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Perspective

Scrutinizing environmental governance in a digital age: New ways of seeing, participating, and intervening

Sanneke Kloppenburg,[1,*] Aarti Gupta,[1] Sake R.L. Kruk,[1] Stavros Makris,[1] Robert Bergsvik,[1] Paulan Korenhof,[1] Helena Solman,[1] and Hilde M. Toonen[1]
[1]Wageningen University & Research, P.O. Box 47, 6700 AA Wageningen, the Netherlands
*Correspondence: sanneke.kloppenburg@wur.nl
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SUMMARY

Digital technologies play an increasingly important role in addressing environmental challenges, such as climate change and resource depletion. Yet, the characteristics and implications of digitalized environmental governance are still under-conceptualized. In this perspective, we distinguish three dimensions of governance: (1) seeing and knowing, (2) participation and engagement, and (3) interventions and actions. For each dimension, we provide a critical perspective on the shifts that digital technologies generate in governance. We argue against the assumption that the use of digital technologies automatically results in improved outcomes or in more democratic decision-making. Instead, attention needs to be paid to the wider political and normative context in which digital technologies are proposed, designed, and used as environmental governance tools. We conclude with key questions for academics and policymakers to broaden the debate on responsible design and use of digital technologies in environmental governance.

INTRODUCTION

Governments, international organizations, and technology companies have high hopes that digital technologies can be deployed to address grand environmental challenges, such as climate change, biodiversity loss, and resource depletion. The European Union, for example, invested €8 billion in a project called "Destination Earth" in 2021. The project's goal is to "develop a very high precision digital model of the Earth (a 'digital twin') to monitor and predict environmental change and human impact to support sustainable development."[1] Connected to Europe's Green Deal, this digital twin—generally defined as a real-time realistic digital representation of a physical entity—is intended to help policymakers to predict future climate risks and develop scenarios to test the effects of different climate policies. Meanwhile, the Coalition for Digital Environmental Sustainability (CODES) was launched under the umbrella of the United Nations. Co-chaired by the United Nations Environment Programme, the United Nations Development Programme, and several governmental organizations, research institutes, and non-governmental organizations (NGOs), this global initiative aims to bring public and private stakeholders and civil society actors together to advance collective action in "digitalizing environmental sustainability."[2] Technology companies also show a growing interest in applying artificial intelligence and other digital technologies to further sustainability goals. A key example here is Microsoft's initiative to build a "planetary computer" to "collectively monitor the Earth and build the intelligence needed to manage it for people and nature."[3] This planetary computer would aggregate environmental data from around the world and make it available for individuals and businesses while also predicting future environmental trends.

These recent initiatives are expressions of a widely shared belief in the potential of digital technologies to expand and improve environmental data collection and analysis, as well as to support "intelligent" environmental decision-making by public and private actors. This in turn is assumed to make environmental governance more effective in terms of improved outcomes, as well as to enhance its democratic legitimacy, as digital environmental monitoring capabilities become available to a wide group of stakeholders, such as citizens and affected communities. At the same time, it is becoming increasingly clear that digital technologies also create risks and pose challenges, including ethical issues around privacy, surveillance,[4] autonomy, fairness, transparency, and accountability.[5] Moreover, not everyone has access to diverse digital technologies and can benefit from their use, which raises questions about the inclusivity of this ever-increasing digitalization.[6] And even when digital technologies are deployed for sustainability purposes, there are still major negative environmental impacts resulting from their use, such as the destruction of ecosystems in areas where minerals are mined, increases in energy consumption, and e-waste.[7–10]

While the above risks and challenges need to be addressed if the assumed transformative potential of digital technologies is to be realized, we argue that there are a number of more profound changes that need our attention. With the increasing digitalization of environmental governance, how environmental issues are framed in the present, as well as the nature and predictions of future issues and responses to these issues, is increasingly mediated by digital technologies. This is not a problem *per se*, but it may become problematic if digital technologies are presented as neutral tools and as value-free technological fixes to

Figure 1. Conceptualizing digitalized environmental governance: Three dimensions

complex environmental issues. Such a techno-solutionist[11] approach presents digitalized environmental governance as an apolitical process when it is not.

