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Making the mos(s)t of nature? Cleantech, smart nature-based solutions, and the 'rendering investable' of urban moss

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Abstract

This article examines the ways in which 'nature-based solutions' (NBS) to urban environmental problems are contributing to a re-imagining of the forms and roles of vegetal life in cities. Specifically, we examine the versions of nature that are being produced within a subset of nature-based solutions described as 'smart' – that is, those involving the enrolment of non-human lifeforms into digital infrastructures comprising sensors, data flows and automated support systems. Whilst NBS are often celebrated for opening up cities to lively ecological processes – thereby contributing to more convivial, 'more-than-human' forms of urbanism – their smart incarnations are becoming a playground for entrepreneurial and financial actors seeking new ways to enclose, commodify and derive profit from non-human life in cities. To explicate this argument, we examine the case of a proprietary 'nature-based solution' to urban air pollution developed and sold to local authorities and corporate actors by a European cleantech start-up, predicated on optimising the air-filtering capacities of moss. Our analysis proceeds in three stages. First, we draw on scholarship on the bioeconomy to show how the commodification of moss in this case is predicated on discursive arguments which depict moss as at once inherently productive and regenerative, but also fragile and scarce in urban environments. Secondly, we show how this smart NBS is rendered investable through the enrolment of moss into a carefully designed digital apparatus, which purports to stabilise and optimise its air purifying work, thereby making its contributions to urban air quality continuous, consistent and calculable. Finally, building on an assessment of the entanglement of this example with specific urban geographies and modes of urban governance, we critically reflect on the role that smart NBS in general

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might yet play in either reinforcing or disrupting prevailing dynamics of privatisation, enclosure and green gentrification in cities.

Keywords
Nature-based solutions, urban nature, smart city, smart environments, Cleantech

Smart nature-based solutions: Non-human life and the dynamics of investment capital

Within the past decade, the concept of 'nature-based solutions' (NBS) has assumed an increasingly central role within scientific research agendas and policy frameworks concerned with enabling cities to tackle diverse social and environmental challenges. NBS are defined variously as actions or initiatives 'that involve working with nature' (Seddon et al., 2021: 1518), or which are 'inspired by, supported by or copied from nature' (European Commission, 2015: 4). While the conceptualisation of nature within efforts to promote such solutions tends to be ambiguous (Nesshöver et al., 2017), NBS are often contrasted with technological (sometimes termed grey) approaches to addressing similar challenges (Bellamy and Osaka, 2020; Osaka et al., 2021; Wachsmuth and Angelo, 2018). However, calls are emerging, within engineering and urban planning spheres, for 'integrated smart and green nature-based solutions for future cities' (Kaluarachchi, 2021), using big data infrastructures and remotely managed sensing devices to optimise and enhance the performance of diverse non-human living processes and capabilities. These calls evidently put into question the technological–natural and grey–green divides, raising questions about how nature is being remade through material interventions mediated by smart technologies. Furthermore, the development of such hybrid environmental solutions – smart yet also nature-based – has become of interest to so-called cleantech start-ups and their ecosystem of potential investors (Goldstein, 2018), calling for more research on the emerging political economies of smart urban nature-based solutions.

In this article, our empirical entry point to these questions is a moss-based NBS to urban air pollution being marketed to local authorities and corporate actors by a European cleantech start-up (hereafter 'The Company'). The device – which we will call UrbanMoss – is described by its designers as 'the world's first Biotech fine dust filter for urban spaces', combining the 'natural cleaning power' of mosses with 'smart IOT [Internet of Things] technology' (The Company, 2021: 4). As a partially patented, nature-based technology, UrbanMoss has emerged from research and development aiming to optimise, control and quantify the air-purifying performance of mosses – non-vascular bryophyte plants whose fine leaf structure belies a prodigious capacity to 'absorb and metabolise fine dust' (The Company, 2021: 4). Indeed, since moss leaves are only a single cell thick, they have sometimes been compared to the human lung – comprising effectively a 'thin watery film… continuous with the atmosphere' (Kimmerer, 2003: 97). By 2018, over 50 examples of UrbanMoss had been successfully installed in urban settings across more than 10 countries. More recently, EU Horizon2020 funding helped to refine the design of UrbanMoss, and newer examples of the technology have been rolled out to more than 20 further locations throughout Europe (The Company, 2024*a*). In scrutinising the forms of experimentation with non-human life being trialled by this specific smart NBS, our intention is not to draw attention to particular organisations, but rather to provide a detailed case study of cutting-edge encounters between capitalism and nature in the context of broader urban sustainability and smart city agendas.[1]

Our aims in this article are threefold. First, we seek to complicate assertions about nature in nature-based solutions by examining how non-human processes and potentials – in this

case pertaining to moss – are conceptualised by actors promoting NBS as vehicles not just to achieve environmental sustainability, but also to pursue broader smart city agendas (Haarstadt, 2017; Kitchin, 2014; Viitanen and Kingston, 2014). Here we draw on Melinda Cooper's (2008) influential analysis of the US biotech industry, specifically her argument that commodification requires capital to not only 'potentialise' non-human life, by constructing it as inherently productive and regenerative, but also 'depotentialise' it by rendering those capabilities artificially scarce.[2] Second, we draw on recent scholarship in more-than-human political economy, where non-humans are recognised as 'constitutive' of capitalist economies from the outset (Barua, 2019: 650), to examine the particular ways of 'working with' moss which are used by UrbanMoss' developers to render their product investable (Battistoni, 2017; Welden, 2023). Here we pay close attention to the interventions into the nature of moss life itself which UrbanMoss' protagonists perform – with the help of digital sensors, data flows and automated support systems – in order to render the performance of moss continuous, consistent and calculable. Thirdly and finally, we examine how this 'investment-drive' produces distinct urban geographies of smart NBS, potentially reproducing uneven and exclusionary urban dynamics associated with environmental injustice and green gentrification (Kotsila et al., 2021; Sekulova et al., 2021; Tozer et al., 2023). In doing so, we highlight the risk that the economic capture of the smart NBS agenda could suppress alternative approaches not just to conceptualising relationships between society and nature itself (Luque-Ayala et al., 2024), but also to rendering cities of the future more socially just, environmentally resilient, and indeed convivial to humans and non-humans alike (Arcari et al., 2021; Hinchliffe and Whatmore, 2006; Maller, 2021; Metzger, 2016).

