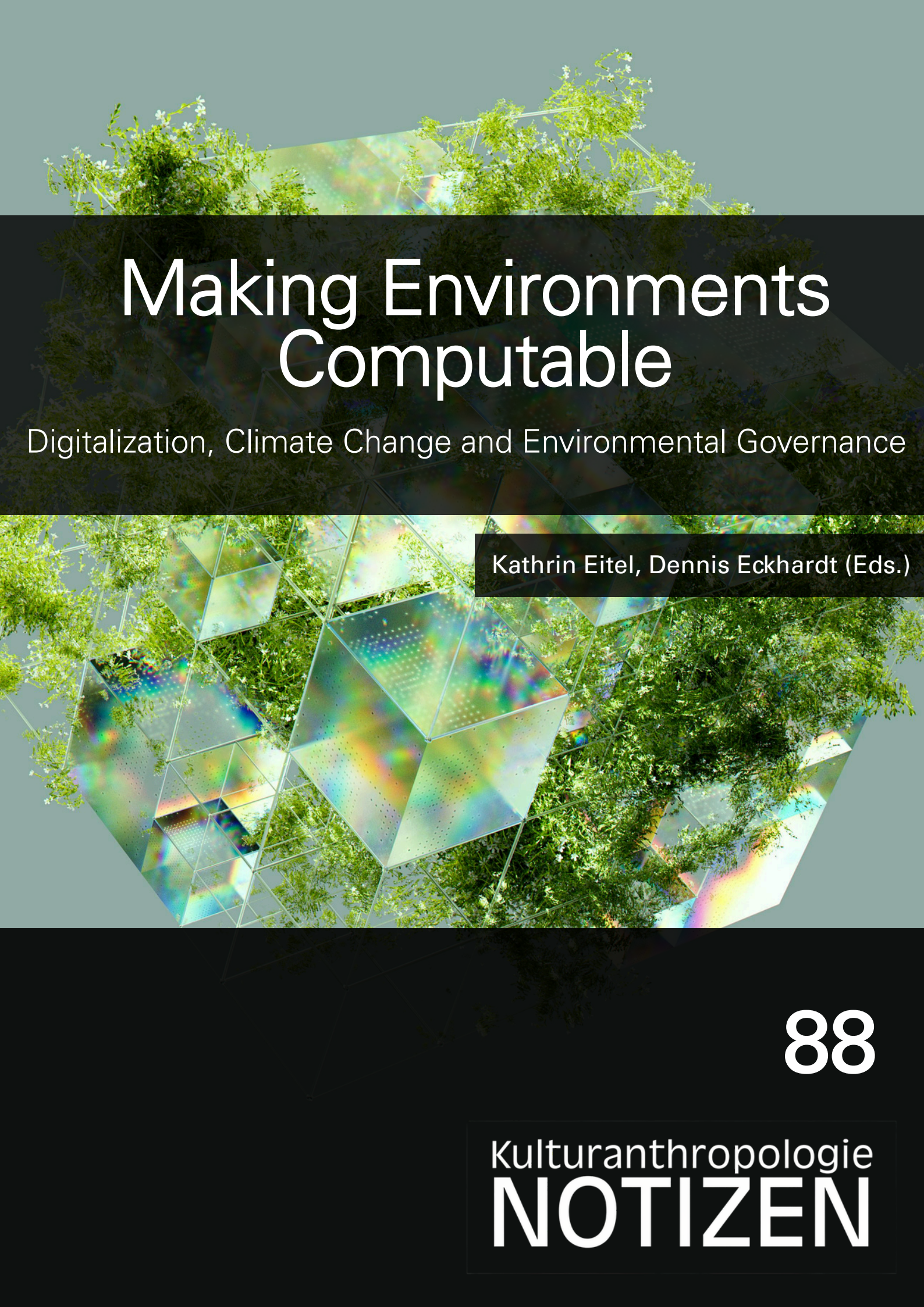




Making Environments Computable

Digitalization, Climate Change and Environmental Governance

Kathrin Eitel, Dennis Eckhardt (Eds.)

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Environmental Computability. The Politics of Knowing and Governing Climate Change

Kathrin Eitel

Abstract

Digitalization increasingly shapes how environments are known and governed amid climate change. This editorial develops the notion of environmental computability to describe the socio-material conditions through which environments become measurable, comparable, and actionable through computational systems, asking what knowledge, infrastructures, and relations of authority make this possible. Rather than simply introducing the contributions to this special issue, it reads them alongside existing scholarship on digitalization and environmental governance, offering a synthesis of current insights into how computable environments become entangled with questions of expertise and extraction, maintenance and care, and inequality—sand with longer histories carried into contemporary climate futures. Drawing on feminist STS, I propose diffraction and refraction as complementary analytical perspectives: diffraction attends to how computational environments emerge through relations, while refraction traces how existing relations of power and inequality are redirected through digital infrastructures. Together, they make visible the politics of environmental computability and the dys/continuities through which digitalization and climate governance become entangled.

Keywords: Environmental computability, Climate governance, Digitalization, Feminist STS, Computational Infrastructures, Refraction

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In the Akaki catchment surrounding Addis Ababa, Ethiopia, researchers collaborated with farmers, football players, and local residents to integrate community-based flood monitoring into existing early-warning infrastructures (Nigussie et al. 2025). Situated observations of river behaviour, rainfall, and seasonal flooding were translated into computational forms of environmental knowledge and integrated into hydrological modelling (Alemu et al. 2023), becoming valuable insofar as they could be made compatible with model requirements. At the same time, these processes also depended on servers and satellite links, on cloud platforms and the data centres that run them—infrastructures operating at a material and energetic scale far removed from local monitoring practices. The example thus shows how digitalization and climate change are already entangled in the production of environmental knowledge and climate futures.

This special issue argues that digitalization cannot be framed only as a technological response to environmental change but rather as something that materializes the conditions

through which environments become knowable and governable. I use *environmental computability* to name this epistemic, material, and political condition, continuously produced through the everyday work of capture, such as sensing and classifying, modelling and standardizing, maintaining, predicting, optimizing. Environmental computability, in other words, is the labour and politics behind turning an environment into something that can be measured, compared, and anticipated. As STS scholarship has long shown, infrastructures, standards, and classifications do more than support knowledge production and enable its circulation — they actively configure the objects they organize (Bowker & Star 1999; Jackson et al. 2007; Edwards 2013; Jensen & Morita 2015). Recent discussions of computational universalism similarly remind us that these seemingly universal computational representations rest on a great deal of infrastructural work through which heterogeneous realities become scalable and comparable (Lee & Ribes 2025). Where computational universalism traces this infrastructural work across any domain computation touches, such as finance, health, logistics, environmental computability keeps the analysis tied to what is specifically at stake when the domain is an environment: land, water, energy, and species that must be extracted, monitored, or maintained for a representation to hold, and futures that must be made plausible before intervention can follow. This semblance of universality depends on a politics of scalability that privileges hyperscales, while leaving out local situatedness and alternative trajectories (Pfotenhauer et al. 2022), including forms of indigenous and local knowledge that resist standardized computational categories altogether (Roturier & Beau 2022). Environmental computability therefore shifts attention from digital technologies themselves to the socio-technical arrangements through which distinct versions of environments become computationally tangible.

Climate change forms an important horizon of these processes, but environmental computability extends across broader fields of environmental governance, including biodiversity, agriculture, and resource management. Research in anthropology, STS, sociology, and geography has demonstrated that computational infrastructures do more than represent environmental change: they increasingly help produce it as an object of knowledge and intervention (Gabrys 2020, 2024; Edwards 2013; Bruun et al. 2022).¹ Environmental STS has likewise shown that environments are enacted through practices of sensing, modelling, and management rather than existing as stable entities awaiting representation (Lippert et al. 2015; Lippert 2018; Baya-Laffite et al. 2025). At the same time, studies on slow violence, environmental justice, and feminist technoscience have drawn attention to the uneven burdens generated by technological systems, demonstrating how infrastructures redistribute environmental risks while reproducing longer histories of extraction, inequality, and environmental racism (Bullard 1993; Nixon 2013; Davies 2019; Okafor-Yarwood & Adewumi 2020; Eitel 2022; Hein & Klepp 2025; Bray 2007; Åsberg & Lykke 2010), work that runs parallel to critical data studies tracing similar asymmetries of visibility and representation within data systems more broadly (Taylor 2017; D'Ignazio & Klein 2020). In this context, computational infrastructures do not sit outside these politics, but are themselves shaped by them.

Although ethnographic research on digitalization has expanded considerably (Boellstorff 2021; Geismar & Knox 2021; Eckhardt & Klausner 2023; Richterich & Wyatt 2024),

¹ Gabrys' own notion of environmentality captures how sensing infrastructures discipline environmental subjects and shape conduct (Gabrys 2014); environmental computability asks not how subjects are governed through data, but how the environment itself becomes governable in the first place, through the comparative and infrastructural labour that lets it travel as a measurable object at all.

computational infrastructures, climate governance, and environmental knowledge have only recently begun to be brought into sustained relation. This includes work on agriculture and food systems (Atasoy 2025), energy transitions (Sareen & Müller 2023), and perspectives from the Global South (Subramanian and Hassan 2024). Meanwhile, STS studies have further demonstrated that digital infrastructures are sites where governance, openness, expertise, and political authority are continuously negotiated rather than merely implemented (Mager et al. 2026). Whatever gets digitalized still runs on resources, labour, and energy — dependencies that often become materially concentrated in data centres. Work in critical data centre studies, in particular, has shown how computation depends on water-intensive cooling (Hogan 2015), on the ongoing work of managing air and temperature (Vonderau 2019b), and on the specific rhythms of data centre operation and maintenance (Velkova & Plantin 2023). Çelik et al. (2026) push this further, tracing scientific data infrastructures through server procurement, institutional routines, energy use, and resource extraction to show how digital knowledge production is inseparable from planetary conditions.

Building on these emerging efforts, this editorial brings these debates together through the notion of *environmental computability*, asking how environments become computationally knowable and what politics follow from their computability. To examine these processes, I draw on the complementary concepts of *diffraction* and *refraction* from feminist STS. The better-known concept of diffraction, developed prominently by Karen Barad (2007) and Donna J. Haraway (1992), directs attention to the relational processes through which computational systems, environments or other entities come into being *together* as they are co-constituted. *Refraction*, instead, can be used as a complementary lens². It asks how longer trajectories of extraction, colonialism, inequality, and environmental governance are redirected rather than displaced through contemporary computational infrastructures. This also allows environmental computability to be understood as both emergent and enduring: as a process through which particular forms of environmental knowledge become visible and affective while existing relations are reworked into climate futures.

The following sections develop this argument by bringing the contributions to this special issue into conversation with existing scholarship on digitalization, environmental governance, infrastructures, and climate change. Reading them as empirical sites through which different forms and politics of environmental computability become visible, this editorial reveals how computational arrangements redistribute authority over environmental knowledge, redirect existing relations of power and inequality, and shape which environmental futures become imaginable, actionable, or foreclosed.

Following Relations: Diffraction and Refraction

Environmental phenomena do not enter computational systems as pre-given objects. They are framed as particular kinds of computational entities through heterogeneous encounters among observations, sensors, standards, software, models, institutional routines, and practices of maintenance. Building on Lee and Ribes' (2025) discussion of "computational universalism", environmental computability draws attention not only to the technical processing of environmental phenomena but also to the infrastructural labour through which

² Refraction is not introduced because diffraction cannot account for history or continuity. Rather, refraction is introduced here to foreground a particular analytical problem: how relations travel, change direction, and acquire different effects as they move across infrastructures, institutions, and temporalities.

particular representations become scalable, comparable, and seemingly universal. Environmental computability therefore names a specific epistemic and political condition in which environments become actionable insofar as they can be rendered legible to computational systems.

Diffraction offers a fruitful way of staying with these relations without reducing them to either representation or technology. Borrowing the concept from wave optics, Karen Barad argues that diffraction is not simply a metaphor but an onto-epistemological practice for attending to the relational production of difference. Building on Haraway's critique of reflection, Barad follows Haraway's observation that "a diffraction pattern does not map where differences appear, but rather maps where the effects of difference appear" (Haraway 1992, 300; see also Barad 2014: 172). Analytical attention therefore shifts from stable entities towards the relations through which they become differentiated ("inappropriate/d other" according to Haraway 1992), stabilized, and capable of acting (see also Bateson 2000 [1972]). Haraway's insistence on situated knowledges (1988) and her later observation that "things do not pre-exist their relations but are materialized through them" (1997, 95) capture this movement succinctly. Following how computational environments emerge therefore only tells one part of the story. Environmental computability also requires attention to how relations travel and what happens to them as they move through new computational arrangements.

Although both Haraway and Barad mention refraction alongside reflection and diffraction, neither develops it as an analytical figure in its own right. I therefore propose refraction as a complementary analytical figure for tracing the temporal continuity of socio-material relations as they persist, bend, and acquire new political effects across space and time. In optics, refraction describes the change in direction that occurs when waves pass through different media (Barad 2007: 51). While diffraction foregrounds the emergence of relations, refraction draws attention to *how existing trajectories of power are redirected* as they pass through computational infrastructures. It asks which forms of expertise, extraction, and environmental governance are bent into new configurations and what becomes amplified, displaced, or obscured in the process. Colonial histories, extractive economies, and regimes of expertise do not simply disappear within computational systems; they are reworked through new infrastructures, standards, and forms of governance. As Yusoff (2024) has shown for geologic and colonial orderings, systems of classification and valuation are always political as they participate in the reproduction of enduring relations of extraction and dispossession. My notion of sedimented knowledge similarly traces how knowledge accumulates along different spatial and temporal trajectories, forming the ground through which new knowledge claims and climate resilience strategies become more or less plausible (Eitel 2026).

Refraction, then, points to more than enduring continuities: it makes visible a *politics of dys/continuity*, the way computational transformations reconfigure existing arrangements even as they create new ones along historically shaped trajectories. I deliberately use the prefix dys- to move beyond a simple opposition between continuity and discontinuity, highlighting forms of continuity that persist precisely through disturbance, friction, and harm. Infrastructures that enable computational environments, in this light, do not cleanly break with longer histories of extraction and dispossession. They grow out of dys/continuities with them, which is what makes them material and epistemic in the same movement.

Becoming Relations

These dys/continuities take shape in the ordinary, often unnoticed labour through which environments are rendered computationally tangible. They emerge through alignments among observations, standards, software, classifications, maintenance practices, ecological processes, institutional routines, and situated forms of expertise. Some environments stabilize in the process; others stay uncertain, ephemeral, or out of reach of computation (Suchman 2012)—a limit this editorial returns to as itself a political question, not merely a technical one.

The flood early-warning system in the Akaki catchment, which opened this editorial, already pointed towards this process. Community observations mattered neither because they represented an authentic local reality nor because they corrected remote sensing. They became consequential once they had been calibrated against hydrological measurements, modelling practices, institutional routines, and computational infrastructures that turned rivers into forecastable entities (Nigussie et al. 2025; Alemu et al. 2023). What travelled through the system was an environmental reality stable enough to circulate between communities, government agencies, software, and predictive models. Diffraction follows these alignments. It asks how computational environments become possible before they appear as coherent objects of environmental governance.

Similarly, *Malin J. Nemeth* and *Malte B. Rödl*'s contribution "Datafied Encounters as Representational and Relational: A More-than-Human Perspective on the Biodiversity Citizen Science Project Artportalen" treats data as the outcome of what the authors call "datafied encounters" between humans, organisms, and technology, rather than as a representation of an already given reality. By investigating the Swedish digital biodiversity platform Artportalen, the authors show that these encounters draw together organisms, observers, taxonomic conventions, digital infrastructures, and environmental governance. Species observations become biodiversity data through the ongoing work of verification, negotiation, translation, and care. Computability is an effect of these socio-material relations. What eventually circulates as an observation retains its traces even as it recedes into the background of the computational infrastructure. Biodiversity becomes computable because heterogeneous ecological encounters are made comparable enough to travel across databases, institutions, and conservation practices.

Data, then, are less the starting point of computational environments than the temporary stabilization of situated practices through which heterogeneous observations come to travel across scales. Jennifer Gabrys' analyses of smart forests make a related argument: environments increasingly participate in computational infrastructures rather than being merely monitored by them (Gabrys 2020, 2022, 2024). Sensors, trees, atmospheric processes, communication networks, machine learning, and environmental management form distributed arrangements in which forests become ecosystems, environmental sensors, carbon infrastructures, and computational environments at once (Gabrys 2016). Observation, intervention, and environmental change unfold within the same assemblage, so that computational perception and ecological process shape each other's conditions.

Questions of comparability and scale return in *Mylène Tanferri*'s contribution. In "Being Granular, Becoming Sustainable: A Preliminary Inquiry into the Wor(l)ds of Smart Farming Developers", her ethnography of smart farming developers turns on what she calls granularity: the aspiration to generate increasingly fine-grained environmental knowledge through sensors, experimentation, machine learning, and continuous observation.

Granularity owes less to technological sophistication than to the patient work of interdisciplinary collaboration, software development, calibration, maintenance, agricultural expertise, and experimental practice. Plants become environmental indicators and fields become infrastructures of observation, while sustainability acquires computational resolution through countless acts of translation embedded in everyday practices of design and repair. Granularity thus names one mode in which environmental computability is assembled.

These contributions share an interest in the mundane labour that assembles environmental computability. Observations become classifications, classifications become standards, and standards become models capable of circulating across laboratories, ministries, digital platforms, and international governance arrangements. What travels across institutions and scales are relations made durable enough to survive the journey, through practices of curation, storage, maintenance, and infrastructural coordination — which is Sørensen and Kocksch's (2021) point about data durability as an ongoing socio-material accomplishment. Older STS work on the making of governable environments runs in the same direction: Laser and Sørensen (2021) show how rivers emerge through shifting configurations of ecological knowledge, valuation, temporalities, and intervention; Edwards (2013) traces how planetary climate knowledge is assembled through observations, simulations, standards, and institutions; Bowker and Star (1999) demonstrate how classifications organize the worlds they describe; and Jackson et al. (2007) and Jensen and Morita (2015) stress the ongoing work through which infrastructures acquire stability. Computability draws these lines together in a single question: how do environments acquire the stability computation requires without shedding the heterogeneity they come from?