In this perspective, we therefore explore the *politics* of digitalized environmental governance. Critical scholarship on how digital technologies are reconfiguring the ways in which data about environmental issues are collected, made sense of, and used to inform or even automate decision-making is growing.[12–18] We draw on this emerging field, as well as insights from science and technology studies, to explore how the use of digital technologies is engendering a number of key shifts in environmental governance. These shifts are discernible in three dimensions of governance: seeing and knowing, participation and engagement, and interventions and actions (Figure 1). Within each of these dimensions, we critically examine how digital technologies affect possibilities to (1) identify and understand environmental problems and sustainability concerns, (2) engage with and participate in environmental governance, and (3) intervene and act on environmental problems.

On this basis, we argue that digital technologies generate a number of shifts in governance. The first is a growing reliance on automated data collection and diagnostics to construct digital representations of the environment. These digital representations constitute a specific form of knowing the environment and as such shape what gets governed and how. Second, in initiatives to apply digital technologies, there is often a preference for multi-stakeholder collaborations in which private actors in particular bring in (expertise on) data and technologies, with implications for data access and ownership. Finally, there is a shift toward ever more automated and data-driven decision-making with the aim to optimize processes. We conclude by highlighting the need to continue to question the assumption that use of digital technologies automatically improves, and has emancipatory effects on, environmental governance. In doing so, we formulate a set of overarching questions that critical social scientific scrutiny of the phenomenon of digitalized environmental governance needs to ask.

SEEING AND KNOWING

The assumption underlying the use of digital technologies is often that more data enable better environmental governance. However, digital technologies also transform *what* is made visible and *how*. Digital technologies, including satellite imagery, sensor readings, and drone footage, create specific representations of environmental issues. As these digital representations prioritize certain framings and understandings of environmental challenges while leaving others obscure, they foreground and privilege particular governance approaches and solutions.[14,19,20] Especially with the advent of artificial intelligence—the ability of a digital computer or computer-controlled robot to perform tasks commonly associated with intelligent beings[21]—these digital representations can increasingly be used to create new knowledge about not only current but also future states of the environment. It is thus important to ask how digital technologies impact the ways in which environmental challenges are made visible and thereby rendered governable in specific ways.

First, digital technologies make visible, increasingly in real time, various dimensions of a given environmental challenge. Increasingly sophisticated and efficient monitoring technologies—such as soil, water, and air sensors; satellites imagery; and drones equipped with sensors and cameras—enable detailed, real-time, large-scale, and efficient data generation. As a result, events and processes as diverse as the behavior of penguins,[22] the climate-induced movement of people,[23] and fishing in remote places such as the open oceans[24] now become increasingly visible. Digital technologies help to realize such "radical transparency"[16] in the present, both in one's backyard and remotely, both in ever more fine-grained detail and over larger and larger swaths of territory, at increasingly high speeds, and continuously, enabling almost real-time monitoring and oversight.[19,25] In fact, data-collection technology has become so powerful that there is a risk of drowning in environmental data.[12,16,26]

However, having more data does not automatically mean a more accurate representation of environmental challenges.[27,28] The data that feed into digital representations of the environment are not neutral and are always predicated on certain selection choices.[29] While data collection is sometimes presented as the mere mining of a natural resource,[30] data are always subject to processing, structuring, and implementation procedures.[31] Data are generated and processed by a combination of hardware (sensors, satellites, servers, etc.) and software (databases, algorithms, and interfaces), contextualized in a certain measuring system (e.g., weight and length), and given a form (e.g., numbers, images, and text).[32] The gathering and "cleaning" of digital data are thus underpinned by human selection and interpretation, as well as processes of inclusion and exclusion.[33–36] As such, it is not surprising that digital data are subject to multiple interpretations depending on who interprets on the basis of which questions and for what purposes.[14] It thus becomes important to ask: who selects the variables that are measured, what assumptions about relevance and representativeness underpin these choices,[37] and what is rendered visible versus what is left obscure?[38,39] This is pivotal because digital technologies always involve a translation of the complexity of the world into computable digits understood against a certain interpretative frame. As a "critical transparency studies" perspective has thus long argued, the uptake, institutionalization, and effects of environmental disclosure (including digitally enabled disclosure) need to be scrutinized within the broader normative and political contexts of its generation and use.[27,28,40]