Smart-ing nature-based solutions

Within scientific and policy debates about mitigating and adapting to global environmental change, a stark distinction is often drawn between nature-based and technological solutions (Bellamy and Osaka, 2020; Osaka et al.. 2021). Similarly, urban NBS are often described as marking a departure from grey, technological or even infrastructural solutions to urban socio-environmental issues. In some accounts, for example, they are judged to be 'complementing grey technical solutions' (Wickenberg et al., 2021: 45), while in others they are seen as providing 'a replacement' (Tozer et al., 2023: 610) or 'a valid alternative' for them (Frantzeskaki, 2019: 101). Some NBS have been provocatively dubbed 'dumb' to differentiate them from dominant smart, technologically advanced approaches to urban environmental planning (Fleming, 2020). Such 'dumb' solutions are embodied for instance by efforts to combat urban heat with more street trees, or to use green spaces as natural sponges for rainwater during storms (Fleming, 2020). Whether they consist in acknowledging, understanding and leaving space for already existing biological or ecological processes to play a greater role in mitigating changing environmental conditions (Coombes and Viles, 2021), or in designing new green infrastructures to actively enhance different non-human capacities (Braun, 2014, Wakefield, 2020), NBS are embedded within a wider societal trend of 'working with' nature (Battistoni, 2017; Welden, 2023), based on the notion of guiding natural processes so that they deliver desirable social or environmental outcomes or services.

However, in contrast with ubiquitous discourses of naturalness, calls are emerging, within engineering and planning spheres, for 'integrated smart and green nature-based solutions for future cities' (Kaluarachchi, 2021). As an example, Nature4Climate, a coalition of 20 environmental organisations promoting nature-based solutions, recently advocated that:

> '*NbS can be greatly aided by innovative technology. Many see nature and technology as polar opposites, and by extension believe that "natural" and "technological" solutions to global crises exist in conflict. We believe the opposite, and so this year we will be turning our attention to "Nature Tech" – technology that can accelerate the deployment of NbS at scale'.* (Nature4Climate, 2021, np)

Such technologies encompass, according to Nature4Climate, drones to aid reforestation, data monitoring systems and public participation platforms. The nature of the technologies listed – remotely managed technologies, data infrastructures and online platforms – reflects the tendency for an increasing diversity of environmental interventions to be supported through digital infrastructures. Environments, in other terms, are becoming 'technologized sites of data collection, processing, and analysis' (Gabrys, 2020: 1). Digital technologies are appealing both for their propensity to deepen understandings of existing environmental processes, and for their potential to open up new ways of configuring, managing and optimising the performance of non-human nature, including increasingly through automation (Gulsrud, 2019; Gabrys, 2022; Nost and Goldstein, 2022). Smart city imaginaries of a significantly deepened understanding and real-time, total control of urban processes of all kinds – whether related to energy use, transportation, commerce, or healthcare (Batty, 2012; Kitchin, 2014) – have thus bled into responses to a range of environmental problems as well. At a micro-scale, they have led to the establishment of so-called 'controlled environments' (Marvin and Rutherford, 2018, see also Smith, 2023), which through intensive data processing and automation promise insulation and protection from the increasingly inhospitable conditions prevailing in a putative 'outside' (Marvin, 2016). At a larger scale, such visions have given rise to proposals for entire urban ecosystems to be integrated into comprehensive digital networks using sensors, real-time monitoring and data management techniques, to create a so-called 'Internet of Nature' (Galle et al., 2019; see also Gulsrud et al., 2018).

Existing scholarship on smart cities has long established that digital technologies, including those aiming to support knowledge and governance of environmental processes, can 'shift the locus of governance from often local or urban governmental actors to more remote and global corporate actors that control technologies and networks' (Gabrys, 2020: 3; see also Luque-Ayala and Marvin, 2016). Accordingly, smart urban environmental solutions – including those that self-describe as nature-based – have rapidly become a playground for so-called cleantech start-ups and their associated ecosystem of investors (Caprotti, 2016; Goldstein, 2018; Levenda and Tretter, 2020). In the area of air pollution mitigation alone, examples of such interventions include TechAirSolutions' micro-filter-based AirSMART Bollard, Airlabs' nanotechnology-based Clean Air Zones, and, in the nature-based sphere, Green City Solutions' moss-based CityTrees and BiomiTech's micro-algae-based BioUrban. As these start-ups rival in imagination to develop, patent and licence their various products, they inevitably re-shape the geographies of urban governance, both through their pre-occupation with the need to attract venture capital investment, and through their efforts to gain access to visible space (whether public or privately owned) where their technologies can be exhibited and demonstrated. When it comes to cleantech solutions predicated on the entanglement of digital technologies with non-human nature specifically, however, the implications go beyond 'shifting the locus' of urban governance, as Gabrys (2020) puts it. Indeed, by staging experimental encounters between the digital and the ecological, smart NBS also have the capacity to re-shape 'everyday experiences, emotions, and sensations of socio-ecological relations' (Nelson et al., 2023: 2099), with potentially significant consequences for prevailing ideas and visions of the form that smart, sustainable cities should take (Luque-Ayala et al., 2024; Moss et al., 2021; Sheikh et al., 2023). Taken together, these elements should prompt researchers, we suggest, to examine more critically and forensically the particular techniques through which non-human nature – whether in the form of moss or algae, as in the examples above, or in other

incarnations – is being 'worked with' (Seddon et al., 2021), optimised and rendered investable in the burgeoning arena of smart urban NBS today.

To address this research need, this article examines the detailed case of UrbanMoss, a moss-based, smart solution to urban air pollution. At one level, our arguments are informed by foundational scholarship which has sought to examine how, following the biotech revolution, life itself has become deeply 'enmeshed in market dynamics', with biological information and materials being understood as crucial sources of capitalist value production (Helmreich, 2008: 463; see also Rajan, 2006). Work on the emergence and growth of the so-called bioeconomy has been especially prominent in science and technology studies and political economy (Birch, 2018; Cooper, 2008). In this article, we specifically draw upon Melinda Cooper's (2008: 49) argument that commodification in the bioeconomy relies on two ostensibly contradictory movements – firstly the promise of a theoretically limitless surplus of productive life, and secondly a 'corresponding move to devaluate life' by artificially imposing limits, in the form of scarcity. These two movements, which Cooper (2008) terms 'potentialization' and 'depotentialization', should be understood as mutually constitutive components of the commodification process. As Cooper (2008: 25) puts it:

> *[P]ostindustrial bioproduction needs to depotentialize the future possibilities of life, even while it puts them to work. This counterlogic is perhaps most visible in the use of patented sterilization technologies, where a plant's capacity to reproduce itself is both mobilized as a source of labor and deliberately curtailed, thus ensuring that it no longer reproduces "for free".*

Building on these ideas, our examination of the processes by which UrbanMoss is commodified as a smart NBS for urban air pollution therefore begins by focusing on the discursive arguments used to both potentialise and depotentialise moss itself. In other words, we examine how the purportedly 'natural' capacities of mosses are rendered tangible to potential investors and clients, even as those same plants are constructed as inherently fragile and vulnerable in the context of urban environments. Since already-capable and well-established moss plants would not necessitate the involvement of capital to do their work, it is instead the conjunction of a promise of future potential with a (carefully constructed) form of scarcity that sets the initial conditions for capital to fill a purported gap.