In each case, diffraction keeps attention on the unfinished relations through which environmental realities become measurable, comparable, and actionable. But these relations never start from scratch. Every classification carries earlier classifications; every infrastructure inherits existing infrastructures; and every computational environment carries histories of expertise, extraction, labour, and environmental intervention. Following those trajectories means staying with relations as they pass through computational infrastructures and change direction along the way. I call that movement refraction.

Redirecting Relations

The trajectories of environmental computability become particularly tangible in *Eduardo Lúersen* and *Bibiana da Silva de Paula's* contribution to this issue, which follows the regional geographies of cloud infrastructure across Germany and Switzerland. In "Scenes from the Regional Geographies of Cloud Infrastructure: Hydrating, Humming, Shuttling", their analytical figures of hydrating, humming, and shuttling reveal data centres as environmental infrastructures whose relations extend far beyond the buildings in which computation appears to take place. For example, water moves through cooling systems, electricity through servers, logistics through transport corridors, sound through neighbouring communities, and landscapes through regional planning and infrastructural investment. The cloud dissolves into rivers, power grids, roads, warehouses, maintenance work, and municipal politics. In their account, computation is enacted as an environmental formation whose material requirements continually exceed the places in which digital knowledge is actually and locally produced.

Their ethnography resonates with broader analyses of infrastructural life that have followed the environmental consequences of digital systems beyond the screen. Abram et al.

(2023) show how energy infrastructures reorder the relations between environments and political economies, while Vonderau (2019a, 2019b) shows that an apparently immaterial cloud rests on constant work that redistributes resources, labour, and value. Scientific data infrastructures cannot be separated from planetary material conditions: they run on energy, on extracted metals, and on institutional routine (Çelik et al. 2026). Read through refraction, cloud infrastructures recall Starosielski's (2015) insistence that digital communication has a material geography, and Crawford's (2021) account of AI as an extractive industry. Santarius et al. (2023) and Höfner and Frick (2019) make a comparable case for digital sustainability claims, while Ortner et al. (2023) trace data centres as contested energy infrastructures. Environmental knowledge and environmental transformation are two faces of the same material arrangement.

A similar movement shapes *Steffen Dalsgaard* and *Hasib Ahsan's* contribution, "Entanglements of Sustainability in Dhaka: The Complications of Deploying Technological Solutions to Capitalist Problems". They follow computational interventions into a city where capitalist urbanization, precarious labour, and uneven infrastructures long predate digitalization. Sustainability technologies do not arrive in an empty landscape. They settle within existing political economies, redistributing responsibilities, risks, and capacities to act while leaving intact many of the asymmetries that produce environmental inequalities in the first place. The redistribution is epistemic as much as material. Paula Helm et al. (2022, 2023) show how ostensibly inclusive forms of digital knowledge production can reproduce extractive and neocolonial relations when data, expertise, and value keep circulating unevenly. Refraction therefore has a distributive quality: environmental computability appears here as an unevenly distributed capacity to anticipate and govern environmental futures. Its infrastructures redirect environmental burdens alongside information. Nixon (2013) calls this kind of harm slow violence, and Davies (2019) follows it into toxic aftermaths; Bullard (1993) had already traced the same asymmetries in his analyses of environmental racism, which reappear today in e-waste dumping in the Global South (Okafor-Yarwood & Adewumi 2020). Environmental justice scholarship has long shown that technological interventions produce differentiated vulnerabilities rather than removing them (Fortun 2012; Eitel 2022; Hein & Klepp 2025).

The same trajectories become visible at a much smaller scale in *Laura Kocksch* and *Estrid Sørensen's* account of scientists who "cuddle" servers by switching them off when they are no longer needed (Kocksch & Sørensen 2023). That is not what seamless automation is supposed to look like. Someone still has to maintain, repair, and judge, even where automation appears complete. Refraction becomes visible here because older traditions of care are folded into infrastructures of optimization and monitoring rather than displaced by them. Puig de la Bellacasa (2017) insists that care is an infrastructural relation and not an ethical add-on, and feminist technoscience has long argued that innovation tends to stabilize existing relations of power and labour instead of overcoming them (Bray 2007; Åsberg & Lykke 2010).

Environmental computability emerges, then, as a medium through which relations are refracted across spacetime. Extraction becomes data extraction, but it still depends on land, minerals, energy, and labour. Environmental management borrows the language of sensing, optimization, and prediction, yet stays tied to older distributions of expertise and authority. Care persists inside infrastructures that grow more automated by the year. Environmental inequalities resurface in new computational geographies, and infrastructures that promise dematerialization simply relocate their material dependencies elsewhere and otherwise (Eitel 2025). The promise of dematerialization (that digitalization is somehow less material and resource-intensive than its analogue counterparts) borrows the form of that possibility

without redeeming it: material dependencies do not dissolve into a more livable configuration but reappear in altered forms. Refraction follows these trajectories: it shows how computational infrastructures bend relations without breaking them, carrying histories of extraction, dispossession, and maintenance into the computational environments now organizing climate futures.

Governing Climate Futures

Environmental computability is inseparable from anticipation: computational environments bring possible environmental futures into the present as objects of knowledge and intervention. Governability here does not denote the successful control of environmental change but the socio-material conditions under which intervention becomes conceivable and institutionally actionable. Floods become forecast probabilities before rivers overflow, biodiversity becomes indicators of ecological transformation before species disappear, agricultural fields become sites of continuous optimization before harvests fail, and cloud infrastructures are planned around projected demands long before computation takes place. Futures acquire material presence through models, simulations, classifications, and infrastructures that allow environmental change to enter the present as an object of intervention (Adams et al. 2009; Appadurai 2013; Schütze 2026).

Across the contributions gathered in this special issue, computation repeatedly transforms uncertainty into forms that can be acted upon in different ways. *Malin J. Nemeth* and *Malte B. Rödl*'s contribution demonstrates how biodiversity monitoring continuously assembles environmental change before it becomes perceptible as ecological loss. *Mylène Tanferri*'s ethnography shows how smart farming developers cultivate ever finer forms of granularity in the expectation that increasingly detailed environmental knowledge will enable more sustainable futures. *Eduardo Luersen* and *Bibiana da Silva de Paula*'s analysis of cloud infrastructures likewise shows that computational environments are built around projected futures of storage, circulation, and connectivity whose material demands are anticipated long before they become visible as environmental consequences.

Prediction, however, is only one element of these computational futures. Environmental computability also redistributes authority over what becomes imaginable, actionable, and governable. Models, platforms, indicators, standards, and algorithms do not merely anticipate environmental change; they establish the conditions under which environmental futures become credible, comparable, and politically actionable. Hajer and Oomen (2025) describe such anticipatory infrastructures as central to contemporary climate governance, while Muiderman et al. (2020) show how imaginaries of future resilience increasingly become embedded in computational practices of modelling and scenario building. Environmental futures emerge not only from ecological processes but also from the infrastructures through which those processes become computationally knowable.

This movement also reshapes the meaning of sustainability itself. Rather than constituting a fixed normative horizon, sustainability increasingly emerges as an ongoing computational accomplishment, produced through optimization, granularity, resilience, prediction, and continuous monitoring. It thereby operates as a mode of governing through crisis knowledge (Eitel & Acksel 2026; Eitel & Kaur 2026), extending earlier observations that climate change is always accompanied by environmental imaginaries through which futures become collectively imaginable (Yusoff & Gabrys 2011). Across domains as diverse as energy transitions and digital agriculture, computational practices reorganize everyday environmental

decision-making while redistributing expertise across platforms, models, and infrastructures (Sareen & Müller 2023; Atasoy 2025). The promise of computational control itself becomes political, legitimizing technological innovation as an adequate response to climate crisis and thereby helping to sustain existing trajectories (Schütze 2026). It is precisely through these anticipatory capacities that the promise of the twin transition—the joint push for digital and green transformation—derives its persuasive force (Beck et al. 2021): digital infrastructures promise not simply more information about environmental change but an enhanced capacity to anticipate, optimize, and govern uncertain futures.

Yet anticipation is itself refracted through existing histories and asymmetries as computational futures are never equally available to everyone, nor do they distribute uncertainty evenly. Some futures become measurable, governable, and investable; others remain uncertain, incalculable, or politically marginal. *Steffen Dalsgaard* and *Hasib Ahsan's* contribution illustrates this particularly clearly, showing how technological sustainability initiatives in Dhaka become entangled with existing inequalities, infrastructures, and political economies that shape whose futures can be secured and whose remain exposed. Anticipation therefore does not suspend the distributive politics traced through refraction, but it extends it into the future, redistributing risks, responsibilities, and possibilities for intervention through computational infrastructures that increasingly define what counts as environmental preparedness.

Seen together, the contributions suggest that environmental computability governs futures not by predicting them accurately, but by organizing the conditions under which particular futures become thinkable, governable, and legitimate. Diffraction follows the relations through which these futures are assembled from heterogeneous encounters among environments, infrastructures, expertise, and computation. Refraction follows the historical and spatial trajectories that continue to travel through these arrangements, redirecting longer histories of extraction, inequality, and environmental governance into new computational formations. Environmental computability emerges precisely where these trajectories become sufficiently stabilized for environments to circulate as computational objects and climate futures as objects of anticipation and intervention.

The Politics of Environmental Computability

This editorial aimed to demonstrate how every alignment that makes environments measurable also carries assumptions about what counts as relevant knowledge, whose expertise matters, how change should be measured, and what kinds of intervention become thinkable. The politics of environmental computability therefore begins before a computational output ever reaches environmental governance — it is already at work in the relations through which an environment becomes computationally knowable from the outset.

Environmental phenomena become computable only through this kind of work, that is, the work of becoming relations, redirecting relations, and governing climate futures. *Becoming relations* draws attention to the heterogeneous work through which environmental phenomena acquire computational form. *Redirecting relations* shows that these arrangements never begin from scratch: classifications, infrastructures, forms of expertise, material dependencies, care, and inequalities persist as they move through new computational formations. *Governing climate futures* extends these relations into anticipation, as models, platforms, indicators, and infrastructures make particular environmental futures plausible in the present. Together, these movements show why digitalization and climate change cannot be

treated as separate domains. The infrastructures through which environmental change becomes computationally knowable are themselves material and environmental formations, while the knowledge they produce increasingly organizes how climate change is anticipated and governed.

Diffraction and refraction make it possible to follow these movements together. Diffraction attends to the relations through which computational environments emerge. Refraction follows what happens to these relations as they continue to travel across infrastructures, institutions, places, and time. This is not continuity as simple repetition; rather, relations change direction and acquire new forms and effects: environmental management becomes sensing and optimization, extraction becomes entangled with data infrastructures, expertise is redistributed through platforms and models, and care persists within systems that appear increasingly automated. Refraction therefore returns us to the politics of dys/continuity: computational arrangements can appear novel, universal, or neutral while still carrying forward older distributions of authority, responsibility, labour, and environmental burden. Not everything becomes computable, and that limit is itself political. For example, a flood that resists modelling or a species that will not be counted do not simply await better sensors or finer granularity but mark the edge of what current infrastructures can render actionable. That edge falls unevenly: some environments remain illegible because no one has yet built the capacity to compute them, others because doing so would not serve whoever funds that capacity. Asking who bears the cost of staying outside computability belongs to this politics as much as asking what gets counted, modelled, and governed.

Environmental computability is therefore a conceptual vocabulary for following these processes ethnographically. It asks how environments become computable, which relations are carried forward in doing so, and how these arrangements shape what can become visible, credible, and governable under conditions of climate change. The question is thus not only whose worlds, knowledges, and futures continue to travel through computational infrastructures, but also how these trajectories might be redirected: which relations are reproduced, which might be interrupted, and which other climate futures could become actionable. These are questions that demand responses in a world of polycrisis, grappling with anticipatory scenarios that exceed the horizon of our own experience. Yet the possibility of redirection should not itself be mistaken for political openness. The capacity to make futures actionable is unevenly distributed, materially constrained, and bound to infrastructures that privilege some trajectories while foreclosing others.

Acknowledgements

This special issue, co-edited with Dennis Eckhardt, grew out of conversations about digitalization and climate change, about environmental governance, and out of a shared sense that these transformations are becoming harder to pull apart as the climate crisis deepens. I want to thank Dennis for building this project with me, and all contributors for their thoughtful engagement and their willingness to collaborate across disciplinary boundaries. I am also grateful to the anonymous reviewers for their careful readings and constructive feedback.

I would also like to warmly thank the organizers and participants of the panel "[*More-than-\(Just\)-Human Politics of Relating*](#)" at the STS Conference Italy 2025, where I first got to share and discuss my early thoughts on refraction. The feedback I got there was invaluable in shaping the ideas in this editorial. Particular thanks to Elisa Giaccardi and Emma Sicher for the conversations that sharpened my thinking on refraction. I am also grateful to colleagues who read and commented on earlier versions of this contribution.

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Datafied Encounters as Representational and Relational: A more-than-human Perspective on the Biodiversity Citizen Science Project Artportalen

Malin J. Nemeth, Malte B. Rödl

Abstract

To tackle the climate crisis and current biodiversity loss, scientists and citizens collaborate through citizen science projects. In the Swedish species observation system Artportalen, species sightings are turned into data and thereafter drawn upon in environmental governance and other official decision making. While this approach suggests that Artportalen's data is representative of reality, this article takes a more-than-human approach that considers existing data and nonhuman others as social participants beyond humans to explore in how far encounters surrounding the project can be understood as relational instead of representational. Drawing on the concept of encounters to interrogate these relationships, we conducted and analysed nine semi-structured interviews and identify four themes: an anthropocentric data-driven perception on a 'representational' digital map; an ecocentric worldview shaped by 'relational' encounters; the shaping of data through the 'science' context; and the assemblages of nonhumans, data, and humans that create motivation and interest in biodiversity citizen science. We conclude by discussing the tensions emerging through the different perspectives that shape encounters.

Keywords: citizen science, more-than-human approach, data journeys, encounters, Artportalen

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Introduction

Nowadays, engaging with environmental monitoring has become more accessible, with multiple and diverse data practices often emerging outside of the scientific community (Ekström 2024; Gabrys et al. 2016). This citizen-generated data might not always reach the same level of scientific validity or sensor-accuracy as researcher-led science, but can be "good enough" to have a societal impact on environmental governance (ibid.). Citizen monitoring offers possibilities to engage with environmental problems in a more democratic way, such as to use

“good enough” data to start conversations with policymakers or to request official environmental inventories (Gabrys et al. 2016). While citizen data enable contesting or questioning regulation practices and decision-making, they are often not deemed similarly credible as scientific data (Ekström 2023). In Sweden, however, citizen monitoring of biodiversity is an integral part of municipal decision-making processes and happens via digital infrastructure of the Swedish species observation system Artportalen (Swedish compound for Species Portal).

Artportalen is a platform to register observations of nonhuman encounters such as specific plants, animals, and fungi (Ekström 2022). Maintained by the Swedish Species Observation Centre Artdatabanken at the Swedish University of Agricultural Sciences in Uppsala, Artportalen offers real time data access to municipalities, NGOs and environmental organisations and agencies in matters concerning nature protection and environmental governance (Ekström 2023). The database therefore is linked to research, citizen science, and governmental work. This makes the platform different from related biodiversity citizen science platforms as it is accompanied by regulations highlighting its status regarding restoration and species protection, and thus for any decision-making on land-use and land-use change. Further, with over 80 million registered observations per year, Artportalen is one of the biggest biodiversity databases in the world (Kasperowski & Hagen 2022; Peterson et al. 2023), and its’ data is globally connected through other databases.

As a citizen science infrastructure, the public, volunteers, and organisations can collect and examine data for Artportalen, as non-professional users might also use it to identify recent observations of specific animals or locations of plants. Thus, Artportalen can be considered a boundary object, being shared with various actors and accompanying diverse practices, expectations and interests (Horst 2022; Star & Griesemer 1989). As such, the variety of ways in which Artportalen is used means that there exist many different data practices related to data generation, processing, use, and its implications for environmental governance.

Often, citizen science data like much other data is assumed to be broadly representational of a reality when considering its biases (Jönsson et al. 2024), but it is also deeply contextualized by its modes of production (Ekström 2024; Peterson et al. 2023), which seldom makes it into databases. Both approaches tend to be focusing on humans and their agency (e.g. von Essen et al. 2022). In this research, we aim to conceptualize and thereafter explore empirically a perspective on biodiversity citizen science, which highlights the role of organic *and* digital nonhuman others in this process. Accordingly, this article addresses two questions within the context of biodiversity citizen science: First, what are the implications of including datafied nonhuman others (e.g. observation data, infrastructure) in an analysis of encounters with organic nonhuman others? Second, how does such conceptual shift influence our interpretations of narratives of knowledge production? This research will thereby contribute to understandings of the role of data and citizen science in environmental governance. To achieve this, we use the concept of encounters, primarily focusing on how encounters are facilitated and mediated by Artportalen as a database and with little attention to the affordances of its connected citizen science observation app. Following Tsing, we conceptualise encounters as moments of interactions where humans and other humans or nonhumans inevitably shape and are shaped by one another (Tsing 2021). Empirically, we build on a series of interviews with people who use and contribute to Artportalen both professionally and privately.

In the next section, we outline Artportalen as our research field before introducing the conceptual framework for this article. Thereafter, we outline the research methods—interviews with people related to Artportalen as contributors and users, and how they correspond to data journeys—and introduce four themes emerging from the analysis. Finally, we respond to the research questions and return to representational and relational understandings of data within biodiversity citizen science.

Research Field

Artportalen is an extensive long-term database for Sweden's fauna and flora (Ekström 2022), where previous encounters have become datafied and thereby prefigure future encounters. Species, including those labelled protected or invasive are datafied, which heightens their salience and urgency in fields like law or ecology. Any datafied encounter is required to have an author, timestamp, location, and taxonomic details, while data on amount, developmental stage of the species, or similar are optional. Often, datafied encounters are used to either justify, condemn or foster human actions towards nature, environments and nonhumans dwelling in them (Ekström 2022; Ekström 2023; Kasperowski & Hagen 2022; Peterson et al. 2023). Such data requires constant negotiations regarding the data's validity and trust between (key-)participants (Ekström 2023; Kasperowski & Hagen 2022). Since Artportalen's data is public, various participants monitor others' observation entries regardless of their interest in the database, leading to a co-created validity (Ekström 2023). However, accessing sensitive data in Artportalen, such as information about red-listed or protected species, is restricted and only handled confidentially (Peterson et al. 2023). Therefore, only a few participants have real-time access to sensitive data. Depending on credibility and trust, some actors earned access through their professional positions. Others may request such information e.g. for research projects which are then transferred manually (*ibid.*). Moreover, Artportalen needs to be understood as a tool with biased data (Jönsson et al. 2024). These varying data practices depend on the participants' expertise and learning processes, giving rise to a lot of uncertainties or inconsistencies in the data (Ekström 2023). Technically open to everyone, imbalances within participating citizens exist; including differences in age, gender, and which species are datafied through participation (see Jönsson et al. 2024). Natural scientific researchers using Artportalen therefore are implying that such biased data needs to be identified and mitigated (*ibid.*). In this article, however, we view such 'biases' as culturally interwoven — a complex outcome of multiple past and present encounters of humans and digital and organic nonhumans (Tsing 2021; Airolidi 2022).