The examples of digital environmental monitoring in the issue domains of deforestation and over-fishing can help to illustrate some of the dynamics mentioned above. In each of these environmental grand challenges, digital, real-time monitoring helps to shine a light on the nature and extent of the problem at hand. Yet, these digital representations may emphasize specific sites and sources of harm while neglecting or obscuring others. The Global Fishing Watch, for example, makes use of satellite-based information on vessel movement with the aim of shedding light on legal and illegal fishing behavior. It uses data provided by private vessel-tracking services, as well as data from vessel-monitoring systems (VMSs). The latter are nationally or regionally managed and are essential for complementation and filling the large blank areas on the Global Fishing Watch map. So far, however, only Indonesia and a number of countries in Latin America have provided access to their VMS data.[24] This means that the "global map of fishing activities" remains geographically incomplete. As a result, the Global Fishing Watch platform may reveal fishing activities, or even illegal fishing "hotspots," in important fishing areas in the Global South, but other geographical areas and vessels under other flags are relatively less visible. What is more, a focus on imagery of vessel movement might facilitate detection of illegal behavior, such as fishing in protected areas, but it also renders fishers homogeneous because it does not allow for understanding different root causes of illegal practices.[24]

In the case of forests, the NGO-led Global Forest Watch initiative deploys satellite monitoring to detect and make visible in real time deforestation patterns across the globe. This is a potentially powerful leveraging of digital technologies to shed light on key dimensions of an environmental grand challenge in a manner that was not feasible in the past. Using a Google Earth-like interface, any individual user with a computer and internet connection can scroll through the Global Forest Watch online platform and zoom in on locations where forests are being lost and even discern where forest fires, logging, and mining takes place. However, the satellites are only able to capture the local layer of these activities. The international drivers of the more proximate direct causes of deforestation, as well as the powerful actors behind international drivers (such as importer demand for agricultural commodities, retailers, banks, and investors along the forest-commodity supply chain), remain more obscure and may thus not become the target of oversight or response measures (Figure 2).

Second, digital technologies also have the potential to change how knowledge about environmental issues is produced. To process and interpret the large volumes of data that are now available at high velocity, algorithms are employed to generate classifications and detect (hidden) patterns by using probabilistic methods. Machine-learning algorithms are computer software that can learn autonomously,[41] i.e., without being literally programmed to achieve a certain output. Machine-learning algorithms learn by finding patterns in training data and enable new forms of diagnostic and predictive analysis by revealing existing relations or deficiencies or by inferring patterns into the future. This shapes how governing actors imagine and anticipate future environmental conditions, which in turn influences how they seek to govern toward specific desired futures.[42–44]

Digital diagnostics and prognostics also "see and know" environmental issues through the possibility for close monitoring and prior warning before issues fully emerge and through seeking to predict the impact of future scenarios. For example, in the Destination Earth project, the European Union aims to create a digital twin of Earth to "test scenarios that would enable more sustainable development and support European environmental policies."[45] However, diagnostic and probabilistic data analysis can only diagnose or predict what is embedded and recognized as a parameter in their algorithm and database design. This is especially important because, as also noted above, digital technologies always involve a translation of the complexity of the world into computable digits, highlighting that what can be counted counts.[37,38,46] This translation thus necessarily involves certain "black boxes."[47]

As critical social science scholarship of these phenomena notes, the need to create uniform datasets that are interoperable and allow for computation "subsumes all contextual, indexical, symbolic or lived differences in data."[48,49] Given that human designers and programmers build the code, human assumptions and epistemic biases are inevitably programmed into and potentially exacerbated by algorithms. Thus, even though capable of learning from massive amounts of data and arriving at dynamic solutions,[50] such algorithmic systems cannot avoid encoding designer's biases. Yet, this bias may remain hidden in the code because the process by which complex clusters of algorithms yield specific conclusions often remains opaque, at least for policymakers. As such, the digital representation—*what* is made visible—also limits how the future is made knowable. For example, digital twins are now being used in environmental governance processes to make the future states of their physical twin visible and thus indicate which trajectories are likely to help achieve certain goals.[51] However, such predictions influence the outcome they predict: the shown potential courses of action are used to intervene in the physical twin to realize one of these courses. The predictions thereby exercise performative effects.[52]

These examples suggest that digitally representing and predicting environmental challenges is a process in which political and normative choices are made. Digital technologies do not simply make more things more visible and therefore more effectively governable; they also shape what is made visible and how. If so, digitally enabled monitoring, diagnostics, and predictions shape the object of governance and thereby the priorities, division of responsibilities across key actors, and type of governance interventions, as we go on to further explore in the next sections.

