the Background

Source: Image by the Authors

Conversely, while computing campuses may be located at exurban perimeters (Figure 7), this does not mean that these infrastructures do not integrate the environments of small towns and other populated areas. In a semi-rural town in Brandenburg, a few kilometers from Berlin, reaching a recently established data center campus required an extensive journey from Southern Berlin, involving two long train trips to the last stations on consecutive lines, followed by a long bus ride and a considerable walk. Construction was still underway, with the campus continuing to expand. The village houses in the foreground of the data center form an uncanny scene (Figure 8), and serve as a blunt reminder of how such facilities intertwine with populated settings in several places (Figure 9).

Oftentimes these sceneries also intersect with sites historically related to energy provision, and one may say that the routing of data coalesces with the routing of energy. Two hyperscale data centers in Berlin are located, respectively, in Marienpark, the site of the former Mariendorf gasworks, and in the Siemensstadt industrial area. Both areas are closely linked to Berlin's industrialization in the late nineteenth and early twentieth century.

In Marienpark, a 24 MW data center launched in 2022 sits within the 300-acre area of the old municipal gasworks dismantled in 1999 (Figure 10), which was once the largest gasworks in Berlin (ARD Mediathek 2024). When we visited the area, the influx of construction materials in the park area was visible, as the construction work also set the preparation for a new data center complex from the British company Virtus, which plans to start operating a four-building 56 MW cluster in 2026 (DCD 2023). The streets surrounding Marienpark bear the marks of a new large-scale construction project, but the dismantled gasworks structures and the decommissioned water towers—one of which now hosts numerous mobile network antennas—anchor the landscape as remnants of an earlier industrial scene.



Figure 8: Data Center in a Rural Village

Source: Image by the Authors



Figure 9: Data Center in an Urban Neighbourhood

Source: Image by the Authors



Figure 10: Dismantled Gasworks

Source: Image by the Authors



Figure 11: Combined Heat and Power Plant

Source: Image by the Authors

The Siemensstadt data center is embedded in a much more explicit industrial atmosphere. While we visited the area, dense vapor rose steadily from the towering cooling infrastructure of the Berlin-Reuter-West combined heat and power (CHP) plant (Figure 11). The geographical adjacency between both companies (and both industries)—which are separated here only by a canal of the Spree River—makes the presence of industrial activity feel more immediate in this case. The power plant supplies heating to businesses and households in Berlin. Adjacent to it stands Germany's largest heat storage facility: a 45-meter-high tank capable of storing 56 million liters of hot water. The Climate Protection and Energy Turnaround Act of Berlin (EWG Bln) aimed to reduce, by 2030, the city's CO₂ emissions by at least 70% compared to 1990 levels, making the city CO₂-neutral by 2045. When it was elaborated, the act declared this transition as both technically feasible and economically viable (BerlinOnline GmbH 2021). A positive outcome for this strategy hinges largely on the decarbonization of the Berlin-Reuter-West CHP plant.

The spatial affordances of such infrastructure disclose not only networks inherited from past generations but also the pathways of emerging technoscapes: while legacy energy plants are slated for phase-out, new infrastructures such as data centers are increasingly supposed to play a significant role in municipal heating systems. In several cities, district heating structures are being retrofitted to use the excess heat from computing centers, even though the technology is still not sufficiently scalable at present (Yuan et al. 2023). Positioning data centers as providers of municipal utilities situates them within a model of infrastructural governance, the benefits of which are nonetheless contingent upon path-dependent development trajectories. When production and consumption are structurally bound up with market logics, retrofitting strategies—such as recovering waste heat from data centers—are more likely to operate unsustainably. In such cases, these strategies risk favouring existing consumption patterns without meaningfully reducing resource use or energy demand. As municipal heating systems develop and data centers start to orient alternative means of public utility provision, the material continuities of industrial pathways should be taken as cautionary tales: overreliance on efficiency measures has caused serious *rebound effects* when energy provision innovations were introduced in the past, incentivizing not only more unsustainable consumption but also new forms of profit-centered exploitation (Luersen & de Paula 2024, Clark & Foster 2001).

