Geoforum 144 (2023) 103801

Contents lists available at ScienceDirect

Geoforum

journal homepage: www.elsevier.com/locate/geoforum

Climate governance by numerical data: The kaleidoscopic political space of a decarbonization dashboard

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ARTICLE INFO

Keywords:
Climate data
Politics
Climate politics
Climate governance
Kaleidoscope
Climate dashboard

ABSTRACT

ClimateOS is a software whose promise is to provide climate policymakers with reliable and actionable transition plans towards decarbonization, thanks to its algorithms' ability to handle large amounts of numerical climate data. What data to feed ClimateOS' algorithms? This is a question that greatly concerns its developers and one that I analyse in this article for its socio-political implications. Specifically, I unpack how developers relate to the accuracy and reliability of numerical data. I suggest that their multifaceted approach to numerical climate data allows ClimateOS to open a political space where the various transition plans the software offers can be tinkered with. This article brings critical geographers and material semiotics scholars in conversation. The former argue that data-driven (decarbonization) governance practices depoliticize climate issues, characterizing such initiatives as the effects and expressions of global political economic processes. The latter show how different environmental accounting practices, at different times, produce different performances of nature; and how different ways of relating to numbers enact alternative modes of treating numbers accountably. In this article, I show how ClimateOS opens a political space that engenders social relations and co-produces articulations of a decarbonized future. Because of its multifaceted approach to numerical data, I characterize this political space as kaleidoscopic, where different and often incompatible political values and logics are enacted simultaneously.

1. Introduction

Dashboard technologies and data-driven climate initiatives have come to dominate contemporary environmental governance (Kitchin, 2014; Nost and Colven, 2022; Machen, 2018). Such initiatives aim to capitalize on the perceived capacity of numerical data to draw consensus and persuade (Deas, 2014; Blakey, 2021); a capacity that is often attributed to the potential of numerical data for, or its promise of, exactness and accuracy. These characteristics often come with an aura of objectivity, impersonality, and universality (Daston, 1992; Porter, 1992; Hansen and Porter, 2012). Leaning on such assumptions, some governance practices employ simulations and algorithms as tools to translate numerical data into actionable plans (Machen and Nost, 2021). Such a translation, however, enacts specific political values and logics, raising important questions about the future of environmental politics.

Geographers have raised poignant critiques of the use of climate data and data-driven initiatives. They have revealed data practices as the effects and expressions of global political economic processes and highlighted their entanglements with local and global inequalities in a context of extractive capitalism and neo-colonial relations. Here, the rise of infrastructures for data production and handling is understood as a product of global dynamics. In this article, I explore how numerical data, in turn, generates political spaces. I lean on the tradition of material semiotics approaches and their sensitivities to the performative politics of technologies. I suggest that climate data and data-driven initiatives produce a political space where different and often contrasting political values and logics are brought together into one socio-technical imagination of a decarbonized future.

I take as my case study ClimateOS. Developed by ClimateView, a Swedish company funded by a diverse set of investors, ClimateOS has to date been adopted by more than forty cities across the European Union (from Linz in Austria to Dortmund in Germany, from La Palma in Spain to Malmö in Sweden), the United Kingdom (Bristol, Cambridge, Newcastle, and more), and North America (Cincinnati). Through sophisticated mathematical modelling, ClimateOS accounts for the complex interdependencies between carbon emissions, urban residents' behaviours, energy production systems, local transport policies, and more. Upon first approach, ClimateOS' most striking feature is not the complex coding and algorithmic sophistication but its dashboard-like interface. Its "transition table" visually synthetizes all or most of the carbon-

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https://doi.org/10.1016/j.geoforum.2023.103801
Received 28 March 2022; Received in revised form 25 May 2023; Accepted 5 June 2023
Available online 15 June 2023

producing sectors of a city (Fig. 1). While the software computes in the background, the interface visualizes future emissions over a chosen period. Emissions increase or decrease in relation to the various inputs of planners: planning for larger shares of electric vehicles on the road, for instance, is what brings them down. Due to its user-friendliness, ClimateOS allows municipal planners to monitor and tweak future CO2 emissions across diverse urban socio-economic sectors with relative ease. They can delegate the complex calculations and interdependencies to the software.

Numerical data have been particularly central in debates over climate change mitigation strategies and have contributed to propelling climate issues into the academic and public spotlight (Nerlich, 2010). Hansen et al. (2008) analysed paleoclimatic data and suggested the need to reduce carbon dioxide (CO2) to less than 350 parts per million in order to preserve a planet with conditions like those that allowed human civilization to develop. Statements such as these appear in many official documents. Among the most notable are the *2018 IPCC Special Report on Global Warming*, which sets 1.5 °C as the limit to global temperature increase from pre-industrial levels before irreversible effects would take place; or the 2015 Paris Agreement, which aims to limit global warming to well below 2 °C.

In mathematical jargon, this type of numerical data represents absolute values of, for instance, degrees centigrade or tons of CO2 emitted into the atmosphere. Because such numerical data is a distance away from indicating what impact any policy might have, they are of relatively little use to climate strategists in local governments and municipalities. In this article, however, I do not take cities and their policies as the specific case study. Rather, I focus on ClimateOS' "aetiology of code" (Kitchin, 2011:947) and show how its multifaceted approach to numerical data allows multiple and at times contrasting political values and logics to co-exist alongside each other simultaneously.

The entanglement of these values and logics in a single transition plan allows for a specific vision of decarbonization. ClimateOS becomes a tool whose socio-technical solutions contribute to articulating relations between people, institutions, and a version of a decarbonized future. I refer to the possibility of shaping future social relations according to different political values and logics as the political space opened by ClimateOS. Following material semiotics traditions, I treat technology not as if it were outside of politics, but as a tool that performatively enacts it (Lippert, 2015; Mol, 1999; Colona, 2019). I show how ClimateOS does not just enact a specific and homogeneous political vision of the future, but allows for different political values and logics to potentially come together, simultaneously, in the same decarbonized vision of the future.

ClimateOS' aetiology favours a pragmatic approach to tackling the urgent climate crises. Such pragmatism translates into an emphasis on what its developers call the "operational value" of numerical data. Thanks to numerical data that have "operational value" – that is, data able to show a relation between a certain policy and a change in carbon emissions – ClimateOS provides planners with a rather heterogeneous array of reliable decarbonization policy alternatives. Each policy, however, necessarily promotes different political values and logics; from an assumption of individual responsibility to reduce carbon emissions to proposals highlighting the necessity of institutional and structural change. Because ClimateOS allows for the simultaneous coexistence of such different and at times contradictory political values and logics, I qualify the political space opened by ClimateOS as kaleidoscopic: as in a kaleidoscopic image, the transition plans produced through ClimateOS force fragments of diverse, incompatible, and contrasting political values and logics together.