In the context of biodiversity citizen science, Artportalen's participants are diverse and engage in multifaceted information practices. Choosing Artportalen as a research field therefore allows us to examine multiple more-than-human encounters in a digital infrastructure and citizen science context with a diversity of professional, official, and private use cases for the data. This facilitates the exploration of how diverse actors understand environments. To do so, we combine concepts within the realm of STS and anthropology (see e.g. Barad 2003; Gabrys 2016a; Tsing 2021; Airolidi 2022; Beaulieu & Leonelli 2022).

Conceptual Framework

When focusing on encounters of humans and nonhumans in a more-than-human world, Anna Tsing's (2021) ecocentric perspective offers an alternative to shift the anthropocentric understanding of a subject–object relation. Her conceptualisation of encounters widens the definition of identity and criticises the idea of a singular and linear history. Instead of being self-contained individuals with humans at the peak of the hierarchy, all beings encounter each other in space and throughout multifaceted histories, culminating in diversity. Such diverse encounters lead to ever-shifting assemblages, rather than fixed communities. Beings also depend on collaboration to survive. Yet not all encounters end up being fruitful collaborations; sometimes encountering each other can be destructive (Tsing 2021). Any organism is thus part of what Tsing calls "contaminated diversity", which describes assemblages shaped by disturbance and historical entanglements (ibid.). Such perspective focuses on relations rather than representations (Tsing, in Harvey et al. 2020).

Tsing argues that "lively encounters *among nonhuman beings*" do not have to start and end with humans (in Harvey et al. 2020: 222); nevertheless, in our context, humans and their use of technology mediate any encounters of technical and organic nonhumans. However, digital nonhumans, or data, even if not excluded, are treated differently in the context of more-than-human relations. For example, through the "progress-as-expansion" narrative, Tsing (2021) critiques how scaling up data in hopes for never-ending progress can foster harmful anthropocentric perspectives, narratives, and practices in line with techno-positivism. Nevertheless, we argue that digital nonhumans and data should be included when considering encounters. Although her framing differs, Gabrys (2016a, 2016b) explores similar dynamics. As humans encounter big data, algorithms, softwares, and interfaces in everyday life, they thoroughly shape the way how the world is perceived and interacted with (Airoldi 2022; Beaulieu and Leonelli 2022). Data is relational; they are created through complex encounters of humans, datafied and organic nonhumans and their environment (Beaulieu and Leonelli 2022). Considering data as 'biased', however, implies that objective data existed in the first place, effectively replacing relationality with representation (Airoldi 2022; Beaulieu & Leonelli 2022).

The concept of encounters allows us to consider the constitutive role of more-than-humans instead of focusing only on human actors. Further, it emphasises the relational nature of all engagements. Data has no memory of its past encounters except through the data and metadata related to its inception, and therefore it appears to lack the contaminated diversity of more-than-human encounters. Reading Tsing's reflections on the stripping of relationships of 'production' (i.e. alienation) of matsutake mushrooms in global supply chains (2021) through the lens of data, we suggest that even when datafied, an encounter retains some or all relational qualities and memories seen from the context of their generation (i.e. for the people, communities, and infrastructures explicitly connected through specific datafied encounters). Conversely, when all semblances of relationships are removed and the datafied encounter is recontextualised with other data, it becomes alienated: more flexible and malleable in future encounters because any contexts, certainties, and uncertainties are removed. But even then, data can be seen as relational and engaged in encounters as they are re-related to other data or related in other contexts. Accordingly, we conceptualise datafied encounters in Artportalen as transformed past encounters, which travel within and beyond Artportalen as data — ready to encounter and be encountered again in their transformed state and thereby be contextualised into new relations.

As mentioned, humans are not the only ones influencing and being influenced by interfaces, algorithms and data. Organic nonhumans encounter technology in many ways, too, for example when being assessed, registered, and studied (Ekström 2024). Hence, data practices and the datafication of encounters not only impact humans' worldviews but also non-human worlds. In this context, there is a diverse array of nonhumans involved: Artportalen, the user interfaces for citizen scientists, the birdwatching community, a person watching birds as well as digital infrastructure, and a bird constitute each other. A person can only be understood as a birdwatcher and possibly a citizen scientist through the presence of birds, a community, and its means of organising and recording experiences. In this context, views on Artportalen as a "social" or "scientific" information infrastructure, including ideas about knowledge creation, expertise, and the nature of data, are constantly renegotiated through such (non)human encounters (Barad 2003; Tsing, in Harvey et al. 2020). Regardless of this, any data found on Artportalen is both a result of past encounters and a context for future encounters. We therefore propose that big data and technologies should be accounted for as actors, considering that data are not neutral self-contained information entities but a result of "contaminated diversity" (Tsing 2021), of individual lifeworlds shaped by previous human and nonhuman encounters. In a more-than-human perspective as well as in multi-species approaches, humans, nonhumans, including digital actors, should be considered.

Methodology

The concept of data journey helps to investigate how data travels across and between different sites of data practices (where data is produced, processed, distributed, and used) which are embedded in time and space (Peterson et al. 2022). Considering data as actors, data encounters different audiences for diverse purposes, which one can notice well in a citizen science project (Leonelli & Tempini 2020; Airoidi 2022; Ekström 2022). Furthermore, when data moves it is often transformed, even "thinned" (Porter 2020).

Data journeys in context of Artportalen have been vividly illustrated by Peterson et al. (2022) who follow what started as an observation of a lapwing through one's full senses becomes a "flattened bird" through filters, ready to travel through computers and networks (ibid.). To be able to travel not only between said audiences but also between various biodiversity observation networks (BONs), these databases, such as Artportalen, "[...] copy, borrow, and feed information back and forth to each other" which overall leads to an accumulation of data of humans and nonhumans, travelling within- and between these networks (Peterson et al. 2022: 293). Even though materiality is still intertwined with travelling data, the movement also influences how its 'truth' is understood, as it is constantly de- and recontextualised (Kasperowski & Hagen 2022; Peterson et al. 2022). In the case of Artportalen, travelling datafied observations have different meanings depending on differing contexts, given that meaning and truth emerge when datafied observations are encountered by other participants in the field. Focusing on encounters between humans, nonhumans, and data allows a widened lens and shift away from human agency. However, by applying the concept of encounters and inspired by data journeys, all are considered to shape one another—here explored at the example of biodiversity citizen science and its use.

Informed by our conceptual framework and the aim to collect insights into encounters at different stages of data journeys related to Artportalen, we decided to conduct interviews with people who are both professional users or contributors to the project—many also use or contribute to Artportalen privately. Interviewees often engaged with Artportalen

throughout their work by using the lists of red-listed species, long-term datasets or Artportalen as a map. Concretely, the interviewees are connected to Artportalen through various professional roles, including working for a Swedish municipality, the Swedish Agency for Marine and Water Management, an NGO, or for Artdatabanken, but also researchers. Moreover, as Artportalen is a public database, where everyone can contribute, most interviewees also engage with it privately, such as for birdwatching. All interviews took place in February and March 2024 in the context of Malin's master's thesis (Nemeth 2024). In the remainder of this article, interviewees are referred to as I1 to I9. The interviews focused both on how interviewees used datafied observations in their profession, such as environmental planning, as well as how they registered their nonhuman encounters, such as with invasive species, as data during their free time as part of the citizen science project.

Through these interviews and creating the data through an interplay of engagement and reflection in form of thematic analysis (Braun & Clarke 2022), Malin identified four themes called *'Gridded Nature': Datafied Encounters as Representational*, *'Nature Without a Grid': Datafied Encounters as Relational*, *Encounters as 'Science': Classification and Care* and finally, *Why Encounters Become Datafied*. The first two introduce perspectives regarding nature, environments, humans, and nonhumans, which influence perception and practices surrounding Artportalen. The third theme presents the narrative pervading throughout each theme. Finally, the fourth theme focuses on motivations and interests leading to specific actions which are embedded in the formerly introduced perspectives. Overall, these themes outline different ways of engaging with and making sense of environments.

As only one author conducted the interviews and collected the data, we write in a first-person narration throughout the results to accurately represent the data collection process. In the discussion section, we return to using "we" to account for the shared interpretation of the findings.

Results

'Gridded Nature': Datafied Encounters as Representational

As mentioned, I named the first theme 'Gridded Nature' since nature is seen through the grid of a map. Maps divide landscapes into grids and coordinates, and even though Artportalen is understood as a tool and data storage, the idea of Artportalen rests on citizen scientists and others continuously datafying their encounters with nonhuman others. Viewing Artportalen as a map, interviewee 8 reflects: "It's a map. And you get a dot on a map. It presents nature in a not-so-dynamic way" (I8: 7). Hence, in that context, data journeys neither start through encounters with nonhumans nor reach their endpoints as results of, for example, research. Situated somewhere in between, insights of past observations are followed by new observations, which again lead to more insights. This creates a feedback loop of datafied observations and aligns with Tsing's (2021) understanding of progress narratives within science.

Many people report for their pleasure, following their passion embedded in a long tradition to map their environment, or to communicate with other like-minded people (I3–I9). This leads to diverse reports as "[...] people will report differently" which creates difficulties (I2: 2; I5; I8). Such unsystematic data is seen as valid by Artportalen's administrators and scientists who use the data for their research yet understood as incomplete or incohesive.

Diverse data indicate diverse practices which can be a hindrance for data to travel smoothly. Not only do researchers struggle with incohesive data, but people working on city development, forestry, or restoration projects do, too. Cities grow, roads are built, and forests are used by their owners—requiring data about what might potentially be protected. ‘Gridded Nature’ plays a big part in any law inquiries and development projects. Be it for species protection in the context of EU laws regarding red-listed species, or future clear-cutting projects. And “[...] as soon as money is involved it can cause a lot of trouble in people’s lives” (I5: 6). To validate any project, nature, environments, and habitats are mapped and gridded. When protected species and clear-cutting projects meet, it is crucial to know exactly on which side of the border the species can be found. This is highlighted by interviewee 5, who explains the importance of accurate GPS data when registering observations: “The fear is that if you give too much accuracy it will lead people to find these nests to collect eggs, for example. But to be able to use it, the accuracy [has] to be high” (I5: 8). Datafying and mapping nonhuman encounters can therefore prefigure future nonhuman encounters and settle the fate of entire nonhumans’ habitats. Mapping registered observations additionally exceeds professional practices, affecting one’s overall understanding of nature. As interviewee 5 outlines:

“[...] when you are sort of [a] beginner with using maps, you tend to look too much at the map. And eventually, you realise that the map is only a picture of reality. And the reality is all around you. In all maps, there will sometimes be a mismatch between the map and the reality.” (I5: 4)

Artportalen as a map thus serves as a metaphorical sense of guidance and structure, rather than depicting reality. Considering this, what is the map of Artportalen revealing? Even though it is handled as a map of datafied nonhuman encounters, Artportalen reveals how humans trace nonhumans they consider particularly interesting and thus worthy of datafication (I1; I3; I9; more on this related to the final theme). The mapped and gridded data points are then constantly (re)contextualised, and views of data as representational or relational are continuously negotiated. Finally, it discloses human actions to either validate their arguments or to prevent projects in the name of the law (I1; I2; I8; I9). This tension between mapping humans, nature, and nonhumans leads to constant negotiations when using Artportalen as a map. Yet thinking through a grid is not the only way to encounter the world. ‘Nature Without a Grid’ presents an alternative which differs from but is closely connected to the ‘Gridded Nature’ perspective.

Nature Without a Grid: Datafied Encounters as Relational

‘Nature Without a Grid’ is another theme, this time however constituting an ecocentric perspective. As an alternative to putting humans in the centre, ecocentrism highlights the importance of nonhumans, humans, and their environments. As interviewee 9 reflects: “The human being has put her, or himself on the top of it. Of everything. And thinks we are something else. But we aren’t” (I9:13). Being in nature here is more about just being and actively trying to take a break from technology (I1). Experience is in the foreground, or as interviewee 3 explains: “You feel the nature more than you think about it” (I3: 4). Instead of fostering their competitiveness by comparing their listed datafied encounters with the lists of others, interviewees often encounter nature alone or with their family to unwind and feel connected to nature (I3; I4; I5; I6; I9).

When it comes to online and offline communities, their connection and shared interest are emphasised which also influences how data from nature and nonhuman encounters are shared and distributed (I3; I4; I6). Interviewee 3, for instance, shares their nonhuman encounters on their personally managed local Facebook group:

“I have a Facebook group [and] sometimes post things about birds or fun things in the woods that I’m seeing. And I see that it’s hundreds of people that live just around here. That are glad to see what I have seen.” (I3: 7)

Artportalen’s map fades to the background while other affordances, such as the shared news of research projects with datafied observations, become more salient. Artportalen as a platform is consequently also treated differently. It is encountered and cared for as well as perceived to be more than the sum of its parts (I6). In place of treating Artportalen as a mere tool to reach one’s goals, it is understood through its community and entangled connection between communities and other BONs. This is highlighted by interviewee 6, who states that “Artportalen was a system. Now it’s also part of a family” (I6: 15). The emerging diverse data practices therefore offer spaces where data can travel between, in and out of.

Considering the rationale of the theme, ‘Nature Without a Grid’ leaves room to critique the ‘Gridded Nature’ perspective by building on curiosity and experience. Contrary to focusing on datafication processes, this call for curiosity emphasises encounters with organic nonhumans over accumulating data. Additionally, travelling data is more deeply embedded in local contexts as datafication is a side effect of encounters. The theme not only allows for critique but also for emotions such as worrying and mourning. These emotions can be identified when talking about people’s hopes and fears regarding the future of nature, environments, and nonhumans. The worry that accepting landscapes with fewer nonhumans dwelling in them due to distinction and environments lacking biodiversity will be accepted as a new “baseline” creates a different urgency to inventory nature than Sweden’s long Linnéan tradition (I2; I3; I7; I9).

Finally, both themes do not oppose each other but are multifaceted and at times complementing one’s perspective. Interviewees often switch between them, which makes both themes dynamic. For instance, interviewees argued that the datafication of nature may lead to a more holistic understanding of nature and environments as more knowledge leads to an overall better understanding. A holistic approach was at times more related to practices I identified within the ‘Gridded Nature’ theme than when focusing on connections and experience, like in ‘Nature Without a Grid’ (I1-I3). The need for a deeper understanding of nature and biodiverse environments aligns with the narrative presented in the following theme.

Encounters as ‘Science’: Classification and Care

Throughout all interviews, there is a narrative suggesting that deeper caring would emerge through more abstract species knowledge or applied species recognition skills. Interviewee 3 explains this position by stating: “Some people, they can see: ‘Oh, there was a bird!’ But they don’t really see it because they have no name [for] it, and it doesn’t mean anything [to] them” (I3: 5). Talking about species identification, they further note: “You see it’s not just a green blur, it’s actually a species” (I3: 2). Put differently, many interviewees suggest that genuinely caring for encounters with organic nonhumans depends on the ability to identify and recognise them. This indicates that recognition and thus care is often afforded to entities

as species, meaning as an abstract classification, rather than an organism encountered without a grid. The idea that determining species dwelling in nature is a starting point stems from narratives arising during the Enlightenment and is an integral part of Sweden's history and tradition. The Swedish naturalist Carl Linnaeus not only shaped how nonhumans are categorised and inventoried to this day but also influenced Sweden's BONs (Peterson et al. 2023). Interviewee 6 explains that "[...] after Linnaeus [it] was more and more a tradition that it was important to know species. We have the starting point with Linnaeus and all of the books that he has [written]" (I6: 11). However, interviewee 3 reflects on various other kinds of knowledge. Before the "Linnéan tradition", people knew about nonhumans and nature, "maybe even more, in some ways" (I3: 6). Interviewee 3 reflects that prior to focusing on species classification: "[People knew] how to use nature and species for food or medicine", however, "nowadays, knowledge about nature starts with naming" (I3: 6). These practices of utilising plants, fungi and nonhumans as medicine and food do not fit today's linear narrative and are therefore rejected. Nowadays quantifying nature is required to "see" and to understand (I3; I6).

Nevertheless, as datafied information does not always travel freely, such knowledge is not universally accessible. Increased knowledge and understanding are suggested to lead to more caring about the 'values of nature' (I1; I2; I4; I8). This seems less straightforward when one aims to trace endpoints of data journeys, as some scholars suggest (c. f. Leonelli & Tempini 2020). This issue is highlighted by interviewee 5:

"[...] sometimes we had opinions from people owning forests that to be able to [consider] what species you need to protect; you need to be allowed to get the information what's there. If it's a secret, there's a very specific bird here. It's very important that you protect it. But you don't tell the landowner. It's very difficult for him or her to take needed caution, of course." (I5: 8)

Not all data is accessible to everyone (I2; I4; I5; I6; I8; I9). "Not knowing" therefore can create tension between different interests and motivations, ultimately leading to conflicts, and restricted journeys of datafied observations can lead to clashing meaning-making processes (I5). In this particular situation, forest owners feel frustrated, either because they feel overlooked by the environmental policies in place, or because they feel hindered from following these policies.

Many different understandings of Artportalen's role and tasks are present which all are interwoven into Artportalen's data. Given the "exponential" rise in registered observations, it is important to consider the diverse motivations behind participation (I6). By no means exhaustive, the final theme presents some motivations and interests related to the practice of registering.