Making it more critical to the case of Berlin, a significant portion of the energy and heating infrastructure of the city, including Berlin-Reuter-West, has been recently transferred from private to public ownership, with the State of Berlin purchasing the district heating network until then operated by Vattenfall Wärme Berlin AG. By reducing corporate power in the sector, this operation is expected to enable a more public-centered design of heat management, bringing social and ecological factors closer together (Sander & Weißermel 2023). In urban planning, scholars argue that this can help counter more technocratic forms of managerialism (Raco & Savini 2019). On the other hand, the longer trajectory of infrastructure brokering in public administration (Carr & Hesse 2022) recommends caution, as the authority built from within governing institutions can also lead to structural and enduring forms of unsustainable development. Both the traces of early industrialization and contemporary urban development plans converge around the data centers in Marienpark and Siemensstadt. As future regional developments are debated, the steady growth of data centers in urban districts and the persistent vapor plume from the Berlin-Reuter-West plant stand as vivid manifestations of the path dependencies through which energy, climate, and computational systems become infrastructurally entangled.

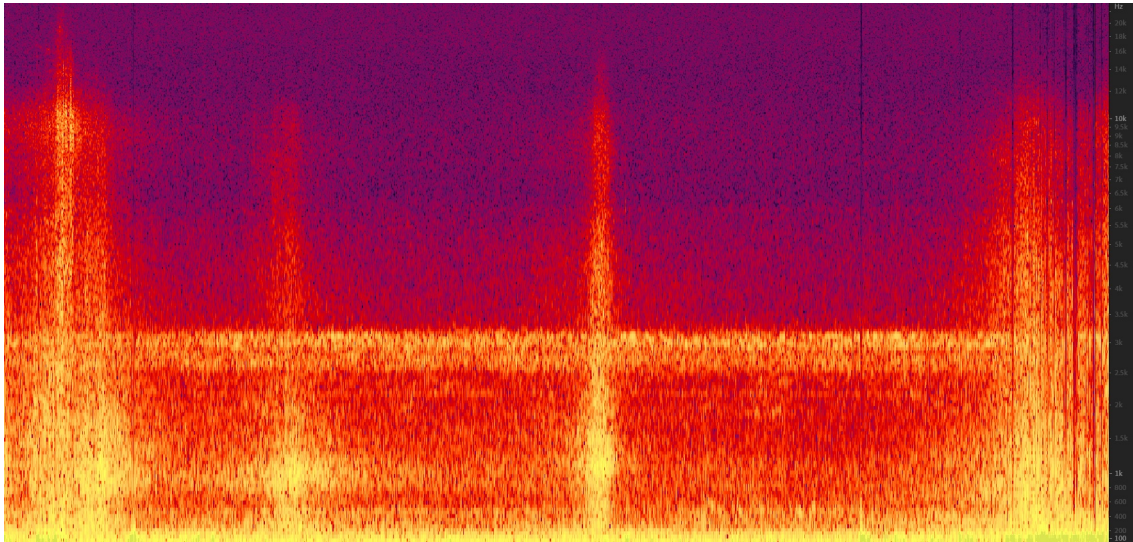


Figure 12: Spectromorphological Analysis 1

Source: Eduardo Luersen

Humming: Ground Noise

While in visual terms data centers normally sit in an apparent restraint opacity within industrial districts or amid logistical hubs, this appearance is contradicted by the very loud humming that can be heard sometimes next to the data center, sometimes even a few kilometers away. Through the monotonous rhythm of the cooling systems necessary to keep the internal server halls at optimal temperature, a specter of the operational regularity of data centers sprawls out through sound—more prominently so when artificial cooling is needed. The humming emanating from the buildings may ultimately represent not only the operation of a single facility, but the cloud's larger metabolism, with data from multitudes of users being stored, processed and transferred from the facility.