At another level, we also aim to extend these ideas by drawing on insights from more-than-human political economy – a growing, interdisciplinary field of scholarship that views commodification in the bioeconomy as the product not merely of discursive knowledge claims, but also of the work performed by non-human lifeforms themselves. Scholarship in this field has particularly studied the entanglements of human and non-human agency at work in the creation of so-called 'lively commodities' – commodities whose 'value is derived from their *status as living beings*' (Collard and Dempsey, 2013: 2684, emphasis in original). While many key contributions in this field have offered rich, animal-based perspectives on the role of non-human life in processes of capitalist value creation (Barua, 2017, Collard, 2020, Porcher and Estebanez, 2019), our analysis focuses on commodification processes predicated upon the extraction of value from plants (Barua, 2023; Ernwein et al., 2021; Fleming, 2017). Scholars adopting a 'vegetal' perspective on capitalism have recently highlighted the need to engage with the tensions and contradictions emerging from the idiosyncrasies of plants' lives, including the rhythms and temporalities they impart on production processes (Brice, 2021), as well as the comparatively limited opportunities for interaction and collaboration that plants – in contrast with animals (Barua, 2016; Porcher, 2015) – bring into work situations (Ernwein, 2021a). Scholarship on plant work, however, often presents plants' enrolment into processes of value production and capital accumulation as predicated on the (re)discovery of certain capacities that are intrinsic to plants, or specific assemblages of plants, for instance to spread and reproduce (Ernwein, 2021b),

to provide shade and cool ambient air (Atchison, 2021), or to act as carbon conveyors contributing to net zero climate agendas (Palmer, 2021). In contrast, in our analysis of UrbanMoss we begin from the presumption that the mere existence of promising plant capacities is not sufficient to make smart NBS alluring to potential investors. Rather, we explore how moss life is rendered investable through its enrolment into a specific digital infrastructure – comprised of sensors, data flows and automated support systems – which allegedly serves to enhance its air purification performance. In other words, we approach the commodification process as one demanding the active reconfiguration and optimisation of moss metabolism, and not simply its exploitation.[3]

Ultimately, the article makes two key conceptual contributions. First, it contributes to problematising and complicating understandings of nature in NBS, by investigating a case that exemplifies the hybridisation of nature-based and smart approaches to urban environmental management. Second, by honing in on the processes by which moss life is rendered investable in the form of a specific, proprietary product, the article also opens up an original conversation between critical NBS research and more-than-human political economy. Beyond offering a detailed case study of how smart NBS are rendered investable by cleantech start-ups seeking venture capital, however, our analysis also raises questions about the environmental justice impacts of novel efforts to 'work with' non-human life using digital infrastructures and data flows. Accordingly, in the final section of the article, our focus moves beyond the internal dynamics of the commodification process itself, to critically reflect on the role that smart NBS like UrbanMoss could play in either reinforcing or disrupting prevailing dynamics of privatisation, enclosure and green gentrification in cities (Bauer, 2023; Harper, 2020).

Researching UrbanMoss

UrbanMoss is a smart nature-based solution to urban air pollution which has been developed and sold by a German company (hereafter 'The Company') since 2014. Originally a start-up project led by a team of two for a university degree project, The Company has since expanded to employ more than 30 staff, including separate teams for operations, sales, and research and development. The Company has benefitted from multiple sources of public and private funding, including a Horizon2020 grant, totalling over 2 million euros as of 2021 (The Company, 2021: 1). The Company has, since 2014, developed several iterations of its core product, UrbanMoss, described as 'the world's first biotech air filter to quantifiably improve urban air quality' (The Company, 2024*b*). UrbanMoss was, at the time of research between 2018 and 2022, a $12m^2$ vertical square comprised of over 1500 individual pots of moss, coupled to a built-in rainwater tank and irrigation system, a network of sensors, and a live connection to a monitoring application. The technology could also be customised to include a bench, provide Wi-Fi, generate power through built-in solar panels, and even display content to passers-by via side-mounted screens. Whilst initially relying on ambient airflow for moss to filter surrounding air, later iterations of UrbanMoss have been updated to incorporate a built-in air ventilation system that aims to bring about a continuous, consistent air flow through the moss 'wall' itself. On average, purchasing UrbanMoss costs an organisation or institution approximately £18,000; it is a partially patented technology, therefore protected by Intellectual Property Rights. At the time of writing, The Company (2024*a*) claim to have successfully completed UrbanMoss installation projects in over 60 locations, spread across more than 10 countries. In the United Kingdom, where later sections of this article will focus, a separate company acts as the exclusive licence holder for UrbanMoss. Early versions of the technology were first installed in London, Newcastle and Glasgow in March 2018, with newer iterations of the product being added to further sites in London in 2020.

In this article, we draw on a combination of primary data generated from interviews conducted with project developers, managers and licence holders of UrbanMoss and observations at public

events (including a virtual tour of a moss farm used to cultivate source material for UrbanMoss itself), as well as secondary data obtained from The Company and its partners' websites, their scientific reports and press releases, and their social media communication. In the analysis, we were attentive to content itself as well as to its form (vocabulary, use of data, stylistic effects) and its context (who is it addressed to, why, and to what intended effect). Of particular interest for this article were ways of knowing and talking about moss, ways of articulating the role of smart technologies in shaping UrbanMoss, and relations to local authorities and investors. The material is pseudonymised following an agreement with interviewed representatives not to name them or The Company. As noted in the introduction, our aim in this article is not to attract attention to a particular company, but rather to provide a detailed case study of the dynamics of commodification entailed in rendering smart, nature-based technologies for urban environmental mitigation appealing to investors, as well as the potential implications of smart NBS for environmental justice.

'Growing clean air': Justifying the need for a new commodity

In this first section of our analysis, we examine the discursive arguments deployed by UrbanMoss' protagonists to justify the existence of their new, plant-based lively commodity as a device for rehabilitating polluted urban environments. We show that the existence of UrbanMoss as tradable biotechnological solution to the problem of urban air pollution is predicated on the dialectical construction of moss as at once innately capable and productive, and yet simultaneously also fragile and scarce. Following Cooper (2008), we approach these contradictory arguments as mutually constitutive components of the commodification process, acting respectively 'potentialise' and 'depotentialise' moss in urban contexts, thereby justifying a need for economic investment to help moss realise its true potential.

UrbanMoss ostensibly relies upon what is presented as the innate air-purifying capacity of moss to ameliorate local air quality. As one developer emphasised in an interview:

> *'[Moss] grows without roots, it has so much bigger leaf surface than any other plant… and it has this amazing ability to dissolve air pollution that settles on its surface and convert it into its own biomass; so those three things make moss so much better at absorbing air pollution than any other plant'. (Interview, 2018)*

Conceived as possessing 'natural filter power' (The Company, 2021: 3), moss is here understood to generate pollution-reduction benefits for urban environments by the very fact of its metabolic activity. In this sense it effectively promises to 'grow fresh air' (The Company, 2024*b*) as an inevitable consequence of its specific 'lively' capacities (Collard and Dempsey, 2013).