In the remainder of this article, I will first review the debates over the relation between numerical climate data and politics. After this, I will introduce ClimateOS and its functionalities in more detail. I will unpack two different meanings that numerical data take in ClimateOS, showing their reciprocal entanglements and how developers seesaw between the two. In the analysis, I will detail how ClimateOS' multifaceted approach to numerical data opens a political space, which I describe as kaleidoscopic. I conclude by considering the possible consequences for environmental politics, including that foregrounding the political space as kaleidoscopic might eventually contribute to enacting it as an arena for different forms of contestation.

2. Politics and numerical climate data

The governance of climate and CO2 emissions stands among the most prominent sectors of public life that are increasingly governed through numerical data, sensing, and algorithm technologies (Sareen, 2020; Machen and Nost, 2021; Blakey, 2021; Shore and Wright, 2015). Scholars in human and environmental geography have highlighted the political and social concerns at stake when delegating critical political choices to computational technologies and data. In climate policy-making efforts, the tendency towards "thinking algorithmically" and the reliance on numerical data and algorithms as planning tools for climate adaptation engender "a hegemonising effect on knowing and acting on climate change" (Machen and Nost, 2021:556). The claims to objectivity, universality, and necessity that this type of thinking promotes not only dismiss and render invisible other ways of knowing and relating to climate issues (Machen and Nost, 2021; Hulme, 2010), but also

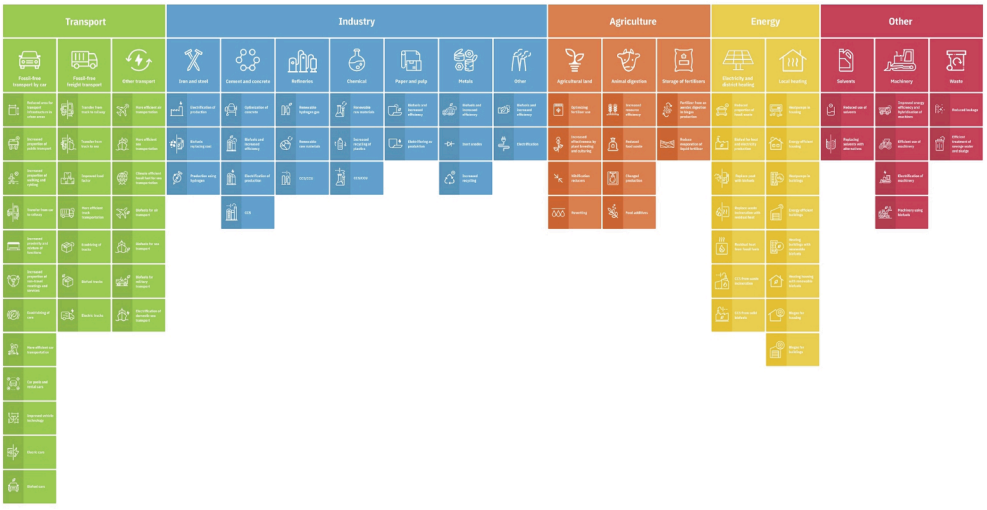

Fig. 1. The ClimateOS Transition Table (Shalit and Dixon, 2020:17).

reproduce the idea of a "singular Nature" (Swyngedouw, 2011:255) as an organizing principle of environmental and climate policies.

The rise of governance by algorithms has fuelled a feverish race to collect ever more – and more accurate – climate data. Artificial intelligence projects to this end are being increasingly spearheaded by NGOs, private companies, and tech giants alike (Nost and Colven, 2022; Bareis and Katzenbach, 2022). In turn, large volumes of data have induced the development of global digital infrastructures to facilitate the production and capture of such data in "forms that can be capitalized upon" (Nost and Goldstein, 2022:4). Such infrastructures are ever more dependent on the use and extraction of scarce natural resources, from water used to cool down data centres (Velkova, 2021), to lithium and cobalt for battery technologies (Bonelli and Dorador, 2021; Sovacool, 2019). Furthermore, Nost and Colven (2022:31) warn how data-driven climate adaptation projects, which rely on energy-intensive data centres and computational technologies, often function as "greenwashing" for large corporations.

The enormous volume of data is, furthermore, distributed unevenly, with wealthier parts of the globe being both more represented in datasets and better able to access and use them. This unevenness reveals a political economy and ecology of data that emerges within the context of global racial capitalism and neo-colonial relations, and it reproduces both global and local inequalities (Datta, 2018) that reverberate beyond climate issues. The case of New Orleans' Resilience Dashboard, created in the aftermath of Hurricane Katrina, is a case in point that shows how this AI initiative, initially aimed at climate and disaster adaptation, ended up being employed as a predictive policing tool based on racially biased data (Nost and Colven, 2022). An example of what Klein (2007) terms "disaster capitalism", describing the exploitation of traumatic events like disasters for economic expansion (Fletcher, 2012) for the benefit of the already rich and wealthy.

To shed further light on how data engender social relations, Kitchin (2011) suggests to carefully examine the "aetiology of code" in software programmes such as ClimateOS. Understanding "how code makes digital technologies what they are, and shapes what they do" helps us to unpack how software contributes to "shaping social relations" (Kitchin, 2011:947). ClimateOS is one among other dashboards and software programmes aimed at governing through numerical data (Kitchin et al., 2015), which deliver a vision of social life as "programmable" (Kitchin, 2011, 2014). In the process, these dashboards and software programmes allow questions about the value and accuracy of numerical climate data – and their politics – to be raised (Blakey, 2021).

In this article, I link geographical debates about climate data and their attention to the politics of dashboards with material semiotics' concerns with processes of quantification and accounting as enactments of realities. This scholarship has shown that rather than being a passive governance tool that describes a reality out there, numerical data contribute to co-producing, to enacting, such realities (Asdal, 2008; Ash et al., 2018; Coopmans, 2018; de Wilde and Franssen, 2016; Lippert, 2015; Verran, 2012).