The spectrogram² in Figure 12 graphically represents the sound emanating from a data center in a semi-rural location east of Munich, about 15 kilometers from the geographical center of the metropolitan area. When we visited this location, the deep and constant humming of the data center arrived long before the facility could be seen. As we arrived at a small green recreation area with a lake, we started hearing a strange drone sound, accompanied by a regular whistle. It was not a distinguishingly loud noise, but a low and constant tone that seemed to envelop everything. As it was late Springtime, the weather was already quite warm, friends were having picnics, and there were some people swimming in the lake. The intermittent sounds in the locality—mostly people talking and birds chirping—formed counterpoints to the deep and monotonous hum in the background. Since the data center is located about 1.5 km from the main access point to the bathing area, we initially thought the sound we were hearing might be coming from a different source. At a distance, we spotted a large parcel storage and shipping facility, with trucks lining up in front of its warehouses.

² The spectromorphological analysis shows that this data center is humming regularly at the 3K range, in addition to stable and intense amplitudes at the lowest range of spectre.

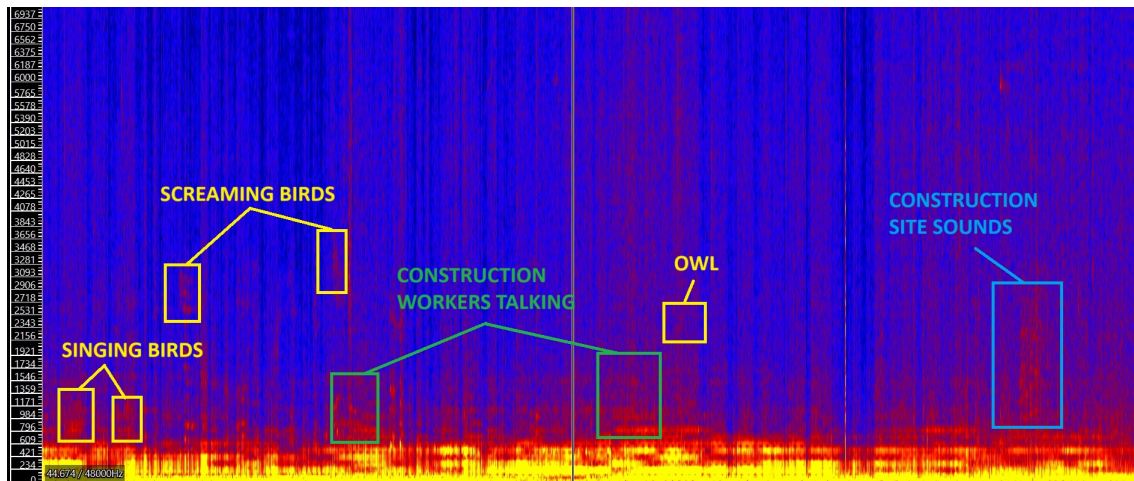


Figure 13: Spectromorphological Analysis 2

Source: Eduardo Luersen

We assumed the noise could be coming from truck engines. However, as we got closer to the area, we realized that the sound was indeed emanating from the data center block on the other side of the road. Since this field trip took place in late May 2023, the air conditioning systems were likely already running at significant capacity to refrigerate the server halls, contributing to the intensity of the noise emitted by the facility.