Attracting interest from potential investors requires UrbanMoss' developers to translate the potential of moss as an air purifier into terms as tangible as possible. At a discursive level, early efforts to promote the technology placed a heavy emphasis on comparing the putative quantity of air purification that would be performed by a single UrbanMoss installation with the number of so-called 'normal' trees that would be required to achieve an equivalent level of air-cleaning performance. The product's public communication strategy therefore relied on the presentation of UrbanMoss as having the same de-polluting potential as 275 normal trees. This however generated tensions and ambiguities in conveying what exactly moss does. For example, this comparison sometimes gave rise to a need to clarify that 'we don't want to substitute trees!' (Interview, 2018). Moreover, while the comparison relied on carbon dioxide-equivalent (CO_2e) figures, moss actually has no significant bearing on the CO_2 content of surrounding air, instead being useful primarily for its ability to filter particulate matter and NO_x, molecules whose modes of existence bear little comparison with that of CO_2. As we explore in the next section, the tensions

involved in this initial comparison with normal trees eventually led UrbanMoss' developers to design a whole digital apparatus of sensors and monitoring devices to help render the work of moss more tangible and less abstract.

Ultimately, what was stressed by The Company's comparison with 275 normal trees was the potency of moss. Yet raw potency must ultimately be curtailed (i.e. depotentialised) in order for moss to be effectively commodified (Cooper, 2008). Depotentialisation serves to justify moss' enrolment within a profit-oriented model of privately developed, technologically optimised, smart NBS. Hence, even while mosses are otherwise known to 'display a unique capacity for growing within urban-specific forms, including Astroturf and tarmac' (Gabrys, 2012: 2923), and indeed to be 'well-adapted to the urban contexts of hard surfaces, polluted sites, and disturbed grounds' (Gabrys, 2012: 2927), moss is constructed by UrbanMoss' developers and licensers as a *quintessentially* non-urban plant:

> *'There was no idea of how to bring moss to the city, because it's a pretty fragile… plant that likes very specific conditions, like you see mainly moss in the forest where it's wet, when it's not so sunny, and it does not like a city itself'. (Interview, 2018)*

This discursive depotentialisation of moss in urban settings is an essential rhetorical move for normalising the presence of private cleantech companies in the smart NBS landscape. The imposition of a sense of fragility and scarcity constricts understandings of the potentiality of moss to registers which demand that it be subjected to support, optimisation or enhancement by the application of specialist knowledge and techniques. What better argument for a cleantech start-up than a crucial environmental service being potentially abundant, and yet simultaneously absent, from the urban landscape? Bringing moss into purportedly moss-deprived urban spaces also justifies the engineering of moss-friendly micro-environments, as we will go on to explore in greater detail in the next section.

By locating fragility and scarcity in moss itself, and not in the conditions of the deployment of UrbanMoss specifically, these discursive arguments overshadow the ways in which the corporate nature of the technology shapes its urban geography, thereby neglecting to attend to urban moss where it (already) exists. Indeed, what is described as an inherent deficiency of moss (i.e. its claimed fragility in the face of hostile urban environments) is in fact largely the product of a specific vision of *which* urban spaces matter and which do not – a vision which is embedded in the technology and its own reductive urban geography. Tellingly, the initial concept for UrbanMoss centred not around the idea of purifying air at all, but rather on creating a 'green billboard' for facilitating corporate advertisement. As such, it was always designed to be placed in wide, open, visible locations, where the impacts of advertisements would be maximised. In fact, the eventual incorporation of moss into UrbanMoss' design was an almost incidental product of the commodity's birthplace:

> *'The very first idea of UrbanMoss was it was going to be a green billboard, so you would be able to make an advertisement from plants. […] And then during that time at the university where The Company was founded, there was a lot of research on moss. And specifically speaking of the absorption of air pollution by moss […] So then the idea was to incorporate moss instead of plants into the UrbanMoss'. (Interview, 2018)*

The square shape of UrbanMoss is perhaps the most obvious clue to its original 'green billboard' identity. But even in its current guise as a fully fledged smart NBS, UrbanMoss retains space both for digital advertisements and for permanent branding by clients. While these aspects of UrbanMoss may not immediately appear to compromise its core, air purifying function, they do generate

tensions around how the product is marketed to potential customers, simultaneously as 'a biofilter', an 'information touchpoint for communication', a 'data platform and mobility hub through Smart City technology', and even simply a 'place to meet and relax' (The Company, 2021: 5). Moreover, images displayed on The Company's website depict UrbanMoss installed in prominent positions within relatively large, open, public spaces such as squares and plazas, which are neither the 'heavily polluted streets' which the technology purports to help clean, nor the most obvious of moss habitat (Gabrys, 2012). Yet it is precisely by locating UrbanMoss in open, sunlit, airy spaces – a world away from the ideal living conditions for mosses – that moss itself is rendered visible, valuable and at the same time critically *dependent* upon the complex technological support structure which is provided by The Company.

Having focused on these initial discursive dimensions of the commodification process, in the next section we move on to examine how UrbanMoss' developers bring specific digital technologies to bear on moss life, as a means of rendering UrbanMoss itself investable.

'Rendering investable': Putting moss to work

Having shown how UrbanMoss' developers discursively construct moss as both capable and scarce in urban environments (a mutually constitutive process of potentialisation and depotentialisation, in Cooper's (2008) terms), we now move on to examine the techniques which are used to render UrbanMoss investable, as one distinct, proprietary product in the smart NBS landscape. More specifically, we pay close attention to the enrolment of moss into a carefully designed digital apparatus – comprising digital sensors, data flows and automated support systems – intended to help stabilise and optimise the metabolic activity and air purifying performance of moss itself. Drawing on more-than-human political economy, we approach these processes as a concerted effort by UrbanMoss' developers to 'work with' moss (Battistoni, 2017; Welden, 2023) in ways that promise to deliver continuous, consistent and calculable urban environmental benefits.

In light of its relatively portable nature when compared to green walls mounted on fixed urban (infra)structures, UrbanMoss can theoretically be located anywhere in the city – a busy street, a roundabout, a square or even a public park – so long as it is authorised. In this way, the product becomes malleable to potential buyers' own projects and visions for rendering urban space – whether public or privatized – more hospitable and desirable to inhabit. The Company even offers modelling solutions to help potential buyers identify optimal locations for installation, so as to maximise UrbanMoss's air-cleaning performance:

> *'[S]oftware makes it possible to create sustainable living conditions in a constantly changing environment and to analyze scientifically what effects different planning scenarios will have'. (The Company, 2024c)*

Some of the locations in which clients choose to install UrbanMoss – the already-mentioned sunlit plazas and squares for example – are likely to be unwelcoming to moss life, or at least to a continuously active form of moss metabolism. Mosses certainly can withstand challenging conditions, for example packing their shoots together to share and hold on to limited moisture more effectively during long periods without water (Kimmerer, 2003: 92). In such conditions however they 'may disappear from view, receding into lines within concrete and brickwork in summer, only to return as a sodden green surface when the rains resume' (Gabrys, 2012: 2927). While extreme air pollution can precipitate the death of moss (Kimmerer 2003), for the most part these adaptive responses render mosses extremely resilient to fluctuating climatological and ecological conditions. However, these responses do not constitute desirable behaviour for potential buyers spending thousands of pounds (or euros) on a purported solution to urban air pollution. It is, therefore, only by

eradicating irregularities from the temporal rhythms of moss metabolism that the ultimate air-cleaning performance of UrbanMoss can be achieved over time. One solution to this conundrum is the inclusion within each UrbanMoss of devices aiming to create a continuous, reliable microclimate, independent of external conditions:

> *'[T]he founders understood that they needed to create a microclimate or environment in which moss would like to stay… so that's when this whole combination of sensors and measuring what kind of environment there is [came in]'. (Interview, 2018)*

This was initially done through a combination, within each UrbanMoss, of accompanying plants and sensor-based automated care systems to reproduce favourable degrees of shade and moisture for moss to work optimally, regardless of each UrbanMoss' location in the urban environment itself. A layer of so-called cover plants was used to provide consistent shade to mosses from the sun, while sensors closely monitored moisture content at regularly spaced intervals throughout the moss 'wall' itself, leading to the modulation of the supply of water – from a built-in water storage tank – to pockets of moss most in need. This combined plant-and-sensor-based apparatus offered buyers the promise of extracting a consistent and reliable amount of air purification work from moss, regardless of the conditions UrbanMoss was placed into. In other words, by alienating moss from prevailing climatological and ecological conditions, UrbanMoss promises to extract work from nature even in the most unpredictable or hostile of environments.

Replacing naturally occurring shady environments with a layer of cover plants was anything but straightforward. Cover plants have their own distinct nutrient and moisture requirements, whose fulfilment often had the effect of suppressing moss growth. Consequently, UrbanMoss' developers have sought to remove moss entirely from ecosystemic relations – those involving other plants:

> *'We used to have cover plants because the idea was that the cover plants were giving shade to the moss. So they were protecting the moss from additional exposure to sand, or to environmental conditions. But what we realised is that cover plants and moss have very different needs, in terms of humidity, nutrition, and that was creating a bit of instability in the biosystem that we created'. (Interview, 2018)*

Recent versions of the product therefore include a shutter-like covering structure for shade; moisture is entirely provided through sensor-activated watering systems.

As for sensors, these are not only linked to built-in water tanks and irrigation systems, but also to an online data visualisation platform which allows clients to monitor the contribution of UrbanMoss to purifying urban air on an ongoing basis. As such, UrbanMoss is not only an automated, self-contained technology, but an ostensibly data-rich one:

> *'If you think about 'green walls' or any urban greening – you put it there and you hope it works… But the moment you have sensors you can actually quantify and see in real time what's happening to air pollution levels around UrbanMoss'. (Interview, 2018)*

There is a limitation to the insights that these sensors can provide, however. Indeed, while changing conditions immediately around an UrbanMoss can easily be measured (relating for instance to temperature, humidity, or NO_x concentrations), this says very little about what mosses are actually doing to the air itself. How much of any observed reduction in temperature, for example, can reliably be attributed to the work of the moss, as compared to other factors? How much of any observed reduction in NO_x or particulate matter concentrations, likewise, results from air passing directly

through the wall of moss, where such fine dust can be captured and metabolised? Ultimately, whilst cover plants (or shutters) and built-in sensors may well help to maximise the capacities of moss, in practice they prove insufficient for ensuring the production of reliable data on UrbanMoss' actual contributions to local air purification. For a reliable comparison of air quality pre- and post-purification by UrbanMoss, air itself must flow consistently and in a predictable direction through the apparatus. Hence the addition – and patenting – of a technology designed to regularise the airflow available to the moss:

> *'It is difficult to quantify how much air you're purifying because you depend solely on the natural wind-stream so you have to make sure that the wind-stream is perpendicular to UrbanMoss, which limits your capacity very much... So now [with the new air ventilation system], knowing our efficiency, and knowing how much air we can filter, we can then quantify the performance easily for the client'. (Interview, 2018)*

In short, the addition to UrbanMoss of an air ventilation system aims to drastically reduce variability in the rates of air purification which the moss performs, thereby rendering this performance constantly calculable.

All of this raises questions about the forms of nature which are being nurtured through the pursuit of smart nature-based solutions to urban environmental problems. UrbanMoss is predicated on the devaluation of the unstable, messy ecologies within which moss is *already* embedded in urban environments, associated as these often are with dark, dank recesses, pavement cracks and even sometimes 'a hint of moral decay' (Kimmerer, 2003: 95).[4] Against these supposedly undesirable forms of moss life, UrbanMoss offers an ostensibly stable digital biotechnological apparatus within which moss is entangled with patented technologies to create a novel, hard-working, proprietary form of bryophyte nature. As discussed in the previous section, moss is constructed at once as lively and innately capable of purifying polluted urban air (i.e. it is potentialised), and yet also as fragile and susceptible to instability in urban environments (i.e. it is depotentialized), such that further investment of capital and technology is required to activate and sustain this enterprising capacity over time. Ultimately however, investment is attracted not simply by rendering the air-cleaning performance of moss visible and tangible, but also by producing UrbanMoss as a form of nature whose performance and contributions to remedying urban air pollution are continuous, consistent, and calculable – a form of nature, in short, which bears no connection to place, weather, or the seasons. Rendering UrbanMoss investable thus takes place along different paths. At a fundamental level, moss is rendered investable through being rendered resilient to almost any type of urban space, so long as it is accompanied by a carefully configured apparatus of sensors and shutters. But it is also rendered investable through being desensitised to short-term fluctuations in environmental conditions, and 'de-seasonalised' such that it no longer responds to intra-annual variations in local climate. It is an a-territorial, a-seasonal, continually performing moss that is offered to potential investors and buyers. Within UrbanMoss, moss therefore doesn't purify air by virtue of its 'natural' abilities; instead, the product's ability to 'grow fresh air' is effectively *coproduced* through 'constant interplay between lively biological energies and characteristics and the formative, generative, forces of commodification and capital' (Collard and Dempsey, 2013: 2685).

Having thus examined the dynamics of commodification at play in the case of UrbanMoss on both discursive and more-than-human levels, we now move on, in the final section of our analysis, to explore the ways in which these 'formative, generative forces of commodification and capital' also act to enrol moss in the (re)production of highly uneven urban spaces, with implications for environmental justice and inequality.

Cyborg moss in capital city: Smart NBS and environmental justice

Despite its relatively small size, UrbanMoss carries the promise to contribute to a wider reshaping of urban governance through becoming a facilitative platform for the development of additional smart infrastructures. In this section we show that although UrbanMoss' contributions to the development of new forms of smart urbanism are – to date at least – modest, the technology is nonetheless indicative of a broader proprietary remaking of urban environmental governance, with consequences both for the perpetuation of environmental and social inequalities and an increase in funding uncertainties in an already stretched local budgetary landscape. To help illustrate the potential implications of smart NBS for environmental justice in cities of the future, we focus our arguments in this last section of our analysis specifically on the case of the first UrbanMoss to be installed in London in 2018.