In her work on acid rain levels in Norway, Asdal (2008) shows how, over the course of a few decades in the last century, different accounting practices regarding pollution levels were able to produce different enactments of nature, or "nature-wholes" (Asdal, 2008:130). Mobilizing specific accounting practices allowed Norway and other Nordic countries to emerge as net importers of pollutants vis-à-vis their other European counterparts, thus producing a space for negotiation within the Cooperative Program for Monitoring and Evaluation of Long-Range Transmission of Air Pollutants in Europe. Asdal's nature-wholes are different than both Nature (with a capital "N") as a timeless and placeless moral high ground and a deadly tool to politics (Latour, 2004), and the idea of a "singular Nature" as something outside of dispute, contestation, or disagreement (Swyngedouw, 2011:255). Rather, different nature-wholes are products of situated accounting practices that emerge in relation to historical and economic contexts. In Asdal's account, the emergence of a nature-whole as an effect of these accounting practices worked to "open a political space, to break a space open, thus allowing it to become a subject of negotiation" (Asdal, 2008:130), rather than suspending public discussion or contestation.

Attending to specific accounting practices, as Asdal (2008) did, shows how numbers and numerical data respond to multiple logics about their quality, beyond the simple dichotomy of true or false. Coopmans' (2018) work on the reporting for a diabetic retinopathy screening programme in a Singaporean medical centre details how different accounting practices reflect questions about what should and should not be done with numerical data. The main goal of the retinopathy screening programme was to reduce the number of non-necessary referrals of retinopathy patients to specialist doctors. In her work, Coopmans describes different versions of "accountable engagement" (2018:110) with numbers, which were performed, respectively, by the graders tasked with giving a verdict on patients' retinopathy images and by the managing director of the screening programme. The graders seemed concerned with producing an accurate "snapshot" (2018:118) of how many patients had been referred to a specialist doctor, how many had been booked for an early follow-up rescreening, and how many had been booked for a regular-interval screening. The managing director, on the other hand, was consistently asking graders to work the numbers and show a trend, be it a reduction or an increase in referrals to specialists. This is what – for the director – would enable an evaluation of the programme's success or failure.

Inspired by Verran (2010), Law (1994), and Woolgar and Neyland (2013), Coopmans (2018) suggests three (non-exhaustive) alternative analytics to unpack what she describes as a "disconnect" between the graders and the managing director. One of the three analytics is of particular interest here. With Verran's (2010) work on the logics and social lives of numbers, Coopmans (2018) shows how the graders engaged in a relation to numbers that converted all of the screening outcomes to "grand totals of single numerosity" (Coopmans, 2018:117), while the managing director's concerns foregrounded an interest in engaging numbers as a "*whole/part* relation" (2018:122, italics in original). On the one hand, there is a relation of one/many, of singularity/plurality, typical of scientific enumeration practices, and, on the other, a relation between a whole and its parts, typical of economic enumeration (Verran, 2010; see also Asdal, 2008).

Different enumeration and accounting logics thus enact realities differently. Carbon accounting practices in particular – as Lippert (2015) shows – "are not mere technologies-of-representation" (2015:127), but rather an assemblage of numerical practices that co-configure how environments exist. Leaning on Mol's (1999; 2002) work on multiplicity and ontological politics, Lippert (2015) argues that carbon realities are enacted in accounting practices, and "if practices enact things in particular ways they could also be enacted differently" (2015:127). For Lippert, then, accounting practices become an issue of politics for the specific reason that they enact one version of reality over an alternative.

In this article, I attend to the aetiology of ClimateOS' code. Not by dismissing the relevance of "political struggles over data production and its deployments" but through paying attention to "how data is generative of new forms of power relations and politics at different and interconnected scales" (Bigo et al., 2019:4). In the next sections, I give an account of how ClimateOS' developers seesaw between two different meanings of numerical data and I query their modes of accountable engagement (cf. Coopmans, 2018). I show how they can coordinate these modes by acknowledging the relevance of both meanings while, in a pragmatic approach to decarbonization transition, they simultaneously put one in the service of the other. ClimateOS produces socio-technical climate adaptation imaginaries (Jasanoff, 2015) that perform alternative visions of a future that could be: extended electrified transportation; reduced air travel; electricity production through renewable resources; etc. These socio-technical imaginaries are crucial in shaping social relations, as they do not just offer a possible socio-technical trajectory, but contribute to the realizations of their future visions (Lippert, 2015; Bareis and Katzenbach, 2022). I suggest that

ClimateOS opens a political space (Asdal, 2008) that is kaleidoscopic: socio-technical decarbonization trajectories can be adjusted and manipulated, which allows for different political values and logics to coexist alongside each other in a kaleidoscopic image of the future.

3. Note on methods

The empirical material on which this article is based consists of documents available through ClimateView's website, the recording of ClimateView's online launch event for ClimateOS, two online interviews with employees of ClimateView, and ten interviews with employees of a municipality in Sweden that served as a test-bed to develop ClimateOS. This work was conducted in 2020 and 2021. Two interviews proved to be fundamental to my understanding of the tool and are central to the argument I advance here. Both interviews took place online, allowing my interviewees to share their screens and walk me through the inner workings of ClimateOS. Crucially, one of these interviews was with an employee of ClimateView and one with an employee of the planning and strategic development office of the Swedish municipality.

In the interest of providing an intelligible and concise narrative that highlights the seesawing between the various meanings of numerical data, I omit many details and functionalities of ClimateOS. I build my argument not through a distant critique of ClimateOS and its developers but through – indeed seesawing with – them, and taking onboard their own concerns and hesitations (Vogel, 2021).

In our conversations, my interlocutors frequently presented examples about transportation and urban mobility, as they believed this topic to be easily relatable. I will do the same in this paper. Some of the names of the people who were involved in the public launch of ClimateOS or the names of authors who published documents that I use in this article cannot be anonymized. I have nevertheless chosen to pseudonymize the interviewees from the municipality and from ClimateView where possible.

4. Introducing ClimateOS

ClimateView, according to its own motto, aims to create innovative technology to help cities understand and execute the shifts necessary to address the climate emergency. The developers of ClimateOS seesaw between improving the *representational* meaning and the *operational* meaning of numerical data, often favouring the latter over the former. Representational meaning highlights the characteristics of numerical data to represent a reality accurately and precisely. In the case of CO2 emissions, for example, knowing that producing "x" megawatts of electric power from coal, under specific technological and material conditions, emits a known "y" amount of CO2 is representationally meaningful. Numerical data is operationally meaningful when it shows a relation between certain actions, policies, or behaviours and an increase or reduction in carbon emissions. Therefore, operational meaning derives from the capacity of numerical data to support informed decisions about a carbon emissions increase or reduction due to a given policy or initiative. Representational meaning is tied to the accuracy of numerical data, while operational meaning is tied to its reliability – that is, its capacity to predict a relation between a policy, initiative, or action and the trend in carbon emissions.