PARTICIPATION AND ENGAGEMENT

Digitalized environmental governance manifests across all levels, from the micro-level of supporting and nudging people

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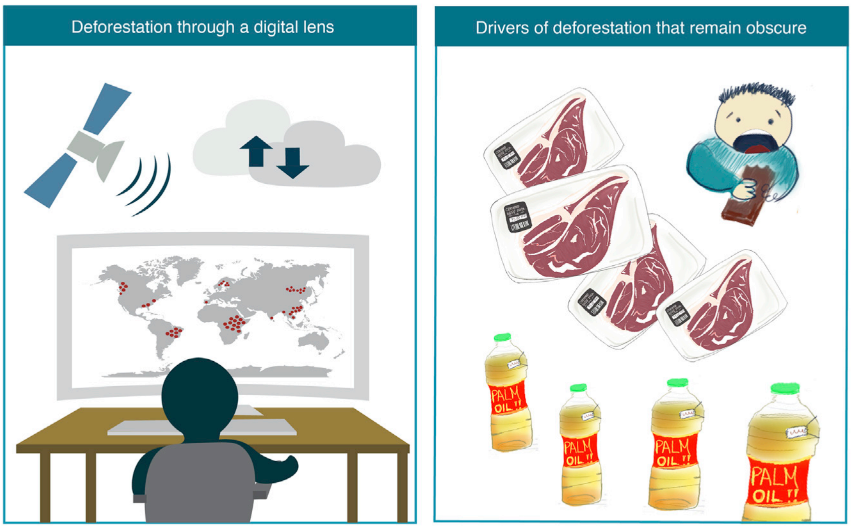

Figure 2. Digitalized environmental governance: Rendering some aspects visible while potentially obscuring others

to develop more sustainable consumption practices to planetary-scale digital monitoring of climate change in initiatives to develop and use digital twins of Earth. One of the promises of digitalized environmental governance is that it opens up new possibilities for participation in governance practices and processes across all these levels, with an assumption that this in turn would enhance the democratic character of governance. But for whom do these possibilities for participation arise, and who benefits? Starting at the micro-level of everyday behavior, we can identify various ways in which people now use digital tools and devices to get insight into the environmental impact of their consumption behavior, to monitor environmental issues, and to participate in decision-making processes.[53,54] In domestic settings, for instance, smart meters and energy displays help citizens and consumers to monitor their household energy use,[55,56] and various smartphone apps provide suggestions for making everyday consumption practices more sustainable.[57] Citizen sensing, defined as "the use of low cost and accessible digital technologies to monitor environments"[58] enables citizens to create data on local environmental issues, such as air pollution[59] and water quality.[60] Finally, in more formal settings of public participation, we see the first applications of digital twins aimed at co-creation and co-design of plans and scenarios for sustainable urban futures.[61] With the help of digital twins, citizens can experiment with different designs and immerse in a virtual reality to experience visual and auditive aspects of designed futures.[62]

While these examples show that, in many cases, the use of digital technologies can foster citizens' awareness of sustainability issues in their everyday lives,[53,63] this does not automatically result in effective or meaningful citizen participation in governance. Critics have questioned the extent to which citizen sensing democratizes decision-making.[58] There is a danger that citizens are reduced to "sensors"[64] and that engagement in environmental monitoring does not result in enhanced participation in decision-making. In addition, even though digital technologies such as sensing devices and crowdsourcing applications have the potential to scale up local grassroots campaigns, they can also alienate people who are not keen or able to use them.[65] An overarching point of concern is the reliance on technology companies as providers of these apps and devices. This includes worries about how corporate actors may extract value from citizens' behavioral and location data without their awareness or consent.[66] Using digital technologies thus provides new opportunities for citizens to exercise environmental citizenship, but the impact may differ: some citizens may benefit more than others, and existing decision-making contexts may be more or less open to acknowledging and addressing citizen's concerns.

Critical questions about the assumed empowering effects of monitoring technologies can also be asked in the context of environmental activism. With the rise of platforms for digital environmental monitoring, such as the Global Forest Watch and Global Fishing Watch initiatives mentioned earlier, citizens and activists can now detect and monitor environmental issues globally. Yet, beneath the democratization of environmental monitoring capabilities lie important questions about who sees and who is seen. The Global Fishing Watch initiative seeks to serve "anyone in the world with an internet connection," yet there seems to be a disconnect given that the subjects they seek to make observable, fishers, are just watched rather than actively engaged.[24] In the case of Global Forest Watch, a study by Rothe and Shim[67] argues that the satellite-enabled "disclosing gaze" is primarily directed at deforestation hotspots in the Global South. Global Forest Watch data on the behavior of the platform's users reveal that the users are mainly interested in South East Asia and South America and that boreal forests in places such as Canada, Russia, and the US do not get the same level of attention.[68] In other words, not all states where deforestation is happening are equally targeted by the users of the platform, limiting the promise of visual activism.[67]