Why Encounters Become Datafied

Motivations and interests are the driving force of practices relating to collecting observations as data. Whereas motivations give people a reason to carry out practices or, for instance, participate in projects, interests in this context indicate why one focuses on one aspect over another. Different motivations and interests can lead to seemingly the same practices, and one person often acts on multiple motivations and interests simultaneously. Building on the previously discussed narrative, being more aware of and caring for the environment leads

to collective action. Instead of being solely dependent on experts for services such as conducting inventories, “everyone can do it” (I1–I3; c. f. Gabrys et al. 2016). Communities can instead use their collected data to advocate for inventories and even policy changes in favour of nature protection in court (Gabrys et al. 2016). Additionally, these inventories can support communities when requesting financial aid from official institutions for such projects (ibid.). Some people go as far as to use Artportalen as a form of environmental activism. Activists utilise Artportalen to fight against urban development or clear-cutting projects by trying to reframe specific areas through an increase in registered observations of protected species in the designated areas. Most of the time such actions are detected and prevented through Artportalen’s validators. Quality assurance is conducted by a network of specially certified people who focus on “spotting anything unusual” (I4; I6). In these instances, motives and practices clash as do understandings of these natural areas. This leads to tension and conflict, occasionally even discussed in public media (I5). Nonetheless, Artportalen “[...] is a very important tool to unify the community” (I2).

But it is not the only motivation that has been defined. Many people also become motivated by comparing their lists of registered observations with others. In this context, Artportalen’s *Checklista* is a gamified element, meaning that it enables a game-like notion regarding registering nonhuman encounters as observations to the database. Like some games, it fosters comparison and to some extent competitiveness between users. Initially part of birdwatching, keeping track and connecting through these lists are an integral part of the hobby (I9). As birdwatchers developed Artportalen and initially did not see it as the big citizen science project it became, lists were included to continue this practice just for fun (I6). Another interest stemming from the birdwatching tradition is tracing rare species throughout the country, either by checking registered observations in the database or following the bird in hopes of encountering it (I2; I3; I5; I6; I9). As mentioned, Artportalen is then used as a map to trace the bird, yet ultimately these are traces of humans tracing nonhuman others that are motivated by datafying and listing their encounters.

Considering nonhumans, I identified three areas of interest that determine whether people register the encounter as an observation or not. The decision in favour of the registration often depends on the nonhuman’s rarity, looks, or behaviour. Almost all interviewees emphasised that rare species are far more likely to be registered in Artportalen (I1; I2; I3; I4; I6; I9). This underlines Artportalen as a map representing human practices over nonhuman dwellings in an area. Species are not only more interesting when they are rare, but their looks also play a significant role. Common and ordinary-looking nonhumans are less interesting and more likely to be dismissed (I1; I4), as “charismatic species” get more attention (see e.g. Fordahl 2024). However, the species’ behaviour may attract one’s notice, sometimes leading to a broader focus. Interviewee 2 told me that during an observation, they sometimes notice how nonhumans encounter each other, which can increase the interest in the observation itself. Encountering species during an encounter can shift one’s focus from particularities to entanglements.

Discussion

The empirical analysis outlined here suggests that interviewees use both relational and representational understandings of data to discuss their use of Artportalen, and that they have some understanding of the ways in which encounters with nonhumans co-constitute their engagement. The ‘Gridded Nature’ and the ‘Nature Without a Grid’ themes showed how

perspectives shape perceptions of environments and what datafication processes can emerge when encountering nonhuman others. Both themes were dynamic and constantly negotiated as interviewees switched between their ways of reasoning, and their understanding of how data and observation related and what they represented. They were also influenced by embedded narratives and practices. The narrative of 'Encounters as 'Science'' bore aspects of both previously mentioned themes. For example, the interviewees' concern with unequal access to sensitive data seems to emphasise the relational preconditions and consequences emerging from data assumed to be representational. In line with narratives of progress and the tradition of species classification, alternative ideas of knowledge creation and historical entanglements were excluded (Tsing 2021). All of these practices returned to questions of distinguishing encounters into those that ought to be datafied, might be datafied, and are unlikely to be datafied even if the data practices might appear similar, which the last theme, 'Why Encounters Become Datafied' discussed further.

We now return to the two questions that must be addressed. The first concerned the implications of including datafied nonhuman others (e.g. observation data, infrastructure) in an analysis of encounters with organic nonhuman others. We conceptualised this as data being encounters stripped of their relationships, but both able to retain relations with their context of production, and of becoming re-related and thus contributors in subsequent circulation, thereby leading to more encounters. For example, in interviewees' accounts of gamification, shared family or neighbourhood experiences, or tracing birds through the country, data retains relationships to individuals, is contextualised within community relationships, and shapes encounters of others. Our approach thus enabled us to see the complex and messy entanglements, where data is nested somewhere in between encounters with nonhuman others, past encounters, and future encounters—thus data, despite its inherent lack of memory is both a product of and a source for contaminated diversity. Accordingly, the digital citizen scientific infrastructure is an essential influence in shaping more-than-human encounters: it contaminates diversity as it takes part in encounters of multiple agents. When humans, organic nonhumans, and data encounter one another, the encounter needs to be acknowledged, and its relevance for datafication or other use established. This has implications on the larger scale: While Artportalen is often considered to be only a mapping of non-human participants, such as animals, plants, and fungi dwelling in their habitats, our research suggests that Artportalen's map reveals which encounters humans consider meaningful and where humans trace such encounters, which are then transformed into data—it is not a map of biodiversity but of encounters of humans who squeezed some of their encounters into a database.

Our second research question concerned how such a conceptual shift influences interpretations of narratives of knowledge production. As suggested above, the narratives of our interviewees had clear traces of a relational understanding of data. However, interviewees often resorted to representational understandings when reflecting on knowledge production: Ideas of knowledge production were regularly systematised, either into the 'Gridded Nature' of maps and GIS systems, or of the taxonomical system in the Linnéan tradition that renders 'Encounters as 'Science''. Knowledge in the context of our research thus appeared to be one of naming, classifying, mapping, inventorying and thereby datafying the environment in established spatial and taxonomic classifications. Re-related into these classifications, a scientific-managerial and anthropocentric perspective on environments and nature emerges where encounters were seen as representations of species existence that need to be navigated in managing nature and land-use (von Essen et al. 2022). Based on our interviews,

this notion is challenged in a few places, such as when interactions of different species appear more interesting than their mere presence, but without possibility or incentive to capture this adequately in the datafication enabled by Artportalen.

This representational understanding of data sometimes even conflicts with a relational view, for example when environmental activists are said to seek to influence what future encounters should be possible by reporting endangered species in specific areas, whilst data verification systems seek to protect a representational logic: the idea of a representation of nature appears to require notions of science that prohibits humans being interested in nature beyond taxonomy. This systematisation of experience contributes to divisions between nature, culture, human, and nonhuman, sorting every agent or place into self-contained entities that rejects alternative narratives and histories (Tsing 2021). Within these systematised, representational views, there is a need for ever more datafied observations, which is part of the anthropocentric progress idea. However, Artportalen served not only as a mapping tool but also as a platform for a passionate and curious community. Datafication processes were sometimes understood as support for such curiosity. Curiosity, as Tsing (2021) argued, is essential to break out of anthropocentric narratives and to shift the focus towards a more-than-human world.

Conclusion

In this article, we conceptualised biodiversity citizen science infrastructure as surrounded by encounters, and data in the tension of relational and representational understandings. The context of biodiversity citizen science was a convenient starting point to explore the frictions and implications of the proposed more-than-human approach, held together by a digital infrastructure, in this case Artportalen. While we used encounters with nonhuman others in a biodiversity context as a starting point, our understanding of data—its origins, contexts, and circulation—is relevant for diverse fields of knowing about nature and the environment, including weather or climate data (Bates et al. 2016). In our example, diverse and at times contradictory practices were framed to be in the best interest of nature or knowledge about nature. For instance, caring for the environment meant utilising Artportalen for environmental activism for some, and focusing on research for further insights for others. Since maps are an integral part of citizen science and policy making (cf. Berti Suman & Alblas 2023), future research could follow up by exploring Artportalen's map through a relational lens, rather than focusing on it as a representation of reality. This, then, could allow a shift from an anthropocentric towards an ecocentric understanding of how humans encounter nonhuman others, taking these encounters more seriously. More broadly, our research underlines that in environmental governance, it is necessary to understand what interests, motivations and meaning-making processes lay behind practices that appear similar. Exploring the ways in which data is relational in its diverse encounters (and not just representational) helps to identify the “contaminated diversities” at play (see Tsing 2021).

Acknowledgements

We would like to thank all interviewees who participated. Without you sharing your time, experiences and perspectives on Artportalen with Malin, neither the thesis project nor this

article would have been possible. We furthermore thank the kind, supportive, and challenging comments from the three reviewers that have greatly improved the quality and clarity of this research.

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Being Granular, Becoming Sustainable: A Preliminary Inquiry into the Wor(l)ds of Smart Farming Developers

Mylène, Tanferri

Abstract

This article examines the integration of digitization and environmental concerns in digital agriculture from the perspective of actors in smart farming in Switzerland. Those actors, previously unconnected to farming, promote the use of granular data to achieve more sustainable practices. Considering granularity as a practitioner-made achievement rather than a technical property alone, I draw on interviews and ethnographic observations, and rely on material-semiotic insights from STS (Law, 2008; Mol, 1999; Lien & Law, 2011) to examine how granularity data is brought into existence through heterogeneous practices. I first analyze how the connection between digital agriculture and more sustainable practices is operated as a *motto*, an aspirational principle that draws from different sources and comparisons. I then show how the production and interpretation of granular data depend on experimental infrastructures, interdisciplinary collaboration, and ongoing human interpretation, all of which contribute to the existence of granularity while enacting specific definitions of sustainability.

Keywords: digital agriculture, smart farming, sustainability, data practices, granularity

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Introduction

This article focuses on the integration of digitization and environmental concerns from the perspective of Switzerland-based actors developing smart farming devices, the latest trend in digital agriculture. In this realm, the use of digital technologies to address climate issues has become obvious across engineering, computer science, and policymaking circles. The United Nations Food and Agriculture Organization and the European Union, for example, not only strive to advance digital agriculture more broadly but also fund numerous projects in this area. Building on previous decades of precision agriculture and Agricultural Knowledge and Innovation System (AKIS) developments (Touzard et al., 2015), this trend now develops into innovations such as real-time monitoring of crops through various tools, including sensors, drones, and other mapping and controlling techniques (Balafoutis et al., 2017; Wolfert et al., 2017; Knierim et al., 2019). These different options all assume that data should be incorporated into human and machine decisions. Coupled with big data analytics

and complex algorithms, continuous monitoring would not only enhance growers' decision-making (e.g., when to harvest or water, and how much fertilizer or pesticide to use); this large amount of data would also contribute to feed so-called smart systems, capable of acting autonomously and intelligently by adjusting directly to it (Abinaya et al., 2024, for a critical discussion see: Gugganing et al., 2025).

To promote digital agriculture and large-scale monitoring, several discourses have been mobilized alongside technical developments. In the 80s and 90s, greater precision and better control were the core justifications. Over the past decades, digital agriculture has taken on an additional purpose: addressing climate issues, mainly under the banner of smart farming. There, the intensive use of data would contribute to keeping or increasing crop yields while at the same time diminishing agriculture's climate impacts (Walter, 2017; Nazirul Islam Sarker et al., 2019; Krutilin et al., 2022; Finger et al., 2019), as a way of decoupling economic growth from its often-accompanying environmental damages (Dalsgaard, 2022). For some, these connections between climate issues and agricultural technologies fall under the umbrella of technological fixes (Rosner, 2004; Ruser & Machin, 2016; Guthman & Butler, 2023), where technologies would solve any environmental issue, while putting social or political problems (or solutions) in the background.

Considered through a techno-fix lens, claims about smart farming's ability to solve climate issues in large-scale agricultural production rely on and contribute to a broader cultural economy focused on "technological and economic response to notions of climate crisis". (Caprotti, 2012: 3). Yet, while fixes and claims for sustainable outcomes in digital technologies for agriculture are often studied through published reports, policies, public declarations, and commercial pitches (Newell & Taylor, 2018; Fairbairn et al., 2022), this article relies on private interviews and preliminary observations in smart farming development settings. I do not aim to sharply contrast public and private discourse (as we will see, these are more blurred categories), but to suggest that proximity with the actors who produce these claims yields specific understandings. While acknowledging potential issues, such as over-identification or the risk of missing broader patterns, I contend that these understandings often remain unavailable to critiques from a distance. In the specific case presented here, a closer examination of participants' words and the wor(l)ds they construct revealed infrastructural and collaborative work, organized around a central element: *granularity*, the ability to provide fine-grained measurements.

Granularity is the main proposition these actors use to link smart farming to sustainability. It is what makes digital technologies legible as environmental solutions for the set of actors I met, which I take to be at least partially representative of the broader field in Europe. Yet what 'granularity' concretely means requires further exploration. Drawing on material-semiotic insights from STS (Law, 2008; Mol, 1999; Lien & Law, 2011), I examine granularity not as a static, externally defined notion, but analyze how its practitioners bring it into existence through heterogeneous practices, both discursive and material, including comparisons, collaborations, and disciplinary exchanges, as well as infrastructures and experimental materials. This approach follows granularity not as a fixed technical property but as something actively made and defined through situated practices.

To better understand granularity from the perspective of its practitioners, and to demonstrate the importance of examining their wor(l)ds closely, I begin by reviewing how digital agriculture and its claim to sustainability have been met by different traditions, such as

(agrarian) political economy and ethnographic approaches of digital agriculture implementation. I then sketch out an ethnographic approach of granularity, which includes examining the collaborations and new networks that have emerged around the projects I observed.

From these, I follow on the connection between digital tools and sustainability as a *motto*, an affirmation often repeated but not specifically substantiated, where “being granular; becoming sustainable” works as *aspirational talk* (Christensen et al., 2021), stabilized through comparisons and metaphors between granularity and other modalities of knowing and intervening in plant growth, sustainable outcomes remain conditional to specific situations and contexts such as water scarcity or regulations and incentives. To complement findings from participants’ words, I then sketch out what it takes to produce and interpret granular data in their worlds. As these activities rely on existing infrastructure – from energy grids to greenhouses – and established knowledge, granularity illustrates the well-established mutual shaping between “new” technologies and existing elements (Star & Ruhleder, 1996; Pickering, 1995). This demonstration remains crucial for challenging the grand narratives of digital disruption and reminds us that technologies depend on, and must integrate with, pre-existing configurations. As Gabrys, Westerlaken, and Fatimah (2024) propose, *actually existing* smart environments are not seamless technological systems; they must accommodate existing infrastructures and multiple ways of knowing. Following how actors speak about their technologies, how this discourse relies on and contributes to new networks, and how granular data practices depend on and need to happen within existing infrastructures and prior knowledge, allows for a more complex picture than the one often painted by both critics and promoters of smart farming and big data.

Sustainability claims and their discontents

Although a detailed examination of how green claims have become intertwined with digital agriculture and its financialization falls beyond the scope of this article (but see: Oui, 2024; Duncan et al., 2022; Sippel & Dolinga, 2023), it is worth noting that such claims have been met with considerable skepticism (Bronson and Knezevic, 2016; Miles, 2019; Carolan, 2022; Fraser, 2022). For example, 30 years ago, Wolf and Buttel (1996) already noted the lack of clear evidence supporting the economic and environmental claims surrounding these innovations. They described these innovations as solutions looking for a problem and argued that they might, at least maintain, if not further, economic and political distributions that support the use of harmful chemicals in agriculture while diminishing farmers’ autonomy. Today, these considerations still hold if we follow Rotz and colleagues (2019) in their review of the politics of smart and digital farming innovations, while some argue that the claimed sustainable outcomes of digital agriculture and smart farming are addressed solely to financial actors, as growers and growing practices have never been a direct concern for their developers (Duncan et al., 2021). Yet, as Clapp and Ruder (2020) proposed, broad appraisals of digital agriculture, whether in favor of or critical of it, often start from smart farming as a unified phenomenon to be discussed at a conceptual level. In this perspective, the development or acquisition of an agricultural technology would either automatically yield more sustainable outcomes or immediately lead to deleterious consequences. In line with this reappraisal, Forney et al. (2022) proposed in the introduction to a symposium on the everyday digitalization in food and agriculture, that the focus on “spotlight” digitization, such as recent innovations not yet implemented, leads to forgetting the everyday engagements with digital modalities on the farm (ibid: 418).

Future forecasts of smart farming's benefits or detriments can be contrasted with ethnographic work seeking to re-situate these tools in specific spaces and places, demonstrating that their actual adoption is not as straightforward as it may seem and complicating the very notion of access to technology as the only potential issue to adoption (Gugganig et al. 2026). Focusing on the daily work and opinions of growers in digital agriculture, ethnographies have explored how such tools both configure and are reconfigured by their users (Higgins et al., 2017; Rose et al., 2018), including as they prepare for an automation yet to come (Legun and Burch, 2021). Ethnographies also helped make clear the human interpretations needed to make sense of precision agriculture tools (Tsouvalis et al., 2000), while recent notions such as the *distributed* farmer (Comi, 2020) or the *cyborg* farmer (Velden et al., 2024) have been used to observe how growers and their decisions are part of a broader network, and how digital tools are incorporated and reinterpreted in farming practices. These different propositions complicate the picture of digital agriculture by examining situated uses and specific cases. Yet similar attention to the practical, situated work of agriculture technology developers remains scarce (but see Heimstädt, 2023a, 2023b, focused on a startup; and Roevers et al., 2024, focused on academic developers). What happens in the daily work of those who directly contribute to developing agricultural technologies and make claims about their sustainable outcomes? Alongside ethnographies of farmers' engagements with digital tools, examining the work of those who develop smart farming solutions helps shape a clearer picture, notably by revealing *how* they connect sustainability and digitization.

Following smart farming developers ethnographically

In preparing for my current project, I conducted 17 interviews with actors in the field of smart agriculture, including policymakers, agronomic research centers, and other organizations in France and Switzerland. This helped refine the sites that would provide ground for long-term ethnographic observations. The contents and topics of these interviews recurrently evoked sustainability and green issues. I thus began to inquire more specifically into what these terms encompassed, where they originated, and how they would translate into practice. Starting in the Fall 2024, I met several actors involved in developing a specific type of smart-farming device: *plant sensors*. Plant sensors are developed to enact phenomena such as leaf transpiration (Z. Li et al., 2024), real-time leaf movement and growth (Geldhof et al., 2021), real-time diameter growth in fruit or stems (Fernández & Cuevas, 2010; Hahn, 2021), or electrophysiological signals (Volkov & Markin, 2012; Tran et al., 2019). This phenomenon, discovered by Chandra Bose and his team in the 1900s (Lenoir, 1986), can be correlated with plant behavior in ongoing measurements of plant responses to various internal and external stimuli, such as water shortages or pest attacks. "Wearable plant sensors" (Lee et al., 2021; Banerji et al., 2023; X.-H. Li et al., 2024), their nickname, points to the fact that these sensors are directly "worn" by plants, in contrast with environmental sensors capturing elements surrounding the plants, such as temperature or humidity. Specialized articles emphasize their potential to produce granular data by monitoring plants' internal processes, drawing comparisons to smartwatches and the ongoing tracking of detailed human physiological data.