4.1. Good enough data

ClimateOS publicly launched on the 31st March 2021, with an online Zoom room crowded with over 300 people from across the globe. Tomer, one of the founders of the parent company, opened the event, promising that his tool would allow cities to start finding their optimal path to net-zero faster. "Not in months. Not in weeks or days, but in minutes." Behind this confident marketing slogan, Tomer's statement was a provocation against the widespread attitude that, according to him, a "big problem like climate change needs big data" and ever more data points to be solved. The implication of such a position, he explained, is that the data is there, somewhere, but "we are just not looking hard enough for it". He concluded that with such a claim comes a crucial problem: this attitude "does not incite action, [but] actually rationalizes staying put to think and consider, ponder and search, when what we really need is to act and learn quickly".

Tomer was advocating for a pragmatic, action-oriented approach. This approach exploits the complex mathematical models and simulations that ClimateOS is capable of, and is based on the numerical data that is available at any given time. An approach primarily focused on producing more data, according to Tomer, would instead bog everyone down, as climate strategists wait for better, more accurate, more exact numerical data on climate emissions.

Tomer, in his own Zoom event, encountered some resistance. As his introductory speech was almost at its end, the first comment from the audience appeared in the Zoom chat: "Mathematical models are just as good as the data they can be fed". Such a comment implies that the value of any mathematical model is tied to the representational meaning of the numerical data – that is, their accuracy.

How to reconcile such a concern for more accurate data with the pragmatic approach that Tomer was advocating? Tomer's guest attached greater value to the *representational* meaning of numerical data, as he was concerned with the accuracy of ClimateOS' mathematical models and their predictions. Tomer, on the other hand, was mainly – but not solely – concerned with the *operational* meaning of numerical data and their capacity to produce reliable predictions. That is, their capacity to reliably show the effects of policy choices or residents' behaviours on carbon emissions.

These two different approaches are not new in environmental governance discourses. The numerical data attached to climate governance have been at the centre of heated controversies, with consequences for policy processes. The precise number of tons of CO2 emitted in, or captured and stored away from, the atmosphere, the accuracy of the impact of emissions on mean atmospheric temperatures, on ocean acidification, or on sea level rise (among others) have been widely dissected and analysed (Edwards, 2010; Nerlich, 2010). In what is known as Climategate (in 2009, as well as its aftermath), the accuracy of the relations between CO2 emissions averages and global warming temperature averages became the focus of some very antagonistic debates. Some were set on denying the anthropogenic impact on climate change that was suggested by the data coming from climate scientists, while others were defending it. The most committed denialists alleged, unfoundedly, that the scientists had committed malpractice and blamed them of religious orthodoxy in upholding the numbers' "absolute certitude" (in Nerlich, 2010:432). Special interest groups leaned into policymakers' desires for more accurate data (Goldstein, 2021), pressuring them into inaction on climate change by hyping the "uncertainty" of climate science (Briscoe, 2004:1).

Issues of certainty and uncertainty often articulate these antagonistic debates, but they also offer the basis for alternative considerations. In the process of infrastructure planning for coastal restoration in post-Katrina Louisiana, some concerned parties asked if they should "study diversions to death or build them?" (Nost, 2020:6). Such a pragmatic approach favours solutions whose consequences are, if not thoroughly, then at least reasonably, known and understood to be effective at mitigating the problem at hand. In the process, this approach underscores how "more precise or accurate data does not necessarily lead to better decision-making or improved socio-environmental outcomes" (Goldstein, 2021:2).

Data accuracy and decision making emerge in a complex relation. When self-organized residents' initiatives collected data to monitor above-the-limit air pollution in their neighbourhoods in the US, the authorities dismissed their findings on the grounds of both bias and validity. Gabrys et al. (2016), however, show that the residents, by establishing patterns within this data, were able to bring evidence of environmental pollution into narratives where residents' own concerns

could figure into a collective account. To this end, numerical data had operational meaning, as they were "just good enough" (Gabrys et al., 2016:9) to mobilize communities and bring authorities to take regulatory steps.

Evaluating numerical data as "good enough" is never void of non-numerical judgements about their quality (Callon and Law, 2005; Lindquist, 2021; Niner and Randalls, 2021). For Tomer's online guest, "good enough" was about accuracy and representational meaning, while for Tomer himself it was mostly about operational meaning and the capacity to establish patterns – though the latter does not dismiss accuracy altogether. The data on environmental pollution in Gabrys et al.'s (2016) account certainly require a degree of representational meaning and accuracy. Yet, the same data became "just good enough data" (Gabrys et al., 2016:9) only once they could establish patterns that afforded operational meaning, eventually provoking a governmental response.

This discussion resonates with the empirical material discussed in this article. In a position paper, Tomer and one of his collaborators explain their take on "good enough" (Shalit and Dixon, 2020:9); that is, when and how numerical data is considered to be operational. In setting up ClimateOS, they state that they needed to determine "what data precision is *good enough to make informed decisions*, while also clearly differentiating between different types of data, and what data has *operational value*" (Shalit and Dixon, 2020:9, italics added).

In the position paper, different modes of accountable engagement with numerical data start to emerge. The necessity for "data precision", accuracy, and the representational meaning of data is foregrounded. It is similar to the type of accountability that Coopmans' (2018) graders were concerned with, highlighting a relation of one/many, of singularity/plurality (Verran, 2010). Conversely, the concern with data that has "operational value", as Tomer emphasizes, is reminiscent of a mode of accountable engagement that is concerned with the relation of part-to-whole (Verran, 2010), which allows numbers to reveal threats and opportunities for decarbonization (Law, 1994). Differently from Coopmans' (2018) case, however, these different modes of accountable engagement do not create a moment of disconnect. Rather, they are performed simultaneously by ClimateOS developers; they are held in tension together, as they both articulate a version of accountability that is measured against the capacity to inform decisions.