From then on, we started taking an audio recorder during fieldwork trips. Eventually, we decided to return to the vicinity of this data center in October that same year, to record the soundscape with proper technical equipment. Upon arrival at the lake area, everything was remarkably quiet. The area was nearly empty, with only a couple of locals taking their dogs for a stroll in the park. As the temperature was about 6 degrees Celsius, accompanied by a cold breeze, there was no one swimming. To our surprise, even with the relative silence, we could no longer hear the data center from the lake area. We pondered that the gusts of wind could be occluding the perception of the sound emitted by the facility, so we decided to get closer, walking the same path as on our previous visit. Only when we arrived very near did we start hearing a continuous but not very intense hum, at a medium-low frequency. It was nothing like the loud, constant tone we had heard during the Summer. The data center was still operating 24/7, as confirmed by the cloud service provider. However, due to the cold temperature, artificial cooling was much less necessary. Thus, the humming we experienced during springtime was most likely caused by the activity of intensive cooling equipment at work. In other words, as their surrounding ecosystems, the artificial environments of data centers also exhibit a sort of seasonality. We can expect different soundscapes depending not only on internal equipment, but also on the external temperature and weather conditions. Similarly, in the Summer, swimmers will likely bathe amidst the humming emitted by the facilities.

The previous case exemplifies one of the most characteristic examples, where the sounds of a recreation space in a semi-rural district intertwine with the humming of a data center, even one that is situated at a reasonable distance. We recorded soundscapes around various other data centers elsewhere. In terms of sonic dynamics and forms, we find a surprising aural heterogeneity. Listening in retrospect to the recordings in data center areas, the low

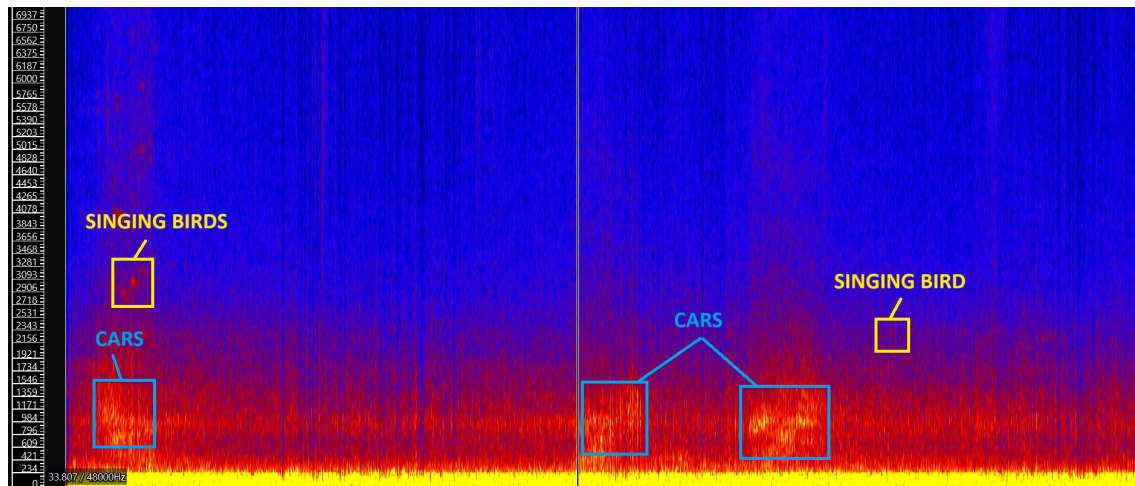


Figure 14: Spectromorphological Analysis 3

Source: Eduardo Luersen

hum emanating from the facilities envelops the everyday rhythms of the districts where they are installed, underscoring the overlaps of the computing centers with regional dynamics.

The three annotated spectrograms that we present in this article (Figures 13, 14, and 15) highlight sonic events in a few of these soundscapes. When listening to the field recordings, sounds which are easily dismissed on site come to the fore. These include the singing of various bird flocks near the facilities, but also the rushing cars speeding down the highways behind some of the computing centers.

Around data center campuses, we could also hear working men shouting at each other occasionally, followed by construction site noises—sometimes these sounds referred to the construction of new data center buildings nearby, such as in the first recording, which corresponds to a campus in Griesheim, Frankfurt.