Green claims surround smart farming innovations in general, and plant sensors are no exception. Companies' websites, public documents, and press articles all include hints that these sensors will foster more sustainable agricultural practices. For example, consider dendrometers, sensors that continuously monitor the circumference of a fruit or stem as it grows,

recording regular, minute-to-minute measurements. Captured on a single tomato fruit, one of the most cultivated plants for food consumption, measurements are then translated into growth trajectories, which may help determine thresholds before the fruit peel explodes under too much combined water and heat, an important issue in commercial production, which can largely diminish yields. Determined thresholds could trigger an alarm warning growers it is time to intervene (by harvesting or reducing watering, for example). Translated into sustainable outcomes for dendrometer-related claims, this means they would help improve sustainability in tomato production by preventing yield losses, thereby reducing food waste at the production level, where economic and environmental concerns would go hand in hand.

In developing dendrometers and other plant sensors, the agronomists and biologists I met have been collaborating with, and in some cases were employed by, sensor engineers alongside data scientists, who often worked in the digital human health sector before their current work. As Latour (2005) argues, rather than replacing human labor, technologies redistribute and often multiply the connections and intermediaries required in sociotechnical systems. The appearance of newcomers who have seldom worked with plants and are now collaborating with established actors in agriculture, such as growers and agronomists, also implies the circulation of expertise and knowledge from other fields into plant cultivation, bringing along specific terms and modes of working. Before moving into plant applications, these actors contributed, for example, to the development of technologies for monitoring human sleep patterns or to the study of human neurons involved in decision-making. Some of them participated in machine learning research on human and animal electrocardiography (ECG) or neuroimaging. A few of them returned to human applications after a labor contract or a project partnership focused on plant sensor development.

Paying attention to who these new participants are and what they bring in terms of concepts and infrastructures provides a crucial historical perspective on the development of digitization and big data (Dalton & Thatcher, 2015). As Dalton and Thatcher argue, understanding who controls data production and what historical conditions enable current data practices helps demystify these technologies. In the case of digital agriculture, this is particularly important as new actors bring terminology and corresponding practices from other domains into agricultural practices and knowledge. Health sciences data practices, in which many of my interlocutors are trained, certainly informed the idea of recording data not only at a single point in time but also measuring and recording it continuously, autonomously, and at an individual level (compare, for example, the stethoscope with electrocardiography). This brings plant sensors in digital agriculture closer to personalized medicine (Oui, 2024), where they would enable individualized, targeted treatments.

Circulation across fields and application domains thus implies that relatively new terms and propositions circulate across specialties. *Granularity*, a term used in computing and sales analysis, is also related to another widely used notion: *information*, which has long been used to draw parallels and facilitate collaboration between biological sciences and engineering. These circulating terms shape how developers make sense of plant data and the algorithms they use (Seaver, 2017; Schinkel, 2023). Framing biological processes as encoded and decoded information, conceptualizing plants as complex information systems, and adopting an information-based understanding of life across living entities help render plants amenable to engineering knowledge and intervention. This not only allows my interlocutors to flesh out – and enact – similarities and differences between humans, animals, and plants within the parameters and constraints of their activities, but, as Dalton and Thatcher (2015) proposed for

spatial big data, these circulations may also contribute to commodification processes. In the meantime, if notions of information help shape common understandings among biologists, engineers, and agronomists and probably contribute to economic circulations, scientific boundaries (Gieryn, 1983) remain at play. While introducing me to the dendrometers presented above, an agronomist told me that some aspects of the explanation are outside her area of expertise. Her portion of it concerns the biophysical aspects of plant growth, she explains. Beyond a certain threshold, she knows the fruit peel might implode, while the “reasons” for this implosion lie with the molecular biologists involved in the project. They might, she said half-jokingly, blame her if she were to answer my questions on this aspect. While considering the origins of data granularity as a concept helps us understand its circulation into agriculture and plant behavior and the boundaries that are still at play, further steps are needed to track the links between granularity and sustainable outcomes.

"Being granular, becoming sustainable": Establishing the motto through comparison

In working with my interview data, I began to engage with these materials slightly differently than if they were a direct source of information about participants' daily work. Inspired by Brice (2022) and Jerak-Zuiderent (2015), I adopted an approach that attends not only to the content of the interviews but also to tones and modes of engagement, treating these as revealing underlying positions and assumptions. It led me to realize that the often-repeated connection between sustainable outcomes and data granularity functions less as an empirical claim and more as a *motto*, as defined by the Cambridge Dictionary: “a word, phrase, or sentence that expresses the principles or beliefs of a person, group, country, or organization.” Importantly, as a motto, the connection between sustainable outcomes and data granularity need not be elaborated or substantiated: being granular necessarily entails sustainability. This reframing helps define the proposed connection not as a demonstrable relationship but as an aspirational or ideological statement, akin to management scholars' description of Corporate Social Responsibility as *aspirational talk* (Christensen et al., 2021): a form of organizational discourse offering ideals and intentions without necessarily being in direct relation with current practices, where realization can remain deferred and uncertain.

In my first interviews in 2024, which were also my first direct contact with participants, the self-evident connection between the digital and sustainable outcomes was largely established through comparisons that appeared well-rehearsed¹ and likely honed for non-specialist audiences. As Deville, Guggenheim, and Hrdličková (2016) remind us, comparison is not a neutral analytical tool but an active practice that makes things comparable, changing them along the way, practically, conceptually, or often both. Comparisons were offered to help me, a social scientist, grasp the sustainability promised by granular data and to favorably contrast it with other approaches. As a well-rehearsed modality of engaging with outsiders, comparisons were used to assign positive value to sensors by contrasting them with less-preferred solutions, rather than to clarify specific processes. Indeed, in these accounts, concrete, technical explanations of how this connection would work were much less prevalent. While all the interviews included some form of rehearsed comparison, the most exemplary

¹ Spontaneous speech presents signs that can be easily recognized, such as more interruptions and fillers (“um,” “uh”), hesitations, and non-linear organization, while rehearsed speech flows more smoothly without self-interruptions or restarts (Corley & Stewart, 2008).

case was a sales manager who, near the end of fieldwork in 2025, gave me a tour of a smart-farming lab. The polished discourse and green narrative seemed so heavily rehearsed that it left no space for spontaneous interaction or concrete answers to the questions I had then learned to ask. I found myself seeking opportunities to engage with the technical staff so I could at least begin to understand what was needed for the device to actually work.

While values such as precision, adequacy, and targeted capacities were present in all comparisons and linked to more sustainable practices, value attribution was particularly evident in a discussion with a technological adviser (who advises growers), who contrasted granular data production with genetic modifications. During our discussion, he proposed that data granularity, which provides direct, real-time knowledge about plants, would undoubtedly be considered by the public as a harmless modality compared with recent genetic technologies. While biotechnologies have long provoked public discontent, data-driven approaches could, in my interlocutor's view, appear less controversial because they do not fundamentally alter plant DNA, which would also help secure public funding for R&D in the sector. But while qualifying granular data as harmless and more acceptable is done through contrast, its benign character need not be clarified. It is the comparison itself that creates the quality, similar to what valuation studies have shown in how (commercial) goods gain value (Callon et al., 2002).

Another kind of contrast used to support the motto employs a metaphor comparing human vaccination and the possibilities of individual-level sensors to current chemical application practices. Granular interventions, as one of my interlocutors at a startup explains, can improve the application of pesticides: "Or you vaccinate your whole population, even those that might not need it, or you go and treat only the weakest individuals to ensure they don't get sick if a specific weather event occurs, such as a dropping of temperatures." (Startup 1, 2024).² The human health interventions comparison shows the extent to which treatments could be applied by using granular data. Plant sensors could enable targeted interventions at the single plant level, providing the right amount of chemicals to the right plants. This contrast underscores the value of granularity, framing sensor-based approaches as more sustainable than existing practices by highlighting their capabilities at the individual level.

Comparisons were also used to qualify the accuracy of granular data by contrasting it with agronomic and practical knowledge. Another startup owner (Startup 2, 2024) detailed the capabilities of the sensors his company has developed and is currently commercializing with several large-scale agriculture clients. To elaborate on the sensors, he compares them to the perceptual practices of industrial growers. The sensors, he explains, work at a granular level by providing continuous measurements. This would enable more precise irrigation and chemical applications, as growers' decisions would be directly tied to the plant's immediate reactions captured by the sensors. This contrasts, he continued, with relying on inferences or traditional recommendations about appropriate rates and levels of water, sunlight, and other elements in plant growth. In this comparison, the signals emitted by the plants are more accurate in indicating their current physiological state: while a visual appraisal might focus on the color or shape of the leaves, signals might indicate that the plant is not currently growing more roots or "caring for its fruits" and thus does not need more water, he tells me. Such an access, he continues, would let the grower know that, even if the plant's overall appearance suggests a lack of water, they can wait before irrigating. When comparing sensors with

² According to the terms offered to research participants, this article avoids all means that would lead to identification. To do so, names, settings, locations, and specific job descriptions have been deleted.

agronomic knowledge, based on external factors such as surrounding humidity and temperature (as well as drain calculations), plant signals appear to be a direct readout of plants' real-time internal needs rather than some general recommendation. If we follow this comparison, direct information about plant states would then lead to more sustainable decisions, as irrigation would be tied directly to plant needs rather than to human assumptions based on environmental measurements – while the assumptions used in interpreting plant signals, and the infrastructure required do not need to be described in details.

Through such comparisons, granularity is also progressively framed in relation to intensive production modes, which then appear less attuned to actual plant needs. At Startup 2 lab, a team member explained in an interview that the team conducted systematic experiments to answer this curious question: “What happens if you let a plant take control of a water system using its signals?” (Startup 2, 2024). When the plant needs water, its signals deviate from a previously established baseline, which can then directly trigger the irrigation system, making the plant responsible for its own irrigation. After a few days of adaptation, I am told, “the plant drinks every few hours, not more, not less” (Startup 2, 2024). The plants developed a very stable behavior, taking care of their own irrigation needs. The underlying assumption of the experiment was that plants may do better at determining their needs than systematized agronomic recommendations focused on yields and growth.

Yet my interlocutors at startup 2 made an important remark: it is only when water is scarce and costly that granular data can fully play a role in reducing irrigation. Granularity in that matter, they explain, only becomes interesting where the lack of water is an issue, for example, in North Africa, where the company has several clients. In Europe, they go on, growers often ask what they would gain from reducing their water use, since water is cheap enough not to affect their overall budget, while their European clients usually have what my interlocutors consider a proactive mindset: they want to test the sensors to prepare for a near future in which water might indeed become scarce and therefore more expensive. Here, the people I am talking with acknowledge that the motto linking granularity to sustainability is also premised on specific contexts. They are also aware of what has been termed the knowledge-action gap (Kollmus & Agyeman, 2002), which posits that greater knowledge does not systematically lead to more sustainable actions. These different examples of comparisons show not only how participants frame the device in a specific light. But also depict also depict a particular environment in which sustainable outcomes could appear. In comparing the potential of granular data for agriculture to vaccine applications in human health or to genetic modifications and contrasting granularity-based decisions with current irrigation practices in conventional agriculture, participants not only frame their technologies to address climate issues with the words they use; they also constitute worlds around plant sensors where granularity could achieve more sustainable outcomes.

Producing granular data: Controlled environments and experimental infrastructure

While discursive comparisons allow granular data to link sustainability and digitization in plant sensors, granularity also requires efforts and relies heavily on existing infrastructures. These practical dimensions reveal nuances between granularity as an aspirational notion and granularity as achieved in practice. This distinction further complicates how sustainability claims tend to be received: either rejected as greenwashing or taken for granted as inevitably

realized. These readings miss what practitioners know and share when asked more questions about their daily practices, a contrast that has long been observed in expectation studies (Brown & Michael, 2003). Once I started observations, I could see how much granular data depends on situated, contingent, and collaborative work. This work, in turn, shapes whether and what kind of sustainability emerges. The labor, infrastructures, interpretations, and collaboration required to operationalize data granularity also mediate its sustainable outcomes.

For example, while participants described their circulation across disciplines and human/plant projects with apparent ease, this narrative became more complex when I pressed for specifics about collaborative work. I learned more about this through discussions with participants working on machine learning for plant signals. In the sensor projects I followed, repartitions in task attributions between data scientists and plant specialists often occurred and were premised on spatial separation, with distinct atmospheres and modes of engagement perceptible between the lab and the fields (Calkins, 2021). In a specific project, expertise was partitioned between data scientists designing the data collection and its conditions to ensure the quality and cleanliness of the data sets (Boumans & Leonelli, 2020) in their offices, on one side, and agronomists caring for both the plants and the data collection process at an agronomic/research greenhouse, on the other. Making data circulate across spaces and research fields can be complex and is often accompanied by descriptive protocols. Labeling data is a process closely aligned with what Vinck (2011, 2012) has described as the equipping work of intermediary objects, which enables coordination and knowledge translation across disciplines. This equipping work can be as simple as adding an etiquette to a sample to record elements such as the date of collection, yet without it, the sample becomes useless once it is circulated widely. In the same way, data scientists need data labeled with contextual elements so that it becomes usable for training algorithms (Pasquinelli, 2019; Jaton, 2021b). For algorithms to recognize specific patterns in plant signals this qualification is essential, for example, to determine exactly when a pest began attacking a sensor-monitored plant in an experiment. Only with this label can the machine be trained to identify patterns correlated with the attack and, eventually, with its intensity. The same applies to marking precisely when watering was terminated in irrigation trials, so that the machine can match it to specific pattern changes by comparing it with another set of plants where irrigation was continued. In the project just mentioned, data labeling was carried out by agronomists at the greenhouse, who work more closely with the plants, both spatially and by training. Obtaining well-labeled data from agronomists working directly with the plants required further clarification of exactly what was needed and in what form.

Yet, labeling practices are embedded in infrastructures, which also play a crucial role in making granular data readable and useful. To provide the contextual information for machine learning processes, the agronomic team could rely on an existing infrastructure, the agronomic greenhouse. I discovered it while participating in plant sensor installation, a preparation (Riom and Tanferri, 2024), with important implications for the main activity of capturing plant signals. As with their commercial counterparts, agronomic greenhouses rely on extensive control and automation. Industrial large-scale food production relied on specialized knowledge and on the pursuit of ideal conditions for plant growth through the control of the environment and its components (Fitzgerald, 2003; for greenhouses, see Blancaneaux, 2022). This longstanding control generates the contextual data required by machine learning to recognize specific patterns in plants: temperature and humidity levels are automatically recorded, regulated, and displayed to a central computer that can be accessed from distant offices.

The agronomic research greenhouse exemplifies how granular data production depends not only on existing experimental infrastructure but also on disciplinary expertise. Heavily equipped to conduct controlled trials, the greenhouse was saturated with markers and pointers to delineate specific plants in space (Lynch, 1988). This experimental culture relies on knowledge-production practices in which one knows how to organize spaces and materials to produce results recognized as objective and valid (Tabouret, 2024). Logbooks and the widespread use of recording instruments in plant sciences and agronomy suggest that longstanding practices of experimental control and documentation support the needs of digital innovation. The labeling of data for machine learning builds upon agronomic production-of-proof conventions and the infrastructures that support this work. The production of models to interpret plant signals thus relies on decades of automated environmental management. Greenhouses actively contribute to the production of granular data by creating conditions in which small variations can be tracked and made intelligible. The lab properties of the greenhouse are thus constitutive of granular data, while labeling the data and determining thresholds also depend on disciplinary expertise. Granularity thus emerges through collaborations among agronomists, data scientists, and plant scientists, pattern-recognition machines, and their infrastructures. There is no granular plant data waiting to be captured by sufficiently advanced sensors; rather, granularity is an outcome of practices, collaborations, and materials.

The granular data thought to lead to sustainable outcomes thus cannot be separated from the knowledge, expertise, collaborative practices, and experimental infrastructures that participants mobilize to produce, make sense of, and inquire into plant data. This dependency also shapes what sustainable agriculture would look like when supported by granular data, as an activity centered on environmental control and rationalized production. The connection between granularity and sustainability can thus be seen as neither automatic nor false, but as enabled and dependent on preexisting materialities and knowledge practices that strongly shape what sustainability means in practice.³ The role of knowledge practices in developing models leads us to explore the roles of interpretation, where the implicit meaningfulness attributed to granularity - the fact that granular data can make sense - depends not only on agronomists' labels, recognized patterns, and the infrastructural requirements to produce granular data, but also on how growers interpret and use sensors and their granular outcomes to eventually turn to more sustainable practices (Gorissen, et al., 2025).

Interpreting granular data: inquiries and the importance of contexts

While the previous sections highlighted essential elements for understanding that producing granular data requires significant human work and relies on existing infrastructure, the next section concerns the interpretation of such data. Indeed, work is not only required to prepare usable datasets for machine learning; it also includes interpreting the machine's outputs, as presented in different visual renderings and calculations, such as graphs and thresholds. To observe this work, I draw from research on environmental data users and their inquiries. Through this lens, granular data on plant lives can be seen as fully-fledged agents prompting further actions and arrangements (Rosin et al., 2017; Ascui et al., 2018). As Hannah Knox (2020, 2021) observed, energy data users do not treat energy data as factual or definitive

³ While new plant sensors prototypes are underway to operate in outdoor growing conditions, a full range of other sociotechnical dependencies is likely to arise.

knowledge; instead, they open further inquiries to investigate their behavior, question the quality of measurements, and probe other factors that could be affecting their consumption, such as the building materials of their homes. Knox's research also challenges the assumption that energy data provides "a stable description of the world upon which decisions can be made." Instead, when examined within the human practices that produce and interpret it, data "bec[o]me actively constitutive of an experience of living in an environment characterized by complex, extensive, and often unknowable relations" (Knox, 2021: 114). To draw a comparison myself: rather than a fixed energy expenditure amount shown on a monthly bill from the energy provider, which is difficult to engage with or qualify, granular data offers more opportunities to engage experimentally with one's own practices, as data is continuously available to the users as feedback, where tests can be led and their results immediately available.