In the end, the increased transparency about environmental issues that can be created with digital technologies should empower recipients of information to hold powerful actors to account and put pressure to improve performance. In the case of Global Forest Watch, there is indeed evidence that environmental activists have used these data to convince policymakers to take actions against environmental offenders.[69] In Peru, for example, one study shows that satellite imaging data from Global Forest Watch were integral in environmental activists' efforts to convince policymakers to take action against United Cacao, a company that had engaged in massive deforestation activity.[69] Yet, although the Peruvian government ordered the suspension of the company's operations, operations did not cease, and the company was absolved of wrongdoing in a local court. The company also applied tactics such as lawsuits and claims of fraud and documentation falsification against public officers.[70] Such an example should make us

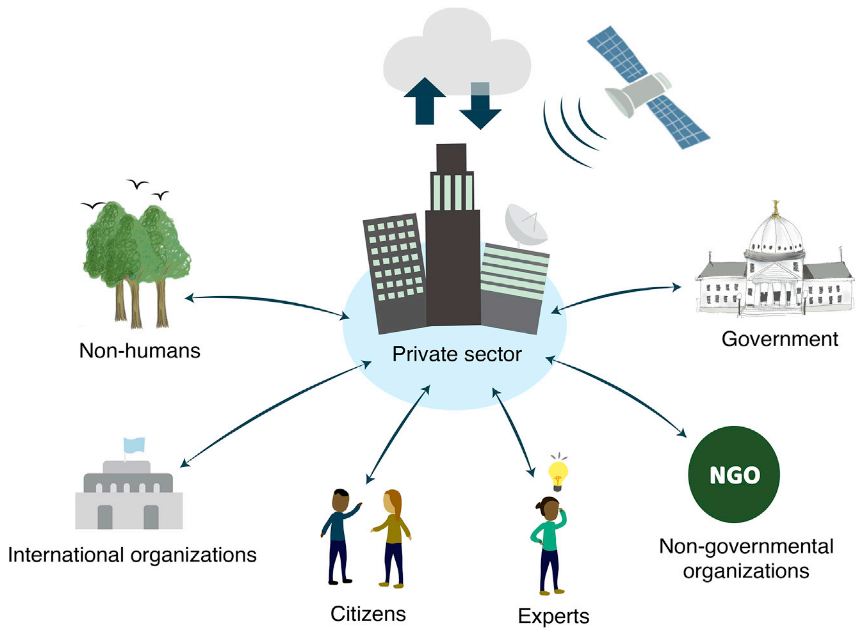

Figure 3. Digitalized environmental governance: An ever more central role for private actors within multi-stakeholder collaborations

aware of the complex and messy political-economic reality of many environmental issues. Even though digital platforms and open data may enable the public to hold companies and governments to account, existing power and market dynamics in an environmental domain may well prevent effective account holding.

It is not just in these domestic and public domains that we can witness new possibilities for participation in governance. In the more institutionalized settings of national and international governance, actors in the private sector are invited to join initiatives for addressing global environmental challenges with the help of digital technologies. For example, the secretariat of the United Nations Framework Convention on Climate Change (UNFCCC) is setting up and facilitating new networks for collaboration, such as the Climate Chain Coalition, a multi-stakeholder community to explore and "mobilize" the potential of blockchain for climate governance.[71] Other examples are intergovernmental organizations organizing specific events such as hackathons or "data challenges" around Sustainable Development Goals (SDGs). The underlying assumption in such initiatives is that governments (alone) cannot solve grand environmental challenges and that private companies with their data and technological solutions are needed to address these problems more effectively.[72]

At the same time, states and supranational organizations are also key enablers of digitalized environmental governance and are making large investments in digital technologies. China has a Digital Earth program,[73] which it presents as an initiative to use "Big Earth Data" to "deal with environmental and societal challenges and [attain] SDGs in the Belt and Road region."[74] As discussed earlier, the European Union is investing in the development of digital twins with the aim of simulating Earth's climate to make predictions about how it will affect humans, especially through extreme weather events.[75] These developments are still very new, but critical research is needed on how these "Earth-monitoring" projects may benefit some countries or regions more than others and how they affect dynamics of international cooperation in environmental governance. For example, will those countries that suffer most from extreme weather events due to climate change also benefit from the knowledge created, or will these monitoring technologies mainly be used for environmental security purposes, such as "managing" climate migration from vulnerable countries?