The previous section has shown the double role played by digital sensors in UrbanMoss – underpinning both the automation of moss maintenance and care on the one hand, and the real-time monitoring of the air-purifying performance of moss on the other. Beyond imbricating the digital and the ecological in ways intended to extract an 'enterprising' performance from moss itself, however, UrbanMoss is also embedded in 'smart' logics at a wider landscape scale, specifically through the promise to contribute to the development and functioning of wider platforms for 'smart' city governance. With respect to the issue of air quality specifically, for example, UrbanMoss is being imagined in ways which emphasise its potential contribution not just to local air pollution reduction, but also to facilitating more dynamic and fine-grained air quality monitoring through the creation of networks of multiple UrbanMoss installations across the city. Beyond air quality, meanwhile, UrbanMoss is also simultaneously being imagined as a potential platform for diverse other kinds of smart sensors and devices in cities. As one Urban Moss representative explained in an interview:

> *'…because you already have so many sensors, there's nothing stopping you from adding more sensors to measure other stuff, like for example traffic flow… which then transforms UrbanMoss from not only being a filter but also a kind of smart city platform'. (Interview, 2018)*

While these wider contributions of UrbanMoss to the development of smart infrastructures and data management platforms remain speculative for now, the existence of such imaginaries nonetheless highlights a potential slippage between the specific goal of addressing urban air pollution and a broader desire to capitalise on the investment opportunities of a prevailing 'corporate smart city model' (Hollands, 2015: 61; see also Luque-Ayala and Marvin, 2016). Indeed, by playing into a logic that regards urban problems of all kinds as resolvable through 'more sophisticated data gathering' (Hollands, 2015: 74), such ideas potentially open the door for smart NBS to function as yet one more vehicle for compounding the influence of global high-tech corporate actors over smart city infrastructures, and hence over urban governance more broadly (Gabrys, 2020).

Regardless of whether visions of UrbanMoss as a catalyst for the development of more comprehensive smart city platforms are or are not realised in practice, however, the technology nonetheless already has implications for existing urban geographies of environmental and social inequality. The case of London, where an UrbanMoss was first installed in March 2018, is particularly instructive in this respect. Determined to launch UrbanMoss in the capital city for publicity and visibility purposes, the product's UK licence holder picked Westminster, and specifically Piccadilly Circus, as the launch site for the product – a central location affording maximum visible exposure of UrbanMoss to big capital, thereby increasing the odds of penetrating the smart nature-based solutions market. Beyond maximising the visibility of UrbanMoss itself, however, this choice of location also served to publicise the licence holder's own company: '*My company now has a logo on a*

big structure on Piccadilly Circus, which is unheard of!' (Interview, 2018). UrbanMoss, in this sense, reveals itself not simply as a *promissory* smart city platform; it is also already an *actual* advertisement platform, offering companies an opportunity to penetrate urban spaces that might otherwise be protected from more conventional forms of visual advertising. In short, the technology's status as an ambiguous commodity – one promising to generate value not just through filtering polluted air, but also through serving as an 'information touchpoint for communication' (The Company, 2021: 5), means that its geography is significantly determined by where capital already is, rather than solely by considerations about air quality or indeed the uneven impacts of poor air quality as experienced by residents and citizens in different parts of the city.

The location of London's first UrbanMoss is also notable because it cuts against the grain of efforts on the part of the local City of Westminster authority to reduce the presence of unnecessary street furniture. Indeed, the licence holder describes the installation process as having been complicated and convoluted, with permission to situate UrbanMoss in Piccadilly Circus ultimately resting heavily on a case being made for the absolute necessity of a new generation of air-cleaning street furniture being rolled out more fully across the capital. Even if London's first UrbanMoss might be viewed as a modest experiment with one form of smart NBS, therefore, that experiment has ultimately served not merely to showcase the air-cleaning potential of moss in cities, but also to legitimise responses to urban environmental problems which look to private capital and investment to develop 'intelligent' technological solutions, rather than responses which aim to address those problems' deeper root causes (Hollands, 2015; Viitanen and Kingston, 2014). UrbanMoss in this sense is already being exploited as a strategic device for constructing corporate involvement in the creation of more sustainable urban environments as inherently benevolent, whilst allowing the pervasive penetration of public space by private property. Normalising the use of proprietary smart NBS to address environmental problems like air pollution, however, neglects to attend to the limited capabilities of many cash-strapped local authorities, especially in areas already subject to economic deprivation and poor public health, to purchase those solutions in the first place. Overall, there is a significant risk that relying on patented, commercial technologies to address such problems could worsen already profound social and environmental inequalities in cities, as only wealthy local councils and – more likely still – affluent private property owners, will realistically be able to afford them.

At another level, there are also important environmental justice implications attached to the ironic reliance of smart, solution-focused technologies on the continued existence of problems like air pollution, as a background condition of urban life. It was in that sense not surprising to hear the UK licence holder for UrbanMoss insist in an interview that air pollution should be tackled through the wider and more ambitious roll-out of such technologies, rather than through legislation or structural change aiming to reduce the production of pollution itself. Company representatives in fact sought to impose a view of the origins of urban air pollution as simply too numerous and diffuse to be amenable to this type of policy response – encompassing not just road vehicles, for example, but also restaurant kitchens, construction sites, and train stations, among others. Against this backdrop, technologies like UrbanMoss were viewed as vital to the future creation of very small-scale clean air zones – operating on a scale of perhaps just 15 to 20m^2 each – which could purportedly act to remediate pollution at key sites almost as soon as it has been emitted. Such thinking, of course, normalises and extends a logic of enclosure which cannot be disentangled from questions of exclusion (Marvin, 2016), raising the spectre that smart NBS will further deepen fractures within urban space between areas and communities benefitting from green gentrification and hence able to defend themselves against environmental ills, and those left to bear the consequences of ongoing environmentally toxic urban systems and behaviours (Harper, 2020; Sekulova et al., 2021).

Finally, it is also important to highlight that, from the perspective of investors, nature-based approaches to addressing key social and environmental challenges in cities are but one opportunity for profit-making among many others. UrbanMoss' UK licence holder was, at the time of conducting this research, also awaiting licences on several other products to be released to invest in new commodities. Even since buying the licence for UrbanMoss in 2017, this organisation had already moved on to technologies for addressing air pollution involving not living organisms (i.e. moss) but ionisation processes. Given the propensity of both developers and investors to switch quickly from promoting one commodified form of smart technological solution to another, there remain crucial questions about the capacity of privately owned cleantech commodities to mount durable or sustained responses to issues like air pollution, potentially leaving publics at the mercy of shifting investment dynamics. Taken together, these points offer valuable insight into the politics of smart nature-based solutions, highlighting not only how little 'nature' itself actually matters to those funding the sector, but also the significant potential of such solutions to promulgate social inequalities and environmental injustices in cities, further separating those able to afford to protect themselves from environmental ills, from those who cannot.