These soundscapes suggest a superimposition of data centers onto their regional surroundings, layering infrastructural hums over the diverse sonic events unfolding in these

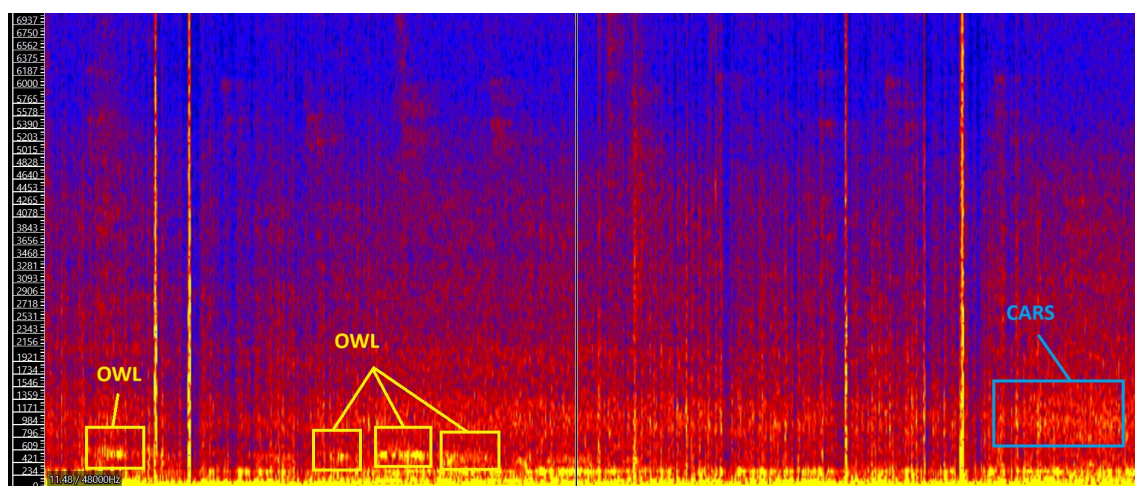


Figure 15: Spectromorphological Analysis 4

Source: Eduardo Luersen

environments. Data centers already produce several sounds within the spectrum of human auditory perception, ranging from steady engine-like hums to more strident noises. They provide monotonous but still rather varied sorts of tones. Capturing soundscapes near other data centers made us perceive a surprising variation in tone, comprising different frequency ranges. The continuous noise of each facility sonifies the cooling apparatus of these resonant boxes, mimicking the dynamic of heat dissipation in these facilities. Therefore, by bringing to the fore this series of sensory impressions, soundscapes outline, in an aural dimension, the enduring flow of contemporary computational processing and the heat-exchanging metabolisms of cloud infrastructures.

Although a more sustained analysis of this dimension lies beyond the scope of this first tentative study, one may speculate that such acoustic conditions could also shape the behavior of other species. It is conceivable, for instance, that the constant sounds of data centers, particularly in ultrasonic or infrasonic ranges beyond human perception, may affect other animals inhabiting these areas. This is a subject that invites further sensory and ecological inquiry. Research attentive to the intrusion of data center acoustics into seasonal rhythms and temporal shifts in animal life, such as those examined in phenology, as well as into patterns of bird navigation and migration, could meaningfully test this hypothesis beyond our curiosity. The current, more speculative work presented in this vignette may, on the other hand, resonate with conventional goals of soundscape research (Schafer 1994), which sought to understand emerging compositional relationships between societies and their sonic environments. In this context, when confronted with new forms of noise in urban and rural areas, it draws more modest insights from acoustic ecology, echoing Hildegard Westerkamp's (2002) call for attentive listening as a basis for sensory practice and engagement with environmental dynamics.

Hydrating: Towers and Waterways

The location of data centers is not chosen by chance. Each placement results from strategic planning to meet critical infrastructure needs and economic expectations. In this context, efficient access to water is paramount to many facilities, as they rely on it for cooling, using systems based on chillers, evaporative cooling, adiabatic pre-cooling, direct liquid cooling via heat exchangers, or other cooling techniques (Figures 16 and 17).