The proliferation of digitalized environmental governance is perhaps most prominent in the domain of non-state organizations, such as NGOs and corporations. A notable development here is the use of digital technologies in transnational private governance initiatives, including certification and labeling initiatives and corporate social responsibility programs.[13,76] For example, digitalized seafood traceability initiatives, such as through blockchain technologies, showcase the growing importance of companies, software developers, banks, and other investors in both company-led and NGO-led projects.[77,78] The use of advanced technologies in these initiatives is often problematic from the viewpoint of inclusivity. Private companies, such as large processors and big retailers, are in general very able and well equipped to participate in the international and high-tech initiatives for sustainable supply chains and benefit from it.[78] This may sustain or even expand the existing power position of these private actors and limit the scope for participation of small-scale producers and local communities.[13,79,80] Furthermore, when participating, small-scale producers such as fishers might face new informational demands, such as record keeping of their catch, as additional burden, particularly if these new demands do not fit well with existing practices.[81]

What is more, by developing or using digital technologies in global supply chains, corporate actors, such as multinational food companies or supermarkets, can promote their own understanding of what sustainability is and how it should be assessed and certified. In global supply chains, corporate actors already apply artificial intelligence to enhance energy efficiency and reduce waste in their processes and operations.[76] Another example is smart agriculture initiatives that offer farmers guidance on how to achieve more sustainable outcomes through early-warning and compliance-monitoring systems.[82] While the use of artificial intelligence and other digital technologies may improve the environmental management of farms and supply chains, it is also possible that these technologies will be used to optimize the eco-efficiency of existing processes.[83,84] If so, this may legitimize business as usual and, as a result,

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Figure 4. Digitalized environmental governance: Automating and optimizing specific ends

perpetuate or even amplify existing modes of overconsumption and overproduction.[76] It is thus worth asking critical questions about *what kind* of sustainability is advanced through digitally enabled private sustainability governance. How can we prevent a narrow approach to sustainability as eco-efficiency and promote more ambitious uses of digital technologies that advance broader sustainability goals and address the true social and ecological costs of our systems of production and consumption?

In summary, from the micro-scale of everyday consumption practices up to the level of global environmental governance, the use of digital technologies opens up possibilities for participation and engagement to a wide range of actors, including citizens and private actors. Yet, it also appears that technology companies and digital conglomerates as "novel intermediaries and brokers"[13] come to play a key role in such initiatives (Figure 3). By providing the digital infrastructure and tools for steering sustainable behavior and (everyday) environmental monitoring, these private actors shape how citizens can engage with sustainability and how they can voice their concerns. Start-ups and big technology companies also get a place at the table in multi-stakeholder initiatives, and transnational corporations collaborate with them to achieve corporate sustainability goals. In optimistic accounts, this shift to a stronger involvement of and reliance on data and technology companies can be interpreted as a strengthening of multi-actor approaches in environmental governance, but we always need to ask how this affects power relations and their implications for desired environmental outcomes: who is empowered via these tools and initiatives, and which social groups, stakeholders, countries, or regions benefit from this versus who is left out?

INTERVENTIONS AND ACTIONS

Finally, a key promise of digital technologies is that they collect and process data to *automate* and *optimize* decision-making processes and interventions (Figure 4). This includes new possibilities for automating compliance and for reorienting the decision-making of actors (from individuals to governments) toward improving sustainability.

In the case of automated decision-making systems, governance actors employ digital devices and data processing to automatically intervene, for example, by directly implementing and enforcing environmental laws, regulations, and policies.[85,86] An example is a congestion tax placed on diesel cars from the Stockholm city center zone enforced by wireless radio-frequency identification technology. Drivers that need to enter the city center with diesel-heavy vehicles are given transmitters. In addition, strategically placed cameras automatically read whether a car's number plate relates to a transmitter. Cars without transmitters are charged with a tax.[87] Here, an environmental challenge is addressed via a technical protocol that processes input made visible and knowable by digital technology and generates output that automatically intervenes in the world to sanction undesired behavior. While automated intervention to enforce a diesel car tax may not immediately be seen as problematic, other examples of automating and optimizing decision-making processes raise more questions.