Conclusions

There is far more at stake in the world of smart urban NBS than simply rolling out the power of 'nature' to solve environmental and social problems. Overtures to the capacities of 'nature' to solve urban problems are fraught for the contestable dualism they imply, as well as the shadow they cast over entanglements between 'nature-based' and technological (or 'grey') approaches – including those self-described as 'smart'. Nonetheless, NBS remain praised for the potential they herald for facilitating more convivial forms of urbanism (Maller, 2021). In this article, we have sought to augment efforts to think through the more-than-human politics of NBS, highlighting how a rarely noticed (Gabrys, 2012) family of organisms – bryophytes – gains legitimacy and visibility through being recognised as natural 'biofilters' that can help address poor urban air quality. However, as our analysis has shown, this new recognition does not translate into the valorisation of existing moss presence in cities, nor the protection or expansion of their habitats, through 'bryophilic' street design and building maintenance for example. Instead, within the utilitarian framework of nature-based solutions, the responses of moss to seasonal, meteorological, and wider environmental variations are cast as nothing less than a hindrance to potential investment. Overcoming this hindrance demands that moss life be subjected to streamlining and automation for a continuous, consistent and calculable contribution to urban environmental improvement.

Beyond this broad – but essential – point, the article has also sought to examine the mechanisms through which logics of capital shape and restrict the potential of NBS (Kotsila et al., 2021; Sekulova et al., 2021). More specifically, we have deployed a more-than-human political economic lens to illuminate how the involvement of the cleantech sector shapes emerging modes of working with non-human nature in 'smart' urban nature-based solutions. Paying forensic attention to microscale interventions into the metabolic rhythms of bryophytes and their ecosystems, our analysis has highlighted how moss bodies become a site through which the role of private capital in urban environmental governance is being reconfigured, and where a new political economy of urban nature is being conjured up. This argument has proceeded on three levels. On the first level, we highlighted an inherent tension in the commodification of NBS, wherein 'nature' needs to be depicted as at once inherently productive and regenerative, but also as fragile and scarce, therefore delineating a requirement for capital investment to help activate and optimise non-human capabilities that would otherwise lie dormant. For moss specifically, this discursive potentialization – to borrow Melinda Cooper's (2008) terminology – proceeds through depictions of these lifeforms as 'natural air cleaners', as well through the establishment of comparisons with other, more relatable,

forms of urban nature (principally trees). At the same time, however, moss is also depotentialized through accounts emphasising its supposed fragility in the face of hostile and unpredictable urban environments. On a second level, our article has also sought to examine how the specific, material interventions into moss life which undergird efforts to render one distinct, proprietary form of NBS – UrbanMoss – investable. More specifically here, we argue that moss is effectively put to work through its isolation from complex ecosystemic relations and environmental fluctuations, and its enrolment instead into a carefully designed digital apparatus – comprising sensors, data flows and automated support systems – which purport to stabilise and optimise the metabolic activity and air purifying performance of moss itself.

Finally, on a third level, we have sought to explicate how the sense of natural fragility and scarcity that justifies the existence of such a thing as UrbanMoss is itself spatially produced. Bryophytes are only scarce insofar as their desired location in the form of a commodified NBS is contrary to the conditions for their unaided abundance. The threats that the specific local conditions of UrbanMoss' deployment pose to the very ability of moss not only to deliver its services, but even to remain visibly alive, serve to justify the involvement of private capital. This capital-oriented urban geography, we have ultimately argued, reinforces existing dynamics of social and environmental injustice, with more cash-stricken local authorities – indeed, public authorities of all kinds – less likely to invest in this 'solution' than richer and generally more well-off customers in the private sector. The use of this type of smart NBS to produce micro-scale 'clean air zones', for example, risks not only naturalising the continued existence of poor ambient air quality in cities of the future, but also further entrenches logics of protection and enclosure of the richest from the very environmental hazards that they are most responsible for exposing vulnerable populations to in the first place.

Even if efforts to instantiate 'nature-based solutions' to environmental problems in cities all too often presume the necessity of commodifying non-human lifeforms in order to harness their potential, however, this does not negate the possibility of working with nature in alternative, non-proprietary ways. UrbanMoss' corporate urban geography, as we have argued, produces the very moss scarcity upon which the necessity of the product itself is predicated. Yet, if moss and other forms of non-human nature were to be recognised and valorised as already thriving and 'at home' in cities, perhaps more convivial and open access approaches to embracing diverse ways of knowing about non-human life, and indeed more public and democratic approaches to working with nature, might begin to reveal themselves as well (Tozer et al., 2020). Beyond the realm of air pollution specifically, there are already promising signs of alternative approaches to working with moss (and indeed other forms of vegetal life), for example to help maintain urban spaces, buildings, or even cultural heritage (Coombes and Viles, 2021). If a broader shift away from commodifying logics of smart urban NBS it be catalysed, this will of course require current scientific and policy enthusiasm for the identification of singular 'solutions' to be revisited. Overcoming the stifling influence of smart, technocratic logics will also, we argue, likely require an embrace of open-ended, plural and inclusive experiments with digital technologies of all kinds, not just to help transform societal encounters with (and ideas about) nature, but also to reimagine the terms on which visions of good urban environmental governance are articulated and defended (Luque-Ayala et al., 2024).

Highlights

- Smart nature-based solutions (NBS) are becoming a playground for actors seeking to derive profit from non-human life in cities.
- We examine how the search for investment capital shape and restrict the potential of smart NBS.

- Nature – specifically moss – is commodified initially through the dual process of potentialisation and depotentialisation.
- We adopt a more-than-human lens to examine the material interventions into moss 'nature' that render smart NBS investable
- Through this 'investment-drive' smart NBS risk reproducing uneven and exclusionary urban environmental dynamics.

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Notes

1. We thank an anonymous reviewer for suggesting this form of words.
2. A classic example of this dual process can be found in the field of plant biotechnology, where the potential scope of global crop yield increases that might be derived from genetic modification is artificially constrained by the application of private property rights to new, more productive crop cultivars (Kloppenburg 2004: 11).
3. One might draw an analogy here with the distinction between the 'formal subsumption' and 'real subsumption' of nature set forth by Boyd et al. (2001: 564), in their landmark assessment of the approaches used by capital to make nature work 'harder, faster and better'.
4. As Kimmerer (2003: 94) puts it, the eradication of unwanted moss in cities, whether from rooftops or lawns, 'is big business' (see also Robbins 2007).

References

Arcari P, Probyn-Rapsey F and Singer H (2021) Where species don't meet: Invisibilized animals, urban nature and city limits. *Environment and Planning E: Nature and Space* 4(3): 940–965.

Atchison J (2021) Shady work: African Mahogany (Khaya senegalensis), cyclones and green urban futures in Darwin, Australia. In Ernwein M, Ginn F and Palmer J (eds) *The Work that Plants Do: Life, Labour and the Future of Vegetal Economies*. Bielefeld: Transcript, 149–161.

Barua M (2016) Lively commodities and encounter value. *Environment and Planning D: Society and Space* 34: 725–744.

Barua M (2017) Nonhuman labour, encounter value, spectacular accumulation: The geographies of a lively commodity. *Transactions of the Institute of British Geographers* 42: 274–288.