4.2. Rate of change

ClimateOS' socio-technical trajectories towards a decarbonized future (Bareis and Katzenbach, 2022) are based on interconnected "transition elements", which are visualized on a "transition table" (Fig. 1). Each transition element stands for a specific activity within a sector of a city or a region: transport, industry, agriculture, energy, and other. The emphasis of each element is on its transition "potential" (Shalit and Dixon, 2020:30). Each transition element is based on a strict mathematical model that calculates the relative carbon reduction afforded by certain activities over others (such as driving a set distance with an electric vehicle instead of a fossil fuel car). ClimateOS does not suggest reducing the number of kilometres that urban residents travel. Instead, it estimates the CO2 reduction that would result from switching to a transport technology with lower emissions for the same number of kilometres.

ClimateOS' algorithms are therefore concerned with the *rate of change* from a specific transport technology to a greener one. This enables its developers to evaluate the operational meaning of the numerical data fed to the tool's algorithms. The emphasis is not on the absolute value of carbon emissions that any activity produces (that is, "x" tons of CO2) but on the potential of switching from one high carbon emission activity to a lower carbon emission activity.

This becomes clearer in the position paper authored by Tomer and his colleague at ClimateView, as they propose an oversimplified example to spell out what they mean by "rate of change":

> a person wants to reduce her carbon footprint, so she intends to reduce her commercial air travel by 50 percent. Does she need to know the exact emissions incurred by flying to do this? No – it is sufficient to cut her airline miles travelled by half. If she wants to reach zero emissions from flying, she could simply stop flying, requiring even less data analysis (Shalit and Dixon, 2020:9).

This example unpacks the underlying logic of the ClimateOS algorithms: estimating carbon emissions unfolds through a logic of relationality, one of thinking in terms of relative reduction instead of absolute reduction (the traveller is not making decisions based on how many kilograms of CO2 her travels contribute, but on a proportional reduction from her own personal total). Rather than foregrounding a (more or less) accurate estimation of CO2 emissions, it centres around the reliable and operationally meaningful measure that halving the miles travelled by planes halves – approximately (accuracy here is less of a concern) – the traveller's carbon emissions from air travel. To bring it ever-so-slightly closer to a complex real-world situation, the traveller could consider shifting 50 % of her air miles to, for instance, train miles. Following ClimateOS' logic, the relevant information towards a reliable CO2 reduction is knowing that travelling by train emits less CO2 than air travel.

Replacing high carbon emission activities with others that emits less CO2 enacts the shift from the representational meaning of numerical data to their operational meaning.[1] Knowing that train travel emits less CO2 than air travel does not give an accurate estimation of the amount of CO2 emitted, but it is reliable enough for a traveller to know that her train journeys imply a carbon reduction.

In their position paper, Shalit and Dixon (2020) suggest that ClimateOS' logic of "rate of change" can be up-scaled to cities, and they give a more detailed impression of how numerical data are weighted according to their operational meaning:

> We can either measure the emissions from existing cars, or measure the *rate of change* by which we replace these cars with more sustainable options. *It is easier to count* the number of electric vehicles in the city than to measure city-wide emissions from existing fossil-fuelled cars. The growing share of electric cars is a relative change – illustrating that emissions data should not be the primary focus when monitoring the rate of change (Shalit and Dixon, 2020:9, italics added).

In this quote, numerical data gains operational meaning for two reasons. First, measuring the rate of change of an activity (e.g. shift from fossil fuel to electric vehicles) is *operationally easier* than measuring the totality of tons of CO2 emitted. Its stated simplicity is proposed as the antidote to "fruitless" hunts for more exact data. These hunts can lead "well-intentioned policymakers astray" and, according to the authors, might even create "obstacles to innovation and meaningful carbon reduction" (Shalit and Dixon, 2020:9). This resonates with calls to have some policy (that works to a certain extent) over no policy at all (Nost, 2020; Goldstein, 2021; Machen, 2018; Bevan and Hood, 2006). Second, and consequentially, Shalit and Dixon (2020) suggest that measuring the rate of change allows policymakers to focus on adopting more sustainable lower-carbon options. It thus favours numerical data that can easily and reliably guide actions and decisions.

The type of accountable engagement with numerical data that is performed in the examples above is reminiscent of the manager of the Singaporean retinopathy screening programme (Coopmans, 2018).

[1] Bolin and Velkova (2020), in the context of metrics in digital environments, distinguish between representational and operational metrics. The former have the function of driving user engagements, while the latter are used as the basis for algorithmic processing and behavioural targeting. While Bolin and Velkova's operational metrics are "under the hood" and hidden from the user, here operational refers to the ability of numerical data to aid informed policy choices.

Foregrounding "rate of change" enacts a relation of whole/part, and simultaneously warns against a potentially misjudged pursuit of more data that would instead produce "grand totals of singular numerosity" (Coopmans, 2018:117; Verran, 2010). Focusing on the rate of change between activities with different levels of emissions means that ClimateOS questions, for instance, *how* we move but not *how much* we move.

This begins to sketch out how ClimateOS opens a specific kind of political space (Asdal, 2008) and how it performs socio-technical imaginaries of a decarbonized future. It contributes to creating specific conditions of possibility for social relations to emerge (Bareis and Katzenbach, 2022; Kitchin, 2011). That is, ClimateOS' socio-technical trajectories towards a decarbonized future tend to rely on the promise of technological solutions (Nost and Colven, 2022), rather than on the option of reducing all CO2-producing activities. Yet, as it becomes clear in the next section, ClimateOS' complex relation with numerical climate data is reflected in the diversity and incompatibility of the political values that are enrolled in the production of its decarbonization transition plans.

4.3. Seesawing between representational and operational meaning

According to Tomer and his colleague (Shalit and Dixon, 2020), measuring the rate of change at which electric cars substitute fossil fuel cars is easier than estimating the total CO2 emissions from all cars in a city at any given moment. Yet, the authors also warn that such relative simplicity should not exempt us from probing the accuracy of numerical climate data. With such a warning, they reintroduce the representational meaning of numerical climate data back into the picture.

For example, if a municipality opted to reduce fossil fuel cars by fifty percent across its territory, other forms of transport would have to make up for the distance that these cars used to cover. The alternative transport could be, for instance, electric public buses, which contribute fewer carbon emissions, but do not eliminate them altogether. Reducing kilometres travelled by private fossil fuel cars by fifty percent does not therefore reduce urban mobility emissions at the same rate. Furthermore, a larger electric public transport fleet would increase the need for electric power, whose CO2 emissions depend on the specific production technology used. The cascade of complexity grows even more by taking into consideration the efficiency of the power grid, carbon capture options, distributed energy production on solar roofs, and more. Thus, measuring the rate at which a mode of transportation (e.g. fossil fuel cars) is shifted to another one (e.g. electric cars) does not directly measure the overall CO2 reduction.