With the increased use of sensors, robots, and the internet of things, automated decision-making systems in environmental governance could also include physical and biological entities. For example, a digital twin for smart agriculture purposes could collect data via sensors, analyze the data, and make predictions about the physical twin (e.g., a greenhouse with tomato crops), as well as act on these anticipations by means of optimization and feedback.[88–90] With this, digital twins themselves can act as (artificial) governing agents.[52] Automated, they can diagnose, correct, and (micro-)optimize their physical twins at a speed and scale that human agents will find hard to keep up with. The discourses accompanying the introduction of automated decision-making and interventions often emphasize optimization and efficiency. But as we have argued throughout this article, digital technologies have their own values and specific (optimization) aims designed into them. A key question therefore is: for what are such automated decision-making systems optimizing, and who decides that?[91]

Next to automating interventions, digital technologies and data processing are used to optimize decision-making processes at an individual level. For example, data analytics and digital devices can be used to support citizens to make more sustainable choices in their everyday lives through nudging[92] via digital means. Here, big data are used to create personalized choice architectures, which are based on analysis of user data, present specific options in a particular way, or even implement a "default" option.[93,94] An example is smart city policies, where city governments collect traffic data and use smartphone applications to nudge citizens to choose cycling or public transportation over the car.[95] While data-driven nudging can be an efficient tool to smoothly steer citizens toward sustainable behavior, there are concerns that it may manipulate individuals and undermine their autonomy, particularly when these individuals are not aware of how their data are being collected and used.[93] A more fundamental issue is that, with nudging, judgment is deferred to the choice architecture,[96] and citizens may end up perceiving themselves as passive consumers and not as active participants in governance processes.[93] A key issue, therefore, is how data collection and personalized feedback could be used to engage users in such a way that meaningful environmental citizenship is promoted rather than undermined.

Digital data, diagnostics, and predictions can also be used to optimize policy decisions with an eye to the future. As recent analyses unpacking the notion of anticipatory governance within critical, interdisciplinary social science scholarship have shown, imagining and seeking to realize desired future environmental states and outcomes through modeling, foresight, and other anticipatory tools is now a mainstay of environmental governance but has varying implications for present-day actions.[43,44,97] Such anticipatory tools and processes may increasingly come to rely on datafication and data-processing techniques. If so, it is vitally important to consider the implications of diverse and potentially contested future imaginaries on governance practices and choices in the present.[42]

One of the digital technologies that transforms the ability of government actors to move from reactive to proactive policies[98] in environmental governance is, as we noted earlier, digital twins. In the Destination Earth project of the European Union, for example, the aim is to monitor and predict climate change by collecting data about the physical environment (e.g., geospatial data), as well as to include socio-economic data, for example, about energy use, traffic patterns, and human movement (based on mobile-phone use), in order to monitor and estimate the societal causes and impacts of climate change.[75] What is more, this application of digital twins can be used to simulate and test which solutions or policies work best in specific locations. An advantage is that the potential impact of specific climate adaptation strategies or large-scale interventions, such as geoengineering, can be evaluated via simulations, where testing in the real world could entail the risk of (unintentional) damage. However, to simulate and evaluate policy strategies, digital twins require an input of criteria to define what the "best" option is. As we discussed earlier, these criteria influence the selection of the sensors, parameters, and algorithms that go into building a digital twin and, with that, its potential output. The anticipation (or glimpse of an alternative reality or world) offered by a digital twin is thus fundamentally dependent on certain normative choices and knowledge paradigms that gear it toward certain goals and interests.[52] Thus, while digital diagnostics offer a promising tool for anticipatory governance, it is vital that policymakers understand the limits and paradigms that shape these digital anticipations.[99,100]

All in all, the use of digital technologies is often imagined to enhance our capacity to act in the sense that it improves our control over complex environmental challenges. When this is promoted and understood in terms of efficiency and optimization, there is a danger that the interventions that digital technologies propose will come to be seen as neutral and objective instead of as the result of normative and political choices. As a consequence, this may narrow the possibilities for dealing with environmental challenges. On the other hand, digital diagnostics and predictions can also support what is termed "reflexive governance."[101] Digital (big) data can represent new aspects of environmental challenges, and machine learning and artificial intelligence can detect patterns and correlations that can become a topic for discussion for policymakers and other governance actors. As technologies such as digital twins help predict, simulate, and test different policy options and strategies and their outcomes, they can create new occasions for reflection and deliberation about values and priorities in environmental governance aims and strategies. When digital twins are connected with sensors that continuously collect and analyze data about the ecological impacts of human activities—for instance, activities on a farm—this information could support actors to closely monitor and anticipate the environmental effects of their practices and choices. In the case of farming, a digital twin could make visible unintended or unexpected environmental damage caused by specific farming practices and thereby enable support to farmers to reconsider their farm management decisions in the light of environmental values and objectives. Digital representations and technologies thus shape how we can act, but whether this narrows or broadens how we understand and make decisions about environmental sustainability first and foremost depends on how we recognize and deal with the normative choices embedded in these technologies and the specific contexts of their use.