Growers led similar inquiries using plant sensors, as I first learned from a developer at another digital agriculture startup who was keen to cite early STS studies on innovation. If we follow his descriptions, experiments take place not only in startup labs and agronomic greenhouses but also in growers' fields. He explained that his company's mobile application, which provides hourly, detailed information on plant growth, ended up creating far more heterogeneous behaviors than the company had intended. The app would give growers access to graphically engaging data visualizations to help them track their plants' behavior. His startup aimed to use the app to scale the solution to multiple European countries while maintaining the same level of information precision. But what happened instead, he told me, was far from expected: "it re-exploded, we were faced with a proliferation of questions, opinions, and practices." (Startup 3, 2024), as recently equipped growers returned to talk about what they were doing with the app. For example, the growers reported significant variations in plant signals from one day to the next, even with similar weather conditions. This prompted their investigations into other factors that could explain the discrepancies, such as recent treatments. It also led them to compare their current practices with what they learned from their inquiries, he recounts. Visser and colleagues similarly found that "the accuracy of sensors is far from given but rather has to be actively established by farmers based on their experience" (Visser et al., 2021: 5), while noting that this human work may be overlooked in accounts that foreground technological capacity. This creates what the authors suggest calling a *precision trap*, the misleading assumption that large amounts of data automatically lead to more precise information, while the interpretive work required to establish such accuracy is dismissed – a trap we should avoid by echoing public claims surrounding automatic results in digital agriculture too quickly. Similar findings are echoed in other domains as well. Dudhwala and Larsen, for example, described the human *recalibration* of administrative AI decisions, where algorithmic outputs are not treated as absolute truths but considered alongside "expectations about a normal condition" (2019: 3), a normal condition established by human experience.

On another occasion, while talking with a grower about sensors, I learned that, far from replacing his diagnostic and decision-making practices, he often questioned the sensors' accuracy, especially when suggestions conflicted with his habitual practices. This was particularly the case with his decisions to apply chemicals, which so far have been largely based on state regulations and an application calendar.⁴ Again, the granularity that potentially leads

⁴ While my observations are very limited, this finding can help address concerns that such tools might diminish farmers' capacity to read and understand their own fields (Carolan, 2020; Krzywoszyńska, 2024).

to sustainable outcomes is not a fixed technical property. Rather, it is the ongoing work of matching specific measurements to specific contexts and events, calibrating granular data by incorporating it into actual practices, knowledge about plants, commercial and regulatory issues, and specific understandings of what sustainability could mean.

The observations presented on the production and interpretation of granular data show how much context is needed to make it meaningful. This complicates some conclusions about big data that would “focus human attention and decision on particular persons and things of interest, whilst annulling or discarding much of the material context from which they are extracted” (Amoore & Piotukh, 2015: 360). In the cases presented here, this material context remains necessary for making sense of granular data about plant lives. This meaning is constituted through interpretive practices such as formulating potential explanations for wide variations in plant signals, questioning sensor accuracy against other means of evaluating plant needs, and (re)connecting granular data results to one's own practices. In that sense, granular data seems to expand, rather than contract, human attention, opening inquiries very similar to those of the energy sensor users observed by Knox (2022): engaging with granular data, they did not treat it as definitive answers but led further inquiries into the kind of changes they could make to be more sustainable. Overall, the sensor developers I met acknowledged human interpretation at every step, from data production to its uses. Once the rehearsed discourses linking digitization to sustainability were reopened, I discovered a situation far more nuanced than bad developers offering technofixes to reluctant growers. If we shift our attention away from grand claims made in public, we discover more subtle appraisals and questions, leading us to be more granular in our own critique.⁵

Becoming granular, being sustainable?

Three main points emerged from mapping smart farming actors and analyzing the connections they establish between sustainability and digitization. Together, these elements show how digital transformations in agriculture may exceed promised (or feared) simplifications, generating new questions and forms of attention. First, these connections do not arise out of nowhere; they derive from developers' prior knowledge and expertise in digital technologies and granular approaches in other domains, such as medical applications. This offers important insights into the links between digitization and climate concerns, as these actors share a central understanding of how plant sensors can benefit sustainable agriculture: their ability to collect granular data on plant life. Hence, the motto I proposed to summarize participants' propositions: *becoming granular, being sustainable*. Second, this understanding emerges through different practices, including rhetorical ones. In my analysis, comparisons

This grower's inquiry into the potential causes of discrepancies between his established diagnostic practices and the sensor readings represents a specific instance of recalibration (Dudhwala and Larsen, 2019), where digital tools do prompt action, but not in a blindfolded or deskilled manner. He was simultaneously preoccupied with the validity of the data and open to revisiting his own practices, should the data prove correct. This raises the question of what drives over-reliance and closure rather than further inquiry, and we can probably not explain away this curiosity by solely considering prolonged use and habituation.

⁵ Asking another set of questions regarding biases in AI, Florian Jatón proposed that concerns or nuances formulated by developers may not receive enough time and space to be voiced, recognized and collectively assessed, an issue he proposes to solve through techno-moral graphs, a tool that might serve in documenting collective issues as they appear in the constitution of algorithms (Jatón, 2021a).

across several domains, both within and beyond agriculture, do important work: they establish the value of granular data by positioning it favorably against alternatives rather than by demonstrating its concrete mechanisms. Comparisons and metaphors contrast individual-level sensor data with broad agronomic recommendations for irrigation and chemical applications, or position granularity against controversial genetic modifications. Through these moves, participants not only make things comparable; they also frame granular data as a better pathway to sustainability and bring up specific worlds where this could be the case. Third, observations of granular data production underscore the importance of prior experience and knowledge, as well as infrastructure and experimental processes. Finally, the developers and growers I followed engaged in ongoing work to determine what the data meant, how it should inform action, and what sustainability could mean in their specific contexts. Together, these elements provide decalage in how we consider digitization in agriculture and the sustainability claims attached to it by focusing on a specific entry point provided by the participants: granularity.

In conclusion, uncovering how granularity is enacted and made sense of, both discursively and in practice, opens at least three potential avenues for future research. In addressing the origins and modes of producing connections between environmental concerns and digitization through claims, we qualify their content, moments, and intended audiences, and we avoid conflating them with actual practices. While the broader cultural economy surrounding sustainability claims and their incorporation into public funding policies should be scrutinized, focusing solely on final formulations and public occurrences offers little basis for understanding how claims stabilize and circulate among various actors and their material, situated practices (Lippert, 2014). This point raises further questions about potential power imbalances among the parties we have examined – growers, developers, agronomists, data and plant scientists – and among them and their investors and business partners. What definitions of sustainability can or cannot be claimed in these networks *and* enacted in the infrastructure and knowledge they rely on?

In considering more closely data production and interpretation, we are led to follow Natasha Dow Schüll in her distinction between Foucauldian notions of technologies of *power* and technologies of *the self*, where she invites us to see (human) sensors as encompassing both categories: control and power, but also a form of (self-)knowledge that invites further exploration. Such a position “seeking to explore a space between the poles of boosterism and readymade critique, entertain[s] the idea that data tracking and quantification might serve as aids to self-understanding and new forms of living” (Schüll, 2019: 911). Through experimentation in growers’ fields and in different startup and research labs, plant sensors seem to occupy a similar space, potentially complicating the biopower narrative, where granular data leads to more questions than answers, and may intervene in the question of how to become more sustainable without solving it once and for all.

Finally, while sustainability claims carry a slippery moral character, involving both a pretension to do good and varying assessments of whether this pretension is genuine or deceptive, they contrast sharply with the diffuse ideal of neutrality and accuracy surrounding granular data. Often taken as the epitome of mechanical objectivity (Daston and Galison, 2010), sensors are seen as instruments capable of capturing ongoing, precise measurements at scales and frequencies beyond human biases or limitations – that is, without human intervention. By examining how data granularity is produced through collaborative work, controlled infrastructures, experimental practices, and continuous human sense-making, we find that granular data is inherently merged with human decisions and interpretations. As

Rob Kitchin reminds us, “data-driven endeavors are not simply technical systems but are sociotechnical systems [...], they are as much a result of human values, desires, and social relations as they are scientific principles and technologies” (Kitchin, 2021: 5). Yet, we may ask, if a closer look at digital agriculture shows that human values infuse both sustainability claims and granular data, why does our moral appraisal tend to fall only on the claims, not on the data practices?

Acknowledgements

This research was supported by the European Union Horizon 2020 under the Marie Skłodowska-Curie Postdoctoral Fellowship grant number 101154733. I am grateful to the research participants who generously shared their time, expertise, and insights. I also wish to thank the editors of this special issue and the anonymous reviewers for their valuable feedback and overall patience. In addition, my thanks go to Romain Blancaneaux, Florian Jatón, Aaron Zielinski, and TiP writing workshop participants for their careful reading and suggestions at different stages of the draft, as well as to the members of the Decoupling IT group for their feedback and support on the final version of this article. While their engagement strongly improved this article, all errors remain my own.

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

Eduardo Luersen, Bibiana da Silva de Paula

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.

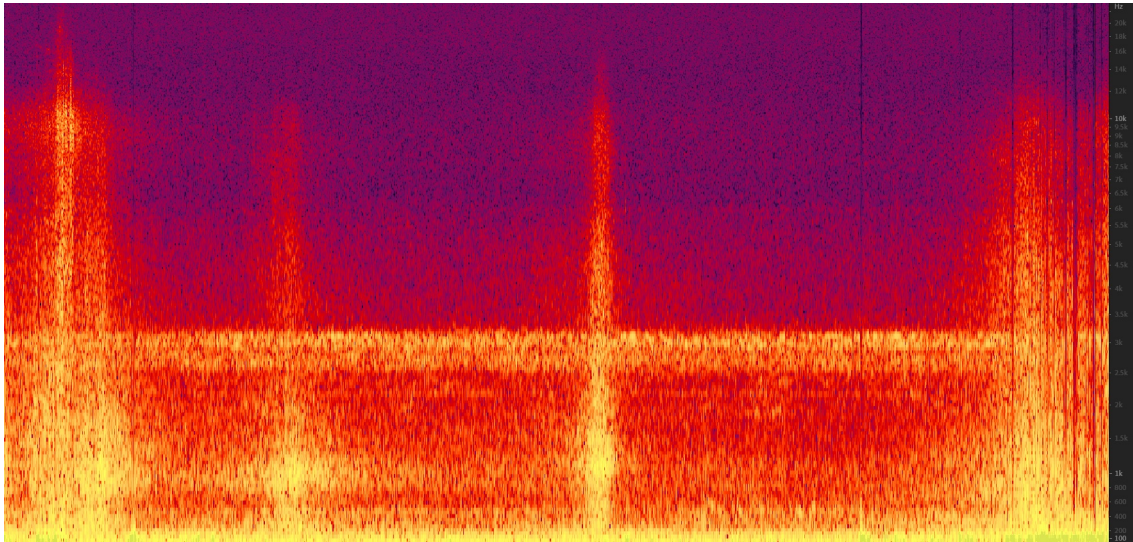


Figure 12: Spectromorphological Analysis 1

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.

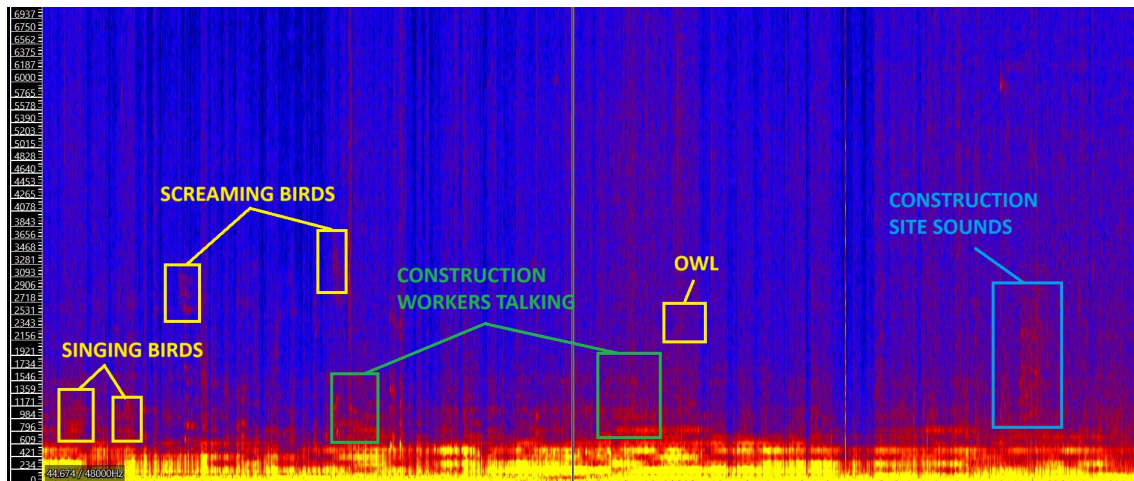


Figure 13: Spectromorphological Analysis 2

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

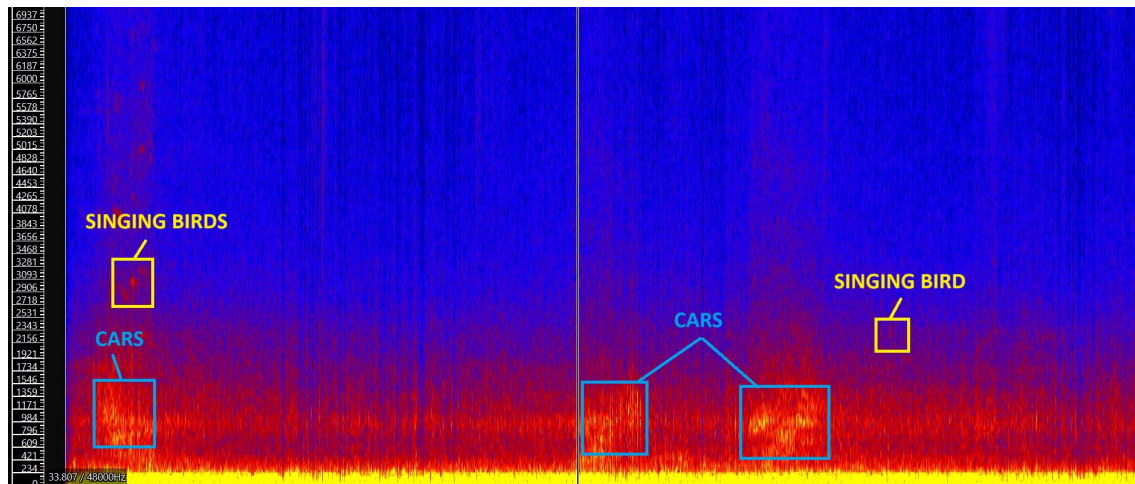


Figure 14: Spectromorphological Analysis 3

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

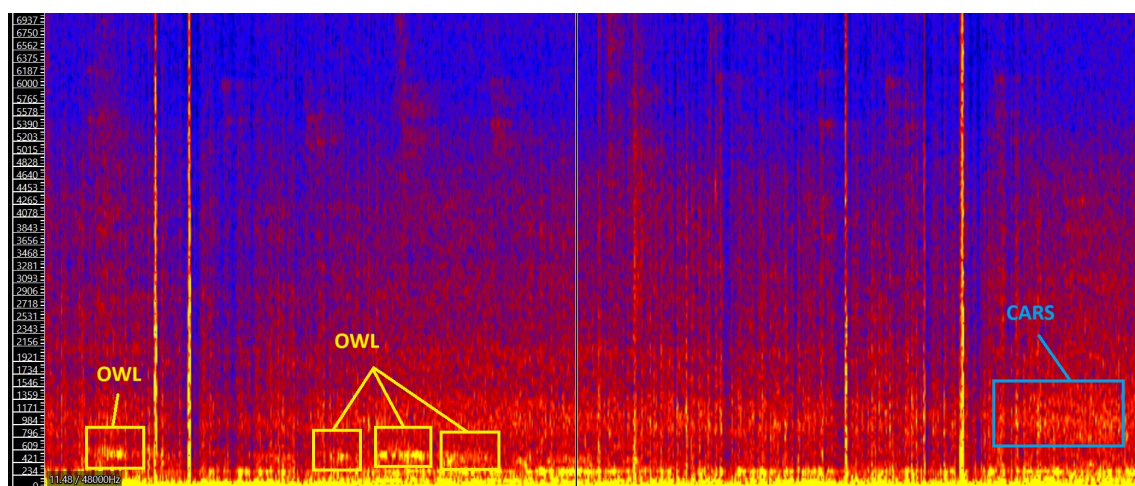


Figure 15: Spectromorphological Analysis 4

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.

Acknowledgements

The exploratory phase of this research and fieldwork, as well as the initial stage of writing, were funded by the Federal Ministry of Education and Research (BMBF) and the Baden-Württemberg Ministry of Science as part of the Excellence Strategy of the German Federal and State Governments. The completion and revision of the manuscript were further supported by the funding of the NOMIS Foundation. Different aspects of this research were discussed during the NOMIS session of the eikones research seminar at the University of Basel and the Earthbound Networks workshop at the Brandenburgisches Zentrum für Medienwissenschaften (ZeM). The authors thank the organisers and participants for their insightful comments. We are also grateful to the anonymous peer-reviewers of this contribution for their constructive feedback. The authors would further like to acknowledge the intellectual exchange at the Zukunftscolleg at the University of Konstanz and eikones – Center for the Theory and History of the Image at the University of Basel.

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Entanglements of Sustainability in Dhaka: The Complications of Deploying Technological Solutions to Capitalist Problems

Steffen Dalsgaard, Hasib Ahsan

Abstract

This article focuses on the ways that technological initiatives aimed at contributing to the sustainability of human lives in Dhaka, Bangladesh, are coupled to social, economic and environmental issues that at best have no easy solution, and at worst leads initiatives to worsen one issue as they try to solve another. With a starting point in ethnographic observations made during a research visit in July 2023, we present how such initiatives and their underlying visions of technological transformations operate in relation to the contemporary vagaries of an international capitalism, which itself is sustained by a faith in technological solutions. Our observations lead us to pay attention to how both the vulnerabilities to the hazards exacerbated by climate change, and the alleged technological solutions to mitigate these hazards, are tied up in social inequalities related to income, class and consumption, but also how they are coupled or decoupled from populations in the Global North, whose purchases sustain local economies in Bangladesh. Namely, discussions of the way that new technological transformations impact upon the environment, or the climate, or sustainability more generally, often take a starting point in the processes of digitalisation taking place in the Global North, where the solutions to climate change are often assumed by mainstream political and industrial actors to be technological and often digital. This article thus aims – through the deployment of ethnographic sensitivity – to shift the digitally focused gaze to a reiteration of the bigger question of how capitalism is multifariously involved in climate change and sustainability more broadly through technological means.