During the ClimateOS launch in March, Tomer gave the stage to Jonathan, the leader of his transition team. At the end of his presentation, Jonathan described ClimateOS as offering a solid base for cities to plan their transition to climate neutrality. As Tomer thanked Jonathan, he also stressed that "to build this solid base, *we do need solid data*. Data that goes into the transition elements' building blocks". Together with Tomer's previous statements, this was a hint to ClimateOS' complex and multifaceted relation to numerical data.

Tomer and his colleague at ClimateView clarify their position by showing that an emphasis on operational value should not lead modellers to do away with the representational meaning of numerical data:

> This is not to say that we don't need GHG [greenhouse gases] emissions data at all. In fact, GHG inventories are necessary for knowing where to prioritise our efforts; however, they are not helpful when measuring the rate of change (Shalit and Dixon, 2020:9, italics added).

ClimateOS' developers find themselves seesawing between operational and representational meanings of numerical data, and thus enacting alternatives of accountable engagement with numerical data. This seesawing becomes more evident when the representational meaning of numerical data, its accuracy, is put into an ancillary service of the data's operational meaning. Knowing specific sectors' emission levels is only useful when compared to other sectors and to the totality of emissions; this is operationally meaningful information that enables prioritizations. Engaging with numerical data for its accuracy thus becomes a means to its increased reliability and its capacity to specify a relation of part-to-whole.

This seesawing was further explained in an interview with Eva, a data modelling specialist at ClimateView. Eva walked me through the initial steps of planning the transition for one of their customers, a city in the UK. For my benefit, she simplified the process and focused on the transport sector, one that she deemed more accessible and one that the company generally takes for their marketing purposes.

The UK city had data on the total number of miles per year that private cars drive on their municipal roads and data on the different type of cars registered within the municipality (i.e. powered by either petrol, diesel, or electricity). The city did not have data, however, on how the total number of miles was distributed across these different types of cars, which widely differ in their specific "emission factors". To solve this impasse, Eva suggested using the national distribution. She admitted that this was not necessarily an accurate representation, and that the distribution was almost certainly imprecise. Considering that the "emission factors" are relatively stable – that is, the emissions that a diesel, petrol, or electric car emit respectively per mile – Eva judged that mixing the national distribution with the local number of kilometres travelled was a "good enough assumption" that "saved them [the city's planners] a lot of time from having to try and chase the actual numbers" and allowed them to start planning the city's transition.

What Eva called "emission factors" are the standardized CO2 emissions of a specific technology, for instance the average CO2 emissions of petrol, diesel, or electric cars per kilometre respectively. Or the average CO2 emissions necessary to produce one megawatt of electric power through coal burning, natural gas, or wind power. Tomer emphasised this during his presentation at the launch event, reminding the audience that such numerical data is straightforward and relatively stable; this data is not hard to find, because – he claims – "these physical facts are identical and applicable across the globe" (see Hulme, 2010).

Complexities come into view when ClimateOS must match such "physical facts" with what Eva refers to as "behavioural" data. Behavioural data for Eva is, for instance, the use of certain technologies or certain behaviours over others, such as driving an electric or a fossil fuel car or riding a bike or using public transport to go to work. Eva stresses the "sheer volume" of such data "that we [at ClimateView] need to plough through in order to get something usable for the climate boards". Here, Eva suggests that operational meaning is not an intrinsic quality of numerical data. Although aligning standardized emission factors with behavioural data is something that the team at ClimateView strives towards, (accurate) numerical data is often insufficient or not available. Thus, the ClimateOS developers make "good enough assumptions" that work (Lippert, 2015) and deploy data that has operational meaning.

Eva's "good enough" proxies, drawn from national data, to estimate the municipal distribution of kilometres per type of car are not a case of goal displacement towards less ambitious targets (Fitzgerald, 1996; Huizinga and de Bree, 2021). Instead, what the material above demonstrates is a commitment to ambitious goals that require full engagement with the numerical data that is available. Rather than tuning down the goal, it shows how numerical climate data is necessarily "practiced" (Nost and Goldstein, 2022:9). It needs to be actively produced and circulated (Vurdubakis and Rajão, 2022), "developed [and] deployed" (Nost and Goldstein, 2022: 9), as well as maintained and curated (Nost, 2020). Eva's proxies – the national distribution of kilometres per type of car – which stand in for the municipal distribution, do not displace the final and ambitious decarbonization goal, but are rather a temporary – if imperfect – fix towards this goal.

Once these assumptions are made, the chosen data feed into ClimateOS' mathematical models. Such data, however, change over time, as further research is performed and more data points are collected. Gabrys et al.'s (2016) call for "good enough" numerical data, here, takes the

meaning of good enough *for now*. Eva explained that if they needed to work with a city or country for which data was not available, they would use "global numbers". While these would not be accurate by any means, they would still retain operational meaning as they would allow planners to start working on a transition plan sooner rather than later. "While they are working, we [ClimateView] could […] do research on national data.".

This modus operandi reiterates Tomer's invitation to start the transition based on the data available, rather than waiting for more – and more accurate – data. During the launch event, Tomer stressed the necessity to share the different practices and reasoning behind climate governance, and specifically "the logical and scientific path of thought that underpins our decision making. Not because they are correct, but because they are most probably wrong to start off with". This approach reflects an aspiration towards more accurate and representatively meaningful numerical data about CO2 emissions, though not at the cost of dismissing operationally meaningful data that is already available.

The developers' seesawing between representational and operational meaning is mirrored in their ways of engaging accountably with numerical data. In Coopmans' (2018) case, the graders' and manager's modes of accountable engagement seemed incompatible and provoked multiple "moments of disconnect" (2018:110). In the case of ClimateOS, however, incompatibility is not as marked. Engaging numerical data accountably in ClimateOS means that the developers produce moments of ongoing synthesis – or compromise – rather than disconnect. They engage numerical climate data for what it is; leaving it alone as an archetypical expression of scientific enumeration practices (Verran, 2010), and simultaneously as data that need poking and prodding to highlight relations between activities and emissions, to reveal threats and opportunities for decarbonization (Law, 1994).