CONCLUSION

Through examining three dimensions of digitalized environmental governance, we have argued here that, with the increased use of digital technologies in environmental governance, three shifts take place. The first is that digitalized environmental governance relies on ever more datafication and data processing to represent and predict (changes in) the environment, yet some aspects are made visible while others are obscured. Second, digitalized environmental governance tends to favor multi-stakeholder collaboration whereby private actors play an ever more central role in providing technology and data. Third and finally, it entails a shift toward ever more automated and data-driven decision-making in environmental governance.

While the substantive effects in practice of these shifts are still uncertain and are yet to manifest fully, we have discussed the implications of each of these three shifts for effective and legitimate environmental governance. While digital technologies hold potential to foster sustainability and manage environmental risks, our perspective article also presents a critical warning. There is a risk that digitalized environmental governance presents environmental knowledge and decision-making as a depoliticized arena. This may happen when digital representations based on large n-data are seen as objective knowledge about environmental issues, when open data and multi-stakeholder participation are simply assumed to democratize governance, and when automated or recommended decisions are seen as the best possible solution to complex societal and environmental issues.

Despite these pitfalls, there are also hopeful developments. We see a growing awareness that digital technologies do not

Table 1. Interrogating digitalized environmental governance through a critical social science lens: Key questions

Key questions	
What is represented?	Which data elements are selected to represent a specific (current and future) environmental issue, and which elements are left out? Who decides on this, and what values and priorities inform this selection of elements?
Who is empowered?	Who is setting the agenda in applying digital technologies to address environmental issues? What are the effects on different actors? Which actors (including social groups, organizations, countries, and regions) benefit from the knowledge and interventions generated by and through digital environmental governance, and which actors do not?
Why and how do we intervene?	For what aim(s) are decisions and interventions automated and optimized? Who decides, and what values and priorities inform the selection of the aim(s)? What are the effects of automated and data-driven decision-making on human autonomy, reflexivity, and responsibility?

automatically result in better environmental outcomes or in more democratic and inclusive governance approaches. In recent years, academics and policymakers have worked on (proposals for) guidelines and legislation for the sustainable and responsible use of digital technologies.[102] These guidelines and legislation call attention to the ecological footprint of technologies and data storage, highlight the need to include all the relevant stakeholders in the design and evaluation of outcomes, and more generally seek to foster accountability and transparency in use of digital technologies.[103,104] This is an important step in mitigating the potentially harmful environmental and societal implications of using digital technologies. However, such principles are primarily focused on ethical issues around data and the technology itself, namely its design and use.

Our perspective article takes this discussion about the responsible use of digital technologies for sustainability purposes further by showing that we also need to take into account the wider political and normative context in which these technologies are proposed, designed, and used as tools to tackle the environmental crisis. This requires asking critical questions about the specific forms of knowledge and governance approaches that digitalized environmental governance furthers; about changes in power relations when specific actors promote, control, use, and benefit from digital technologies; and about the scope that data-driven and automated decisions and interventions leave for discussion and reflection. In the growing enthusiasm for applying technological solutions to environmental challenges, such fundamental questions may risk being skipped. We therefore call on academics and policymakers to pay attention to the political and normative context within which digitalized environmental governance occurs. We outline a number of key questions to enable such reflection (see Table 1).

It is our hope that asking these questions inspires us not only to do things better but also to do better things with digital technologies.

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AUTHOR CONTRIBUTIONS

S.K. developed the outline of the article, refined it further together with A.G., and invited other co-authors to join. S.R.L.K., S.K., and S.M. led the work on the different sections (S.R.L.K., "seeing and knowing"; S.K., "participation and engagement"; S.M., "interventions and actions") and invited contributions and feedback from all authors. S.K. and A.G. took the lead in developing the introduction and conclusion with input from all authors. S.K. and A.G. also led the revisions after receiving feedback from all authors.

DECLARATION OF INTERESTS

The authors declare no competing interests.

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