Unlike traditional industrial sectors prior to regulation, data centers rarely release conventional pollutants into water bodies, though their cooling systems can generate thermal effects that must be managed. As some of them may withdraw substantial amounts of water for cooling, this could lead to increased concentrations of existing air contaminants due to warming or evaporation. Therefore, careful treatment and maintenance of the infrastructure is required to prevent the spread of disease through heat dissipation systems. When cooling towers are involved, fans and related equipment can foster environments conducive to bacterial growth, such as *Legionella*. Following a *Legionella* outbreak near a petrochemical plant in the Nord-Pas-de-Calais region in 2003—which led to several infections and casualties, and was attributed to a faulty industrial cooling tower—France introduced stricter regulations to prevent airborne transmission of the bacteria near industrial facilities (Nguyen et al. 2006). To mitigate Legionnaires' disease and other health risks, data centers in high-density areas within the EU must adhere to maintenance protocols established by the European Agency for Safety and Health at Work (EU-OSHA 2017). However, the use of disinfectants like



Figure 16: Cooling Towers over a Data Center in Frankfurt am Main

Source: Image by the Authors

chlorine in cooling towers, while effective against pathogens, may end up contributing to air pollution.

While national regulations governing water use apply to all industrial facilities, data centers included, adherence to specific frameworks like the EU Code of Conduct on Data Centre Energy Efficiency (European Commission 2024) remains voluntary. This code outlines best practices, including implications for water management methods, to improve energy efficiency and minimize environmental risks, yet it does not legally mandate compliance unless reinforced by local or national regulations. Considering voluntary frameworks, Mél Hogan (2018) cautions against relying on Big Tech companies to self-regulate environmentally, noting their historical ties to the fossil fuel industry and repeated failures to meet stated goals. For instance, in response to regional concerns about the water usage of data centers in drought-prone areas, such as in projects to build new campuses in Spain (Aragón) and Uruguay (Canelones), Microsoft and Google have pledged to become ‘water-positive’ by 2030 (Li et al. 2023). This means replenishing the water that data centers have consumed, using closed-loop cooling systems to recycle water, while investing in new water infrastructure for local communities. However, these corporate pledges may be ineffective, not only due to the increase in data processing and storage needs that is projected for the same period (Monserate 2022), but also because, again, these promises are voluntary and non-enforceable.

So far, these agreements have provided substantial flexibility to the business of data centers, and therefore facilities tend to establish themselves where they can operate with better cost-effectiveness, stability, and affordability regarding energy, land and water supplies. As water is also an important element to produce electricity, in many cases there are observable continuities between the physical location and pathways of energy providers, electricity conversion stations, and data center operators.

In some of our field trips, as we walked from train and bus stations to the data centers, the sound of a river reached us long before we could see the computing facilities. In Basel, we chose to follow the Birs riverside path all the way to an industrial area where the city’s largest commercial data center (to date) is located. We walked alongside the river for several kilometers, and gradually the landscape began to give place to a mix of vegetated areas and



Figure 17: Lines of Air Conditioners and Cooling Towers behind a Data Center in Brandenburg
 Source: Image by the Authors

intermittent industrial scenery. Along the way, we often stepped on metal manholes, used for the maintenance of underground pipelines and cable systems. As we continued along the river, most of the city's modest number of skyscrapers faded into the distance, while the sounds of truck traffic on the nearby highway grew louder. At the same time, a different kind of white noise emerged. It soon became clear that it was the sound of a small dam nearby. This spot connected the river trail to the lightly trafficked highway, while also giving access to a residential neighborhood. The hydroelectric plant and this residential area are already near the data center. The entanglements between rivers, energy infrastructures, and data processing facilities become obvious once one begins to pay attention to the landscape.