This type of synthesis affords very complex and intricate socio-technical climate adaptation imaginaries, which, through the simulations of ClimateOS, can contribute to the "installment of these futures" (Bareis and Katzenbach, 2022:875). The seesawing, balancing, and synthetizing of different modes of accountable engagement allow ClimateOS to open a political space where these futures become "subject[s] of negotiation" (Asdal, 2008:130) that bring together different and often incompatible political values and logics.

5. The kaleidoscopic political space of ClimateOS

A manager in the planning and strategic development office of a Swedish municipality was drawn to ClimateOS' potential to produce reliable carbon emissions simulations that could account for a large spectrum of activities and sectors. The political leadership of the municipality gave the mandate to "Reduce. Reduce. Reduce" CO2, though the work of municipal planners was often complicated by the impossibility of municipal policies to effect drastic change in residents' behaviour (Colona, 2023).

Jonathan, the leader of ClimateView's transition team whom I introduced earlier, encouraged his audience of planners and climate strategists to think of the transition elements (Fig. 1) as "individual campaigns that for the first time you can place in one overall system, being able to connect strategies and actions to quantify shifts". For my interlocutor in the Swedish municipality, ClimateOS' modus operandi provided potential interdependent solutions to carbon reduction in her city, from mobility policies to larger-scale energy production systems. It opened holistic – if incremental – opportunities to reduce emissions that did not necessarily require drastic changes in residents' behaviour. Thus, ClimateOS contributes to shaping and producing climate policies, and, as Kitchin et al. (2016) suggested for the case of the Dublin Dashboard, such tools affect the futures of the institutional and political landscape in which they are embedded, "coproducing the installment of these futures" (Bareis and Katzenbach, 2022:875).

These futures start their life as a product of ClimateOS simulations, akin to roadmaps for a decarbonized future of a city (Colona, 2023). They consist of socio-technical climate adaptation imaginaries (Jasanoff, 2015) that detail ways of living in the city for residents, as well as carbon-friendlier ways of producing energy, building houses, among others.

Jonathan, the leader of ClimateView's transition team, concluded his presentation at the launch of ClimateOS by stressing that each of the transition elements are "plug and play". While they consider all of the major sectors of a city's economy, he explained, each municipality can decide to work on some and not on others (e.g. decarbonizing transportation rather than the construction industry). This feature leaves to cities themselves the choice of *what and how* to prioritize in the transition towards lower emissions. They can design their plans according to different criteria, from their levels of ambition to the contextual feasibility of any action, to local political agendas.

For example, one of the tool's strategies to reduce CO2 emissions from urban mobility and commuting is to increase individual ownership of electric vehicles. A parallel solution to the same problem is to increase the number of days residents work remotely from home, as this will reduce the overall number of kilometres workers need to commute. These two examples were used by Eva during our Zoom interview, when she set up a simulated case and shared her screen for my benefit. She showed me the interface a planner would use to tweak carbon reduction goals and activities within each transition element. In this simplified multi-year-long simulation, however, she had "mathematically overdrawn a target". She had assumed a fixed number of kilometres for commuting per year over the same simulated multi-year period, a good enough assumption for Eva. As she tried to increase the average amount of time of remote home working a resident could carry out, thereby eliminating the need for commuting the respective home-work-home distance, ClimateOS' interface prevented her from doing so. She realised she had imputed too large of a shift towards electric cars, which was also accounting for part of the distance that workers would no longer need to commute as they would be working from home more. She had hit the carbon reduction goal for that specific transition element: "people are driving so much electric cars, and there is no more room in 2030 for so much remote working".

With her mouse, Eva brought down the share of electric cars in the municipality. Now, with "fewer electric cars in the streets […], people could remote work more". She explained: "that's an example of the interdependency" of the transition elements, which work under a sort of budgetary constraint. The total number of kilometres commuted per year on the one hand, and the portion of this number covered by electric cars, or removed through home working (what Eva called behavioural data), are reminiscent of, respectively, the whole and the part in Verran's (2010) analysis of the logic and relations of numbers in economic enumeration.

The interdependency Eva spoke about goes beyond the confines of each transition element. If she left the mobility transition elements and moved over to those concerning energy, she would also be required to enter an estimate, a good enough assumption, about the shift from electricity production using fossil fuels towards wind and/or solar power; or about improving the efficiency of the electric grid; or the increase in carbon capture capacity. All of these shifts, Eva showed me on her screen, would increase the potential reduction of CO2 achieved by driving an electric vehicle, because the electricity required to power these cars would be produced with greener technologies (wind or solar). Since ClimateOS assumes accurate and stable "emission factors", CO2 reduction is also calculated as "grand totals of singular numerosity" (Coopmans, 2018:117), which in turn foreground a logic of singularity/plurality (Verran, 2010) in ClimateOS' numerical data.

In ClimateOS' socio-technical trajectories of decarbonization, different ways of relating to numerical data and different numerical logics find space simultaneously. Similarly, ClimateOS does not require homogeneous or even compatible political values or logics for its trajectories. On the one hand, encouraging residents to buy electric vehicles (Colona, 2023) or to work from home assumes an underlying

neoliberal political ideal of individual responsibility, where residents are encouraged to account for their own emissions. It enacts a relationship of responsibility between individual residents and the environment (Machen and Nost, 2021; see also Tozer, 2019). On the other hand, promoting structural changes to improve the efficiency of the energy grid or shifting to fossil-free energy production systems performs a future where the responsibility for carbon emissions (and their reduction) is shared more widely between industry, national or local governments, and the ultimate users.

Moreover, promoting home working or reducing food waste at the consumer level on the one hand, and the potential carbon emissions reductions afforded by carbon capture technologies on the other, enact profoundly different political futures. Carbon capture technologies rely on the techno-solutionist assumption (Nost and Colven, 2022) of reducing carbon emissions alongside the growing demands of a capitalist economy. Alternatively, other solutions that promote a (relative) reduction in the consumption of resources (e.g. not travelling for work, or wasting less food) loosely work on the assumption that the origin of all emissions should be reduced at all costs.