Keywords: digitalisation, climate change, technology, sustainability, environment

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Introduction

This article provides a discussion of the ways that technological initiatives aimed at contributing to the sustainability of human lives in Dhaka, the capital of Bangladesh, are coupled to social, economic and environmental issues. We argue that these mutually entangled issues – by some referred to as ‘wicked problems’ (Rittel & Webber 1973) – have no easy solution,

and at worst the deployed technological initiatives will often worsen one issue as they try to solve another. With a starting point in ethnographic observations made during a research visit to Bangladesh in July 2023, we present how such initiatives and their underlying visions of technological transformations operate in relation to the contemporary vagaries of an international capitalism, which itself is sustained by a faith in technological solutions. In this way, we align ourselves with social science critiques of technological 'solutionism' (e.g. Morozov 2014; Green 2019; Crawford 2021) to engage in a broader discussion of the relation between technology, sustainability and global inequalities entailed by contemporary capitalism.

While the plan for our research visit was to meet with software companies, garment industrialists and municipal planners to investigate how IT was deployed as a tool for decoupling economic growth and climate impact from each other (see Dalsgaard 2022), our observations in the city led us to pay attention to how the vulnerabilities to the hazards exacerbated by climate change, and the alleged technological solutions to mitigate these hazards, had been tied up in social inequalities. It also showed to us how the conditions for these vulnerabilities are coupled or decoupled from the lives of populations in the Global North, whose purchases sustain local economies in Bangladesh. That is, like others before us we will argue that discussions and initiatives aimed at promoting sustainability in the Global South cannot be seen in isolation. Initiatives cut across sectors – electrification affects climate change, which again affects health issues, which again can be related to labour opportunities, income, class and consumption, and much more. Initiatives also connect across global divides. At the same time, we argue that discussions of the way that new digital transformations impact upon the environment, or the climate, or sustainability more generally, can also not assume a starting point in the processes of digitalisation taking place in the Global North, where the solutions to climate change are often assumed by mainstream political and industrial actors to be technological and often digital (e.g. Dalsgaard 2022). Conversely, many initiatives as well as challenges faced by actors in the Global South are instructive to some of the difficulties that different human societies (North or South) are facing, and according to some observers (e.g. Ghosh 2021), populations in the Global South such as Bangladesh are less likely to see climate change as a technological issue. To them it is about the geopolitics of a western-dominated capitalism. For these reasons, our article speaks to a bigger question of how capitalism is multifariously involved in climate change through technological means.

We suggest that discussions of capitalism such as David Harvey's work on neoliberalism (2005), and Kim Fortun's stress on a "late industrialism" (2014), along with similar attempts at emphasising the uneven geographies and sociocultural perceptions of the global economic system, point to the prominent role that qualitative social scientific explorations ought to have in understanding how (often digital) technologies, economic production and responses to various forms of crisis come to be coupled or decoupled across global time and space. Dhaka is a rapidly growing megacity which a recent UN population report estimates to have 37 million inhabitants – expected to grow to be the world's largest city by 2050 (United Nations 2025). Already today it suffers from severe climatic and environmental problems of increasing heat and air pollution. It is also home to a garment industry, which feeds the world market with fashion. Partly as a result of this global connectivity, there is international scrutiny on a range of its local sustainability issues and how they can be improved, socially or technologically. Altogether, Dhaka can thus be construed as a striking example of the complications of contemporary global capitalism, and a site where the neoliberal order of

international trade agreements and governance of labour meets the hazardous leftovers from a late industrialist mode of production. As argued by Kim Fortun (2014) in a commentary on Bruno Latour's AIME project, "it is not just the chemical haze [of late industrialism] we need to worry about, though we must keep it in mind and learn to deal with it in practice. There is also conceptual haze, a cumulative effect of habits of relation, mind, and politics that makes it difficult to see the conditions of our times." (2014: 325). Taken together, the observations we made during our fieldwork made us think about the global couplings – mostly asymmetrical – hidden in this conceptual haze. We are here thinking of couplings of the contrasting expectations to value generation held by multiple actors dispersed across the globe, the asymmetrical way in which these actors at any given time impact upon the social lives of each other, and by which sociotechnical means they do so. Analytically, we thus pursue what we see as a description of contemporary capitalism in practice by doing what Latour advocated prior to the AIME project: that the analyst must describe and trace relations or associations (Latour 2005). While Fortun (2014: 315) has reservations about the things that Latour's AIME work leaves unaddressed (history, paradoxes, conflicts of interest etc.), we still think his original sociology of associations otherwise referred to as actor-network theory is a way to navigate the conceptual haze and encounter both the connects and the disconnects, and the internalisations as well as the externalisations of the political economic system.

In what follows, we approach this by moving across three 'clusters' of urban sustainability issues facing inhabitants in Dhaka, where discussions of technological 'solutions' play a dominant role: health, electrification and labour. We use the term cluster merely as a heuristic to refer to related, yet for our purposes of presentation separate, empirical themes, which we present in the order that they emerged from our fieldwork. This also serves the purpose of giving the reader a sense of Dhaka as an ethnographic setting. Our original questions of urban infrastructures came to first relate to responses to a dengue epidemic, which again come to relate to the changing climatic conditions (heat and humidity) that allowed dengue-infested mosquitos to spread (cluster 1). These questions about urban conditions of living were again related to the polluted air of the city, which again led us to pursue questions of the provisioning of renewable energy on the one hand, and more sustainable (non-polluting) forms of public transport on the other (cluster 2). A final major sector of importance to discussions of sustainability, and especially late industrialism, is the garment industry. It is the country's largest consumer of electricity, and along with initiatives to reduce its pollution of local waterways, it is also entangled – in the name of sustainability – with tech-driven attempts to reconfigure labour and working conditions (cluster 3). What the issues of these clusters have in common is not merely their mutual interlinkages related to class and inequality, but that any proposed technological solutions – whether infrastructural or digital – arguably come with other problems which may stem from and often exacerbate such inequalities. Finally, we pursue a discussion of these with references to the above-cited critiques of capitalism among others, which helps us link the problems in the Global South to technologically determined initiatives taken in the Global North.

Cluster 1: Infrastructures produce heat and mosquitos

One of our main purposes in Dhaka was to study national and urban climate mitigation initiatives, and especially how digital technologies could play a role in this. Yet already on our first appointment with senior city government officials we had to make changes to our schedule due to a dengue epidemic spreading rapidly within the humidity of the urban space.

While the dengue emergency at first appeared to be far from our original research topic, once we started pursuing the integration of digital technologies and energy infrastructures in the city-scape, the themes came to be more closely related than we have originally thought. The emergency meant that our contact person in the municipal government and many people in his team were commandeered out of their offices to clean up gutters around the city, because they provided breeding grounds for mosquitoes. Dhaka is a bustling metropolis with intense and sometimes chaotic traffic of cars, scooters, busses and ‘CNGs’ (elsewhere known as tuk-tuks). The first of six metro rail lines has recently opened to alleviate the road congestion, and a subway is also under construction (Adhikary 2023). As with other cities of southern Asia (Wee 2022), the concrete and the tarmac of the built environment retains heat in what is popularly known as the ‘heat island effect’ (e.g. Deutsche Welle 2023), and the temperature has risen in recent years likely due to a combination of climate change and the onset of El Niño. The individual response (from the more affluent) is to install air condition (Mortuza 2022). Yet cooling the indoors comes with the cost of spewing out more heat into the streets, where the more disadvantaged citizens only have the shade from trees or buildings to help them. To cool the cityscape, urban planners – between 2023 and 2024 with input from a newly appointed ‘Chief Heat Officer’ (Mostofa 2024) – attempt to retain water in the city in basins and lakes, but together with waterlogging and a frequently blocked drainage and sewerage system after the seasonal monsoon downpours, these water reservoirs provide excellent breeding grounds for mosquitoes, which then increases the risk of dengue and other mosquito-borne diseases. Indeed, the combination of high-density population, rapid and unplanned urbanisation and atmospheric changes in the form of heavier rainfall and higher humidity are said to exacerbate the outbreaks (Bonna et al. 2023), and the outbreak in 2023 was reported by the World Health Organization to be the worst on record (WHO 2023). Climate change is also frequently connected to increases in the prevalence of dengue (e.g. Nabil 2024).

Where the severity and risk of dengue and other epidemics can be related directly to climate change, the attempts to devising urban infrastructural solutions on the one hand involve the direct control of water which is both manual (cleaning of gutters and sewers) but also frequently technological via data-sensing equipment used in attempts to predict, control and direct flows of water. During an interview with a senior municipal public servant, we were introduced to a ‘Smart Dhaka policy’ based on the vision of making municipal government decisions more data-driven. It included such collection of data (on water, air quality etc.) but also initiatives to increase public participation and coordination (see also Banu 2023). This policy thus on the other hand touched upon ideas for more indirect and long-term solutions promoted to mitigate climate change by national and municipal authorities. Our specific interest here was the initiatives put in place to reduce energy consumption in combination with the provision of cleaner energy. By this we refer to cleaner not only in terms of lower emissions of greenhouse gasses, but also in terms of air pollution. Dhaka’s air is frequently labelled unhealthy to breathe, even when compared other cities of the region. In December 2024, it was reported to reach yet another high (Islam 2025).¹ In 2024 Bangladesh ranked six last out of 180 countries on Yale University’s Environmental Performance Index.² This points to environmental challenges on a variety of parameters with air pollution and

¹ See for example the air quality monitoring website <https://aqicn.org/station/@469258/#/z/12> (accessed November 23, 2025).

² See <https://epi.yale.edu/epi-results/2022/country/bgd> (accessed November 23, 2025).

greenhouse gas emissions among them. Much of the air pollution originates from sources in neighbouring India, but the energy mix of Bangladesh itself is according to the website Electricity Maps also largely made up of fossil sources,³ although with nuclear and renewables in the making (Sarker 2023). Western tech-oriented commentators addressing clean energy transitions stress how ‘electrotech’ – technologies that engender electrification from renewables – is expanding rapidly in the Global South (Ember 2025). However, the roll-out of electrification involves a plethora of crisscrossing interests, and their success in reducing emissions or air pollution is by no means automatic.

Cluster 2: Electrification through bottom up or top down initiatives

To highlight the relations of social inequality entangled with electrification initiatives, we will here contrast two different technological transitions that both potentially could benefit the urban population by reducing air pollution. One (about the production of electricity) has been implemented top down through national legislation, the other (about decarbonisation of urban transport through electrification) has emerged bottom up through informal sector entrepreneurialism.

Taking the latter first, one of Bangladesh’s more notable ‘clean’ energy transition examples is electric rickshaws propelled by batteries rather than by gasoline (or the legs of a cyclist, which is not humanely sustainable in the increasing urban heat). This electrification of transport has come about earlier and faster than the similar electrification of vehicles in the Global North (e.g. Khan 2020), and it emerged on the initiative of small-scale importers and manufacturers in the country’s informal economy. It has happened without any formal support from national policy and without any central organisation or design. The electric rickshaws have in fact faced opposition from national elites (including industrial lobbying organisations) and they have been banned on major roads in metropolitan areas and thus primarily relegated to operate in side streets in Dhaka and in rural areas. The justification is that they are deemed unsafe and are contributing to the chaotic status of urban traffic. As characteristic of the unregulated informal sector, their emergence and popularity have been said to show the incompatibility between the grand technology-centric narratives of sustainability propagated by the state and national business elites, and the practices of small-scale actors that may be both energy- and resource-efficient (van der Straeten 2022). The electric rickshaws are here seen by elites as a ‘matter out of place’ both in space (as not belonging in a ‘modern city’) and time (as a technology of the past). Jokingly, they have even referred to the electric rickshaws as the ‘Bangladeshi Tesla’ (see The Economist 2025). These rickshaws are as much cultural symbols of class and status as they are an economic necessity for the less affluent, and the sociotechnical controversy over their role in Bangladesh’s transport infrastructure relates to a complicated national picture of political and economic power and inequality. No matter what, public interest has surged since their appearance and electrification of smaller vehicles more generally is still growing rapidly (Halder 2023). Recently, The Dhaka North City Corporation has moved to regulate electric rickshaws by commissioning a redesigned model with 16 types of safety features, such as, hydraulic brakes, improved seating, indicators, headlights etc. These are developed by the mechanical engineers from Bangladesh University of Engineering and Technology (Moslem 2025). Under this regulation, rickshaw owners and drivers will be required to purchase these new models exclusively

³ See <https://app.electricitymaps.com/zone/BD> (accessed November 23, 2025).

from authorised manufacturers, and drivers required to undertake training. This process arguably indicates a form of neoliberal state appropriation of a bottom up initiative with regulatory power used to handing it over to capital interests. It may effectively end up channeling profits towards select producers, reinforcing elite interests through control of both industry and market rather than addressing the needs or agency of the (informal) working class.

Even so, electrification of transport may not automatically be an indication of a ‘clean’ energy transition. As mentioned above, the electricity of Bangladesh’s grid is still far from being dominated by renewable energy, so the electrification of transport is not necessarily of benefit to the environment or the climate. Plans to provision renewable energy is not a new initiative, though. While in Dhaka, we noticed that many of the city’s high-rise buildings are equipped with solar panels on their rooftops, but during an interview we were puzzled when the interviewee (a senior municipal official) in passing made a sarcastic comment about the rooftop solar panels not working. In 2010, the government passed a law making it mandatory for all new constructions in Dhaka to include solar, and there are today more than 80 000 rooftop solar panels installed in the city. However, news agencies have reported that the majority of these panels – perhaps as many as 80% – are not operational (Antara 2023a), which explained the comment of our interviewee. The law from 2010 did not make any demands about how the installed solar was to be integrated into the urban grid (each building had to purchase its own batteries for storing electricity), nor did they set any requirements on quality or maintenance. As a result, many of the existing panels and batteries were the cheapest possible options, which did not last long (Antara 2023b). Nor were they easy to integrate into the infrastructures of the (usually high-rise) buildings where they were placed. Users (whether these were owners, renters or janitors of these buildings) were not equipped to – nor interested in – doing maintenance work, and the dust from air pollution likewise reduced the capacity of the panels to operate effectively. According to critics, the policy has at best resulted in a waste of money. At worst it has – again according to critics – generated a major source of hazardous e-waste, which Bangladesh’s renovation systems are not equipped to handle (Antara 2023a). Altogether, the failure of the policy meant to introduce renewable energy into Dhaka demonstrates one of the challenges in planning and rolling out technological solutions: when doing so, there is a need to take into consideration at the very least how various infrastructures will be interacting, how different types of users become defined through the process and may or may not work well with the technology, and how the technology may go through different life-cycles, where its value changes along the way.

Cluster 3: Labour and technology in the garment industry

The third and last cluster of relevance to our discussion is the textile industry, which is one of the biggest consumers of electricity in the country (e.g. Habib 2016). One recent assessment ranks it as using one third of the country’s total industrial energy consumption (Uddin et al 2024). For that reason alone, it is difficult to address public climate mitigation policies without paying attention to this sector. Yet electricity consumption is not the only challenge for this industry, nor where technological solutions are necessarily deployed first. Bangladesh is one of the major producers of readymade garments for the world market, but the industry has had a checkered reputation not the least because of the 2013 Rana Plaza disaster, which forced factory owners to rethink how to administer health and safety conditions for their workers. The industry has likewise been heavily polluting both in global terms (Anon 2018),

as well as local ones, with for example Hazaribagh, a neighbourhood in Dhaka, at one stage being labelled by *Time Magazine* to be among the 10 most polluted places in the world due to the many tanneries in the area (Walsh 2013; see also van Schendel 2020: 281-85).

Recently, pushes for sustainability among customers and retailers in the Global North has forced the garment and textile industry in the Global South to 'do something' on both working conditions and pollution, and at least according to international building certifications something has happened regarding compliance to codes addressing worker safety. For what it is worth, Bangladesh factories today dominate the rankings made by the US Green Building Council – a private organisation which promotes sustainability in building design and construction, and has developed a standard for building rating systems called LEED (Leadership in Energy and Environmental and Design). Of the 100 most 'eco-friendly' apparel factories in the world, 52 stem from Bangladesh (Anon. 2023). Yet, regardless of the improvements within the workplace itself, many of the garment workers still live in cramped accommodation near the factories and the polluted rivers, where exposure to mosquitos is high. Industrial areas are often cited as having a higher prevalence of dengue (e.g. Bhuiyan 2024).

Our visit to a medium-size garment factory in Dhaka was meant to bring us insights about how the managers or owners of such a factory saw the potentials for digitalisation of their production, and how the digitalisation could potentially make it more sustainable. Would digitalisation save resources and (or) be seen as more environmentally friendly? A communication platform for the garment industry claimed that "Bangladeshi apparel manufacturers have introduced cutting edge software technology to reduce waste of clothing, laser technology in denim washing and latest technology in washing to reduce environmental impacts." (Anon 2019). Yet to our surprise the factory owner we met was adamant that human labour was cheaper than technology, so while he was intend on taking some sustainability targets seriously (e.g. saving and reusing water and providing basic benefits for his workers including training), he did not see more advanced technology as a solution he would invest in. He also felt that many of the demands from buyers in the Global North (e.g. to reduce the environmental impact of their production) would be costly to implement, because the buyers were not willing to pay more for the products. When we were later given a tour of the factory, we were then surprised to see that they did have one factory line which was automated, and some specialised stitching was likewise carried out by machines, but it may as well be these examples that convinced the owner that the cost-benefit calculations of automation do not always work out as promised.

Considerations of sustainability are obviously more complicated than the owner's answers indicate. Yet, one could interpret them as a signal of a positive change compared to the early 2010s, when then-WHO Director-General Margaret Chan noted how international trade agreements resulted in two predominant strategies from global commercial interests. One was to water down public health policies in industry through lobbyism (where the public sector in the Global South was perhaps more easily swayed than for example European environmental protection agencies), while another was for those same interests in the name of free trade to take governments to court over environmental regulation aimed at protecting citizens, aka factory labour (Chan 2013, see also Fortun 2014; Karim 2014). International capital (the global brands that own or fund production in a country like Bangladesh) has since then pushed for the introduction of safety compliance measures in collaboration with other textile industry stakeholders. The motivation for the multinational corporations have been to gain legitimacy to their brands, yet the new measures are by some seen as a fig leaf that fails to address the structural problems of the sector, where the state still pursues neoliberal

policies that favour the interests of international capital over the local rights and needs of labour (Alamgir & Banerjee 2019).