Figure 18: Unplugged Pipe
 Source: Image by the Authors



Figure 19: Broken Cable
 Source: Image by the Authors



Figure 20: Flues of a Data Center in Brandenburg

Source: Image by the Authors

Along the riverside trail, tangled between vines, shrubs and other sorts of vegetation, we spotted a particularly thick pipe running near the water (Figure 18), most likely a decommissioned water pipe that once connected the industrial area of Münchenstein to the urban center of Basel. Though the pipe has been disconnected, it remained dangling by the riverside as a reminder of discontinued infrastructures. The other end of the pipe ran into a wall extending into the water, alongside smaller pipes and cables that had not been disconnected, at least not at that point.

Bridges along the route often served as outage points, where outdated or broken cables (Figure 19) would occasionally surface from the water. Crossing a small viaduct brought us just a few meters from an energy distribution firm, located immediately adjacent to the data



Figure 21: Data Center by a River

Source: Image by the Authors



Figure 22: Lake Next to Data Center

Source: Image by the Authors

center. It is no secret that high-capacity data centers, even before the most recent AI surge, can incur energy bills in the six-figure range per month (Pilz & Heim 2023). Access to efficient, affordable energy often dictates the placement of these facilities, occasionally leading to energy and computing infrastructures lying side by side. From these serendipitous walks, it becomes apparent that the pathways of data processing and energy provision are deeply intertwined, likely to the point of interdependence—made visible through the geospatial overlap of these infrastructures. Reflecting this pattern, just a couple of blocks from the same energy provider, plans are underway for a new data center of comparable size slated for completion by 2027.

A more subtle observation can be made about the connection between these infrastructures and water tables. Throughout our fieldwork, we consistently found data centers located next to riverbeds and bodies of water (Figures 21–24). Walking through the main computing campuses in each city we visited, we often found ourselves passing through data center corridors that, in some cases, ran parallel to rivers and canals for several blocks.

Drawing a direct connection between water withdrawal and geographic proximity to water tables may be beside the point here. When closed-loop liquid cooling systems are in place, water withdrawal is generally not a major concern—though the same cannot be said for facilities that rely on evaporative cooling. Again, the issue of water, or more broadly the data center's hydric metabolism, tends to be more critical for indirect uses (such as energy provision) and supply chains (including manufacturing and the overall equipment lifecycle) than for direct water usage. However, incorporating images of these landscapes can reframe the data center rush as part of a wider ecology, highlighting the frequently overlooked hydric aspects of cloud computing and its thermally controlled environments. In the imaginary of



Figure 23: River Next to Data Center
Source: Image by the Authors



Figure 24: River Next to Data Center
Source: Image by the Authors

ambient computing, water bodies are seldom understood as essential to the optimal performance of servers and the routine functioning of computer-intensive services, although they indeed are.

Final Considerations

Through these vignettes, we discussed how cloud infrastructures actively enact circulation dynamics between global and regional environments, entangling at a very material level with different urban and rural topographies. In light of an increasing demographic of human and non-human users, the support systems of planetary-scale computation may yet configure new infrastructure spaces (Easterling 2014), affecting how cities, zones, and territories function at different scales. This is enough reason to bring into focus the material tensions embedded in the very design of cloud infrastructure: on the one hand, data centers distribute their operations globally; on the other, they concentrate computational and non-computational resources in specific locations. A structural obfuscation of their environmental entanglements ensues from this dynamic of outsourcing. As Asta Vonderau (2019) argues, data center operators can oftentimes employ discursive strategies to disentangle their facilities from local social contexts by framing their work as frictionless global flows of data, downplaying the material specificity of infrastructural sites and, by extension, their environmental footprints. A closer engagement with infrastructural aesthetics can help temper this discourse, while adding to the established repertoire of anthropogenic climate change imagery. This approach is not able nor intended to provide measurable data on the environmental impact of digital infrastructures, but it can nonetheless catalyze constructive tensions in the analysis of the infrastructure–environment nexus, highlighting a broader range of regional–global relationships. In this sense, the cloud appears less like a standard picture of a server hall, and more as a messy superposition of air-conditioning units, cooling towers, and flues (Figure 16–24) around village houses, construction yards with cable rolls, fenced modular blocks, and the low hum of 24/7 heat-dissipation equipment.