ClimateOS allows and holds onto radically different futures simultaneously, where opposite political values and logics live alongside each other. Techno-solutionist projects of decarbonization often promote a vision of "green growth", an ideal of economic expansion compatible – and at times even interdependent, as Tomer and his colleague wrote in their position paper (Shalit and Dixon, 2020) – with planetary ecological processes (Hickel and Kallis, 2020). These are often pitched against calls toward "degrowth", as an equitable reduction of societal material and energetic demands that inevitably produces waste (Kallis, 2011). While these two specific political logics have been argued as incompatible and radically different (Hickel et al., 2021), the emphasis on the operational meaning of numerical data allows ClimateOS to work under both assumptions.

Coopmans (2018) deploys the metaphor of the kaleidoscope to show how shifting between the three distinct analytics she proposes is akin to rotating the dial in a kaleidoscope, thus creating different patterns and orders of what it means to engage accountably with numbers. Thinking with the kaleidoscope is helpful here as well, though more as a source of metaphorical inspiration than as an accurate engagement with of Coopmans' analysis. Much like turning the kaleidoscope's dial, Eva's manipulation and turning of different dials in ClimateOS' digital interface produce different patterns: different socio-technical trajectories and imaginaries of decarbonization.

Like the fragments of a kaleidoscopic image, the image of a decarbonized future in ClimateOS forces fragments of diverse, incompatible, and contrasting political values and logics together under one transition plan. What is visible then are bits and pieces of these different political logics and values, lying next to each other in what is often a technologically appealing configuration, but not quite an organic image. The aetiology of ClimateOS (Kitchin, 2011), I suggest, opens a political space that is kaleidoscopic. Its emergence can be traced back to the developers' seesawing between the representational and operational meaning of the numerical climate data that are fed into ClimateOS' algorithms, and the recurring emphasis and primary (though not sole) focus they put on the latter.

6. Concluding remarks and epilogue

In this article, I have attended to the ways in which software developers seesaw between the representational and operational meaning of the numerical climate data that they feed into ClimateOS' algorithms. At first, representational and operational meaning appeared to be in opposition, as developers revealed their preference for the latter. They suggested that the numerical data used for ClimateOS – and in its absence, assumptions about it – needed to be good enough (cf. Gabrys et al., 2016) to prompt planners towards producing reliable decarbonization policies, and to avoid the endless and ineffective chasing of ever more – and more accurate – numbers (Nost, 2020; Goldstein, 2021). Yet, they also recognized the importance of accurate emissions data to steer priorities and, circularly, to improve the operational meaning of the numerical data and the reliability of ClimateOS' transition plans.

Inspired by Coopmans' (2018) work on accountable engagement with numbers, my analysis suggests reading this seesawing as a way for developers to acknowledge numerical climate data for what it represents, and, at the same time, to detail what can be done with it. Seesawing between these two approaches eventually promotes socio-technical trajectories of decarbonization that, much like in the image of a kaleidoscope, assemble diverse and often incompatible political values and logics under one transition plan. These transitions within ClimateOS have a performative force (Bareis and Katzenbach, 2022), as they have the capacity to shape future social relations (Kitchin, 2011) and the everyday lives of residents.

The use of technical artefacts in environmental governance and management is an expanding field of inquiry into the politics of numerical climate data and its accounting practices (Asdal, 2008; Lippert, 2015; Machen and Nost, 2021). In Asdal's (2008) account, different accounting practices about acid rain levels in Norway enacted different "nature-wholes" that could "take part" in politics at different points in time. Coopmans (2018) shows how her interlocutors articulated their respective modes of accountable engagement with numbers as hardly reconcilable. What looks different in the case of ClimateOS, given its kaleidoscopic character, is that different approaches to numerical climate data are simultaneously held in mutual and interdependent tension. Modes of accountable engagement with numerical data as operationally meaningful are emphasised by – and are not in spite of – an attention to its representational meaning.

My suggestion that ClimateOS opens a kaleidoscopic political space runs parallel to critiques of the global political economy of labour and resources that such tools necessarily rely on and exploit. ClimateOS and other such tools certainly contribute to governance practices that reproduce the hegemony of a specific type of climate knowledge (Machen and Nost, 2021); one that is typical of the dominant Euro-American scientific rationality and that is entangled in global and local inequalities (Hulme, 2010). Yet, the suggestion I have advanced here focuses specifically on the performative functions and social relations that ClimateOS can engender. Lippert's reminder that "if practices enact things in particular ways they could also be enacted differently" (2015:127) is helpful here. Amid the reproduction of a hegemonic scientific rationality, ClimateOS opens a political space where fractures, fissures, and frictions between different political values and logics are not rejected because of their reciprocal incompatibility.

In the Swedish municipality where I conducted fieldwork, activist groups such as the local *Fridays For Future* chapter had access to a mirror account and a mirror climate board of the municipality's transition plan on ClimateOS. There, the group could rotate the dials of their own kaleidoscope and provide suggestions for policies and focus areas. The municipality planners and climate strategists, however, were unsure about how to incorporate these inputs into their official transition plan (and to my knowledge, they did not), and instead used it as a sort of pilot experiment. I found this to be an interesting attempt at re-articulating the political space provided by ClimateOS into a more concrete arena of political engagement. Far from a techno-optimist suggestion, this raises the question of whether and how the kaleidoscopic political space of ClimateOS-like tools could allow for a re-tooling of contestations over decarbonized futures.

Ultimately, these final reflections need to be weighed against the fact that ClimateOS is a young tool in continuous development; though some municipalities have adopted it, its kaleidoscopic transition plans are yet to be fully and widely implemented. As ClimateOS continues to be used as a tool of climate policymaking across the (wealthier) world, moments of contestation will arise over the representational and operational meanings of the numerical data it uses, the transition plans it produces, and the specific political values and logics of such plans. These moments

should be the subject of new research on such a defining topic of this time.

CRediT authorship contribution statement

Francesco Colona: Conceptualization, Methodology, Writing – original draft, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The authors do not have permission to share data.

Acknowledgements

This article could not have been possible without the help and welcome of the people working in the Swedish municipality where I conducted face to face and online fieldwork, and the welcoming and the interesting conversation with the people at ClimateView. This research was supported by STIPP Sweden, (the Swedish Transformative Innovation Policy Platform) and Vinnova (Swedish Governmental Agency for Innovation Systems). The empirical work and part of the writing for this article was conducted at the Technology and Social Change unit of TemaT Department at Linköping University. I am very grateful to all the colleagues in the STRIPE seminar group for their generous help, the members of the BRGE group and the Global Digital Cultures research seminar at the University of Amsterdam. I am especially grateful to Julia Velkova and Else Vogel for very close reading and feedback.

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