The flexibility of technology-driven capitalism

What can we analytically make of these observations of clusters? Obviously the case of the garment industry brings to mind well-rehearsed Marxist debates about the costs of capital versus the costs of labour, and what purpose the introduction of technology plays in this calculation (see, e.g., Harvey 2017). We will thus begin our discussion by first relating the last cluster presented above to some of the most frequently stated theoretical claims about the role of technology in neoliberal capitalism.

Only a few years ago the majority of discussions of labour conditions in the Global South would emphasise the exploitation of a disposable workforce, which is denied rights, protection and decent wages (see, e.g., Harvey 2005: 167-171; Karim 2014). This is still not entirely a thing of the past, although some reports claim that things have improved. Brands, retailers and trade unions signed a legal accord on fire and building safety in 2013 (Bangladesh Accord s.a.), and also women's labour unions have managed some – albeit arguably small – victories (e.g. Karim 2014). Critics on the other hand point out that this accord may herald a new CSR (Corporate Social Responsibility) paradigm that provides buyers with new ways of controlling liabilities in their supply chains (Salminen 2018), and that it has generated a divide between on the one hand 'mainstream unions' aiming at a conciliatory stance and technocratic improvements, and on the other hand workers more radically opposed to the structural conditions of precarity that many of them face (Ashraf & Prentice 2019).

Our observations, but also the circumstances of weak labour regulation and the attempts to enact a form of safety standards, brings us back to the role of technologies in the workplace, because where specific parts of a production process may be automated for the sake of reducing costs, automation has often been accused of making it easier to manage and control labour. This is a classic theme in discussions of technology in labour processes (e.g. Crawford 2021), and while we did not pursue such questions about management and control empirically, it is always potentially at stake where automated processes are intertwined with the widespread construction and collection of data, which characterises the contemporary era of surveillance capitalism. That is, weighing the costs of labour and how to control it is not a new managerial concern. Karl Marx famously argued that technology weakened the bargaining power of labour when it replicated skills held ('monopolised') by human workers (see Harvey 2017: 122). In a classic article in *Science and Technology Studies* (STS) on the politics of artefacts Langdon Winner in a similar vein relies upon the views of Marx and Engels to discuss how the introduction in California of the automatic tomato harvester led to the development of hardier tomatoes (that could be harvested mechanically without being squished) but also to a concentration of production in fewer companies (those that could afford to invest in the harvester). Yet this was, in Winner's interpretation, not simply a conscious plot between large agribusiness and academics in mechanical engineering to force small growers – and their labourers – out of business. He concluded that "What we see here instead is an ongoing social process in which scientific knowledge, technological invention, and corporate profit reinforce each other in deeply entrenched patterns that bear the unmistakable stamp of political and economic power" (Winner 1980: 126). The allure of technology may thus stem in a multiplicity of concerns and circumstances, and not the least in the commercialisation of technology itself as David Harvey argues in his discussion of Marx's view

on technology. “When technology becomes an independent business, it no longer responds primarily to needs, but it creates innovations that have to find and define new markets.” (Harvey 2017: 125). How many industrialists have historically introduced technologies for the sake of disruption alone, or simply because they would not risk that their competitors would do it first, even if they knew it would come with losses? And how many of these introductions are the result of the tech sector convincing businesses of other sectors that new technologies are indispensable? As Harvey further states, such a “business thrives upon and actively promotes the fetish belief in technological fixes for all problems” (ibid.). Kate Crawford’s (2021) excavation and mapping of the origins and deployment of artificial intelligence is a case in point.

Yet this is where we also see the actual unfolding of technological deployment within capitalism to be more nuanced. The capitalist push for technological solutions is strong but not always overbearing. The factory owner we interviewed may not be interested in deploying technology for its own sake, but it was certainly present despite his claim to the contrary. Likewise, the technological solutions to heat, air pollution or traffic problems end up being entangled in other concerns or controversies. For example, the current national government earlier this year signed a directive that air condition should be set to a maximum temperature of 25 degrees Celsius to reduce pressure on the electricity grid (The Business Standard 2025). This regulation is understandable and probably useful, if there is any way to enforce it. Even so, the government is often criticised for doing little to address the causes of the problems (air pollution and emissions), despite calls to regulate motor vehicles or industrial emissions (Islam 2025).

While the global reach of capital surely affects whatever choice governments, industrialists and labourers feel that they have, it does not mean that new technology always need to be, or even end up as, the answer. Beliefs in technology as purely ‘enabling’ (see Strathern 1996), or as a teleological given, are in themselves cultural phenomena. Harvey’s view is that the emancipation needed by labour is more likely to be one that sets it free from the dominance of capital (2017: 126), but his discussion of Marx makes it clear that technology – as an investment of capital – is an agent in service of neoliberalisation, not an emancipatory one. At least not for those still engaged in industrial labour (Harvey 2005: 157-59).

This perspective may of course also need nuance, when countered with the controversy over bottom up innovation in electric rickshaws. Here Jonas van der Straeten concludes that their popularity while having little to do with environmental sustainability per se can be derived from a potential for being “highly competitive in a largely unregulated market environment characterized by a scarcity of material resources and financial capital but [...] high availability of low-paid labor” (2022: 159). In other words, not all technologies are easily governed or controlled by capital or the state even if they face alternatives bolstered by state support (see Moslem 2025). The attempts at governing rickshaws should be seen in the light of the above-mentioned criticism that the government has failed to curb air pollution by insufficiently regulating heavier vehicles (busses and private cars), unauthorised construction work and industry such as (sometimes illegal) brick kilns and other smoke-producing factories (Islam 2025). Also, not all centralised and regulatory demands to technology lead to the expected outcomes like the regulation demanding solar panels on buildings in Dhaka. Government efforts in total may here appear uncoordinated and the Bangladeshi public administration is often accused in public of consisting of an excessive bureaucracy, where the different departments fail to coordinate efforts (Adhikary 2023). This rehearses classic debates in anthropology about state actors as more or less coherent agents (e.g. Gupta 2012), and it

invites the consideration that neoliberalism is likewise a non-uniform process. Neoliberalism transforms and mutates over time (see Harvey 2005), and – as it is known to incorporate critique – it has been accused of co-opting sustainability as a concept and as a discourse. The latter becomes presented as a matter of “technological adjustment and innovation” (Tulloch and Neilson 2014: 33) as a way to reconcile it with the market and economic growth.

Connections to the Global North

Yet there are significant differences between the clusters when it comes to how visibly their controversies over technology and sustainability transcend different social or national boundaries. The Bangladeshi garment industry is deeply reliant upon global supply chains and of markets of retailers and customers, and any discussion of its sustainability (including of what counts as ‘sustainable solutions’ and who are the relevant agents that can bring sustainability about) must take such transcendence into account. To draw out what expectations to sustainability and their technological couplings mean for this industry in particular, let us shift the gaze to sustainability debates in the Global North, and Denmark in particular, where we as researchers are located. Here there are strong calls for pursuing a circular economy with either reuse or recycling of materials in order to make reductions in the unsustainable production of garments. Yet this pursuit of a ‘solution’ to the global overproduction of garments – however justified it may be – seems as much to be about generalised cultural perceptions of what different populations around the world ‘need’ (often in the form of technologies) rather than an accurate understanding of the global processes, relations and inequalities at stake. Lamia Karim, an ethnographer who has done research in the ready-made garment industry since the 1990s, was asked in the wake of the Rana Plaza disaster by one of her students “What should I do? Should I stop buying clothes manufactured in Bangladesh?”. Karim refers to this ‘what is to be done?’ as ‘the great modernist question’ (2014: 52). In our reading of this comment, it points to a modernist cultural belief that the speaker (the western consumer) sees him or herself as the maker of their own fate – and as a privileged western individual also as the maker of the fate of others. This is a form of agency that often is associated with neoliberalism (Gershon 2011). It nonetheless disregards the agency of the factory workers themselves, which Karim’s ethnography tries to evoke.

A similar modernist reaction could be expected in a Danish context. Danish consumers for example may own more clothes than they ever use (Garde 2023), and second-hand apparel markets in Sub-Saharan Africa are being flooded with garment leftovers from the Global North (Hansen 2022). Much of this is ‘fast fashion’ of poor quality and little durability, which makes it difficult to reuse or upcycle. Yet reducing imports and the purchase of garments from a country such as Bangladesh will have very tangible but negative effects in the form of layoffs of textile workers. Western consumers and fashion retailers are increasingly concerned about the climate impact of the textile production, but the rural poor in Bangladesh still often rely on having kin employed in urban areas so they can remit money to help pay for school fees, for investments in tools or materials, for medical bills or just contribute to the daily subsistence and survival. Even banning child labour – which would be done out of the best of intentions – may be problematic if it undermines local economies and does not set in place opportunities for those same children to, for example, go to school (see Harvey 2005: 177). Reductions in demand in the Global North will invariably lead to fewer income-earning opportunities for rural or working class people in the Global South, unless some-

thing else is developed in its stead. How this can be done is the difficult issue. Karim's suggestion is to ensure that consumers and retailers support producers that allow for unions, and especially those that support female workers because their income also provides them with a leverage for increased women's rights in their broader social networks. As Karim's interlocutor's stated in response to her student's question: "'Made in Bangladesh' is a label they have to support to help improve our lives. Tell them not to give up on our labor." (2014: 62). Continuing such support may not be a move that on its own changes much in the bigger picture of neoliberal capitalism outlined by David Harvey (2005), where modes of production are dominated by the power of global capital, but all small moves may matter.

One further reflection from this discussion could be that reusing or recycling clothing in the Global North does not help generate incomes, where they are needed the most. Demand for better quality garments or 'slow fashion' could be an alternative option (Anon 2018), but to enforce it will not be easy as long as fast fashion is the more profitable for both factory owners and retailers. According to Luc Boltanski and Arnaud Esquerre (2020) the popularity of fast fashion stems in what they call the trend form of valorisation. By this they refer to the production of culturally and symbolically authentic and 'enriched' commodities that are valuable because of a combination of three factors: the frequent turnover of items in circulation, an unequal distribution of these same items (yet with an opportunity also for less privileged consumers to desire and attain these items), and an association between these items and the hierarchical positions of privileged actors (2020: 222). These commodities (typically clothing) furthermore rely upon prior commodities – the items that are no longer trendy – being turned into 'trash'. Thus a part of the trend form's logic "impels it to make things outdated" (2020: 234). How to change such deeper cultural logics of valorisation is an open question, and not a change that will happen overnight. However, paying more for more durable items – and thus hopefully allowing for more decent wages and social benefits for garment industry workers – or supporting the development of other less polluting sectors in the Global South would allow for a more equitable impact than one that can be reached by merely focusing on reusing and recycling fashion which is produced in a way that does not even allow for it to be reused or recycled (Hansen 2022).

By way of a conclusion

While there are no easy solutions to the sustainability challenges in a country such as Bangladesh – whether related to heat, outbreaks of diseases, electricity, or work and labour conditions in the garment industry – the conflux of what scholars of various orientations have referred to as neoliberalisation (e.g. Harvey 2005), the enrichment economy (Boltanski & Esquerre 2020), and the remnants of late industrialist processes of production (Fortun 2014) does at least indicate that particular sustainability initiatives cannot stand on their own. Nor can sustainability issues such as those we have outlined above be solved 'technologically.' They must be integrated with sector-wide policies and even with initiatives that go beyond the limits of specific sectors. As mentioned, this could be initiatives that generate jobs in other sectors than the garment industry, yet are also fitted to the types of – often gendered – labour that is affected by shifting consumer trends in the Global North. Fast fashion with all its afflictions – as much as the drive to solve problems technologically – is a neoliberal cultural dream, where one may never feel 'good enough' or 'trendy enough' and always can have more or improve (solve) things even further (also through technology). Somehow doing away with this dream will surely help the individual consumer, but if we want to address

the interlocking social, economic and environmental aspects of the current climate crisis then merely stopping the shopping is not sufficient in itself.

The concept of neoliberalisation has for a long time presented the social sciences with a very general umbrella term that can somewhat address many of the factors behind these asymmetries, including how technologies may – or may not in some of our cases – play a role in this. Yet noticing how problems are tied up in neoliberalisation cannot stand alone if we want to approach an understanding of the more down-to-earth aspirations of specific actors trying to relate to these circumstances of asymmetrical interconnection. Firstly, increases in epidemics worsened by climate change may for example usher in renewed investments in biotech (as a privileged citizen from the Global North one of the authors was inoculated with a brand new type of dengue vaccine before departing for Bangladesh), but for the most vulnerable it not only causes new risks, it may even mean delays of social services when white collar municipal public servants are commandeered out to clean gutters to stop the spread. Secondly, the climate crisis may result in idealised expectations to renewable energy such as rooftop solar, or it may cause national elites to make plans for grand-scale energy revolutions, but when these are not sociotechnically integrated into existing infrastructures – urban, social or technical – their benefit is negligible and may even generate harmful e-waste. Thirdly, discourses of sustainability and circular economy may logically appeal to consumers and retailers in the Global North, because they reflect frustrations with a fast fashion-dominated culture of valorising ever-shifting trends. Yet, only few appreciate the complications at the other end of the supply chain, where some may prefer environmental destruction over poverty. For these reasons, concepts such as Fortun's late industrialism, or similar attempts at stressing the uneven geographies and sociocultural perceptions of the global economic system, will play an important role in social scientific explorations of how technologies, economic growth and climate crisis responses come to be coupled or decoupled under a larger umbrella of achieving 'sustainability'.

Acknowledgements

We are first and foremost indebted to our research companions of the DecouplingIT project, and especially the employees of the Friendship NGO, who worked as our collaborators in Bangladesh. We are also indebted to the many hospitable people we meet during our research. Thanks are also owed to the reviewers and editors for pushing us to finetune the argument. The funding for this project came from the ERC Consolidator Grant #101045473.

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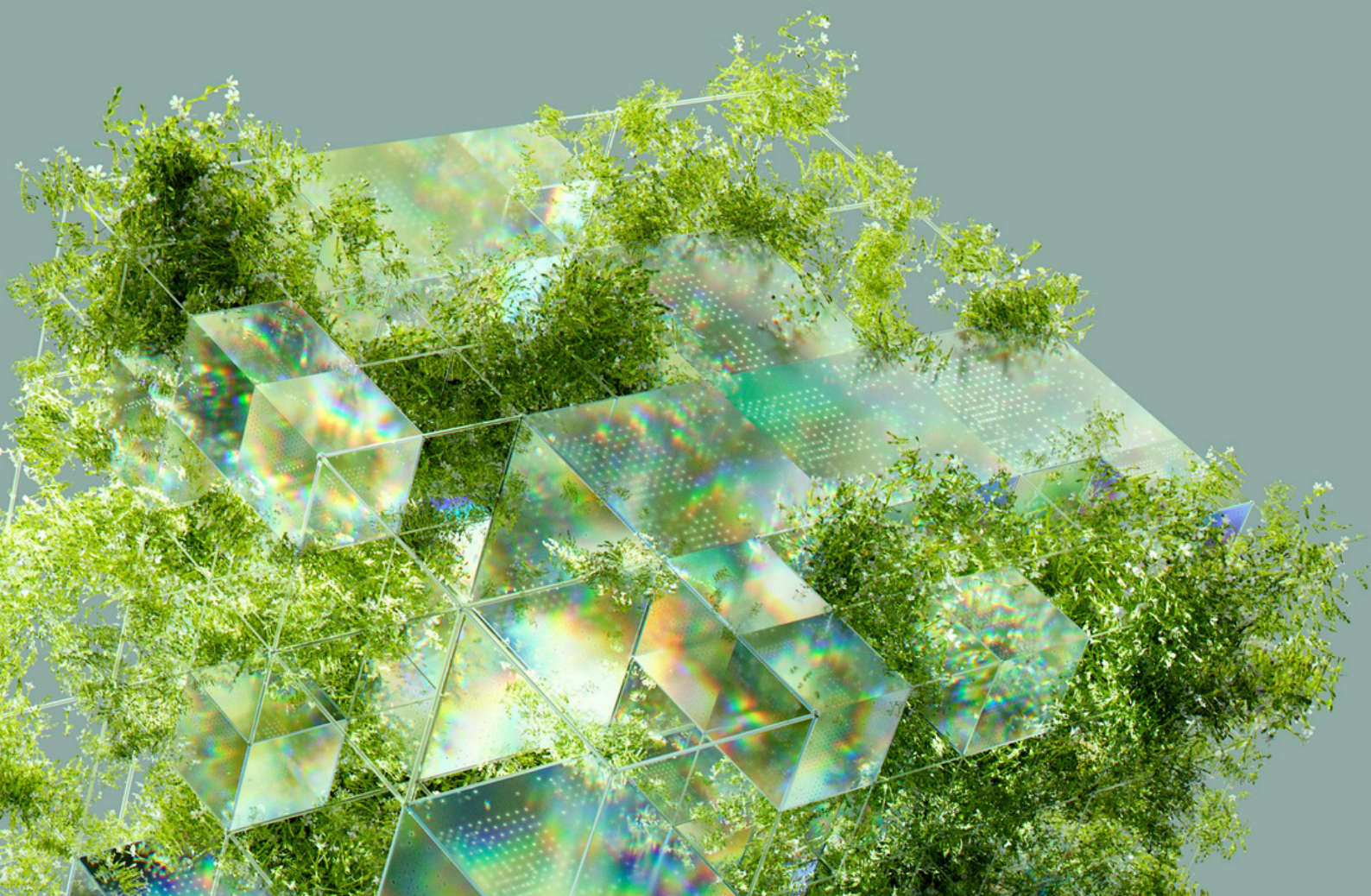
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Impressum

Kulturanthropologie Notizen.
Publikationsreihe des Instituts für Kulturanthropologie und Europäische Ethnologie
der Goethe-Universität Frankfurt am Main
Heft 88 (2026)
ISSN (Online): 2748-4912
www.ka-notizen.de
DOI: 10.21248/ka-notizen.88

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Die Artikel dieser Ausgabe haben ein Peer-Review-Verfahren durchlaufen.

Redaktion: Gisela Welz, Martina Klausner, Dennis Eckhardt, Timotheus Kartmann,
Seçil Yıldırım
Titelfoto: Pexels
Layout: Kathrin Eitel