We conclude by revisiting the three explored movements: routing, humming, and hydrating. Together, they foreground unusual and sometimes counterintuitive ways of perceiving the interplay between cloud infrastructures and their surrounding environments. Routing highlights the geospatial entanglements of data flows with energy circulation and legacy logistical networks; humming points to the audible pulse of industrial-scale computing; hydrating foregrounds the ancillary and overhead logics in managing regional resources. In sum, they trace, as an analytical thread, how data centers organize scale. The digital exchanges (and non-digital trade-offs) of the cloud manifest themselves to the senses at logistical sites, humming across distinct yet monotonous frequency ranges. As computer processing is ongoing, what is in fact audible in the vicinities of data centers is mainly the electromechanical activity of air conditioning systems: while images present the cloud as a renewed form of industrialism, sound renders computation as a heat dissipation metabolism.

While they cannot yield generalizable frameworks, these *in-situ* impressions of data center campuses can underscore the volatility of infrastructures, unsettling the common assumption that they are inherently stable and stabilizing systems (Schabacher 2022). The practical assemblage of geodata, rough and volatile estimations, theoretical insights and sensory observations in the article probes a provisional but multi-scalar learning about infrastructures. Analyzing data centers through their regional material entanglements is, thus, a partial yet constructive way to address also the instability of knowledge about them across different

scales. This is particularly relevant when considering how cloud regions have been developing globally. In the face of rising protectionism, trade wars, and geo-economic trends toward decoupling, governments at different latitudes have been legislating for what they dub 'digital sovereignty'. As Louise Amoore (2018) puts it, this state-centered maneuver underscores an attempt to render the cloud jurisdictionally intelligible, wresting it back into a form over which existing frameworks can exercise oversight. Ultimately, however, attempts to render the cloud intelligible in this manner may themselves give rise to unfamiliar relations between digital corporations and regional actors that exceed what can be materially surveyed. As James Maguire and Brit Ross Winthereik (2021: 545) put it concisely in their study of the digitalization of the Danish state, the relationship between data center corporations and regional stakeholders concerns an "exchange of capacities" that far exceeds the material trade-offs between energy and data. As they argue, in such formations, the state is in some sense becoming a little more tech-like, as it develops the capacity to make very particular promises about future regional development, while Big Tech corporations are simultaneously becoming more state-like, as they develop, though not at all unproblematically, the capacity to be seen as legitimate entities involved in the provision of utilities normally attributed to the public sector.

Therefore, it is recommendable to retain an understanding of the *locus* of the cloud as a rather unstable spatial construct. As tech companies recommission shuttered nuclear plants and coal-powered energy stations to meet the energy demands of their data centers (Crawford 2024), it remains crucial to insist on critical epistemological interventions over the post-industrial ideological assumptions of digitality. One is again reminded of Sean Cubitt's (2017) assertion that the task of computing is a cyclic flow of extraction, transfer, recombination, and outsourcing, that there are no new materials, and that sources of energy may be circular but are not newly created. This underscores how digital infrastructures may appear in the wider panorama of images of anthropogenic climate change. Therefore, exploratory — if speculative — visual and aural research into data centers and the broader infrastructures of ubiquitous digitization unravels operational logics that the conventional abstractions of cloud computing systematically filter out. In the best-case scenario, this can unfurl untapped aspects of the relationship between the development of digital infrastructures and their environmental implications, contributing, *in medias res*, to a much-needed multi-scalar understanding of this constellation.

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