Barua M (2019) Animating capital: Work, commodities, circulation. *Progress in Human Geography* 43(4): 650–669.

Barua M (2023) Plantationocene: A vegetal geography. *Annals of the American Association of Geographers* 113(1): 13–29.

Battistoni A (2017) Bringing in the work of nature: From natural capital to hybrid labor. *Political Theory* 45(1): 5–31.

Batty M (2012) Smart cities, big data. *Environment and Planning B: Planning and Design* 39: 191–193.

Bauer W (2023) Reframing urban nature-based solutions through perspectives of environmental justice and privilege. *Urban Planning* 8(1): 334–345.

Bellamy R and Osaka S (2020) Unnatural climate solutions? *Nature Climate Change* 10: 98–99.

Birch K (2018) *Neoliberal Bioeconomies: The Co-Construction of Markets and Natures*. London: Palgrave MacMillan.

Boyd W, Prudham WS and Schurmann RA (2001) Industrial dynamics and the problem of nature. *Society and Natural Resources* 14: 555–570.

Braun B (2014) A new urban dispositif? Governing life in an age of climate change. *Environment and Planning D: Society and Space* 32: 49–64.

Brice J (2021) Vegetal labour and the measure of value: Reckoning time and producing worth in capitalist viticulture. In Ernwein M, Ginn F and Palmer J (eds) *The Work that Plants Do: Life, Labour and the Future of Vegetal Economies*. Bielefeld: Transcript, 123–145.

Caprotti F (2016) Defining a new sector in the green economy: Tracking the techno-cultural emergence of the cleantech sector, 1990–2010. *Technology in Society* 46: 80–89.

Collard R-C (2020) *Animal Traffic: Lively Capital in the Global Exotic Pet Trade*. Durham: Duke University Press.

Collard R-C and Dempsey J (2013) Life for sale? The politics of lively commodities. *Environment and Planning A: Economy and Space* 45: 2682–2699.

Coombes MA and Viles HA (2021) Integrating nature-based solutions and the conservation of urban built heritage: Challenges, opportunities, and prospects. *Urban Forestry & Urban Greening* 63(127192): 1–10.

Cooper M (2008) *Life as Surplus: Biotechnology and Capitalism in the Neoliberal Era. Seattle*, WA: University of Washington Press.

Ernwein M (2021a) Vegetal labour in the ecological regime of urban maintenance: Reproduction, collaboration, uneven relations. In: Ernwein M, Ginn F and Palmer J (eds) *The Work that Plants Do: Life, Labour and the Future of Vegetal Economies*. Bielefeld: Transcript, 105–121.

Ernwein M (2021b) Bringing urban parks to life: The more-than-human politics of urban ecological work. *Annals of the American Association of Geographers* 111(2): 559–576.

Ernwein M, Ginn F and Palmer J. (eds.) 2021. *The Work that Plants Do: Life, Labour and the Future of Vegetal Economies*. Bielefeld: Transcript.

European Commission (2015) *Towards an EU Research and Innovation Policy Agenda for Nature-based Solutions & Re-naturing Cities* – Final Report of the Horizon 2020 Expert Group. European Commission, Directorate-General for Research and Innovation, Brussels.

Fleming A (2020) The case for … making low-tech 'dumb' cities instead of 'smart' ones. *The Guardian*, 15th January 2020. https://www.theguardian.com/cities/2020/jan/15/the-case-for-making-low-tech-dumb-cities-instead-of-smart-ones (last access 14 August 2024).

Fleming J (2017) Toward vegetal political ecology: Kyrgyzstan's walnut–fruit forest and the politics of graftability. *Geoforum; Journal of Physical, Human, and Regional Geosciences* 79: 26–35.

Frantzeskaki N (2019) Seven lessons for planning nature-based solutions in cities. *Environmental Science & Policy* 93: 101–111.

Gabrys J (2012) Becoming urban: Sitework from a moss-eye view. *Environment and Planning A* 44: 2922–2939.

Gabrys J (2020) Smart forests and data practices: From the Internet of trees to planetary governance. *Big Data & Society* 7(1): 1–10.

Gabrys J (2022) Programming nature as infrastructure in the smart forest city. *Journal of Urban Technology* 29(1): 13–19.

Galle NJ, Nitoslawski SA and Pilla F (2019) The Internet of nature: How taking nature online can shape urban ecosystems. *The Anthropocene Review* 6(3): 279–287.

Goldstein J (2018) *Planetary Improvement: Cleantech Entrepreneurship and the Contradictions of Green Capitalism*. Cambridge, MA: MIT Press.

Gulsrud NM (2019) Smart nature? Views from the cyborg tree. In: Braes E and Steiner H (eds) *Routledge Research Companion to Landscape Architecture*. Abingdon: Routledge, 103–112.

Gulsrud NM, Raymond CM, Rutt RL, et al. (2018) Rage against the machine'? The opportunities and risks concerning the automation of urban green infrastructure. *Landscape and Urban Planning* 180: 85–92.

Haarstad H (2017) Constructing the sustainable city: Examining the role of sustainability in the 'smart city' discourse. *Journal of Environmental Policy and Planning* 19(4): 423–437.

Harper ET (2020) Ecological gentrification in response to apocalyptic narratives of climate change: The production of an immuno-political fantasy. *International Journal of Urban and Regional Research* 44: 55–71.

Helmreich S (2008) Species of biocapital. *Science as Culture* 17(4): 463–478.

Hinchliffe S and Whatmore S (2006) Living cities: Towards a politics of conviviality. *Science as Culture* 15(2): 123–138.

Hollands RG (2015) Critical interventions into the corporate smart city. *Cambridge Journal of Regions, Economy and Society* 8(1): 61–77.

Kaluarachchi Y (2021) Potential advantages in combining smart and green infrastructure over silo approaches for future cities. *Frontiers of Engineering Management* 8: 98–108.

Kimmerer RW (2003) *Gathering Moss: A Natural and Cultural History of Mosses*. Corvallis, OR: Oregon State University Press.

Kitchin R (2014) The real-time city? Big data and smart urbanism. *GeoJournal* 79: 1–14.

Kloppenburg J (2004) *First the Seed: The Political Economy of Plant Biotechnology*. Madison, WN: University of Wisconsin Press.

Kotsila P, Anguelovski I, Baró F, et al. (2021) Nature-based solutions as discursive tools and contested practices in urban nature's neoliberalisation processes. *Environment and Planning E: Nature and Space* 4(2): 252–274.

Levenda AM and Tretter E (2020) The environmentalization of urban entrepreneurialism: From technopolis to start-up city. *Environment and Planning A: Economy and Space* 52(3): 490–509.

Luque-Ayala A, Machen R and Nost E (2024) Digital natures: New ontologies, new politics? *Digital Geography and Society* 6(100081): 1–9.

Luque-Ayala A and Marvin S (2016) Developing a critical understanding of smart urbanism? *Urban Studies* 52(12): 2105–2116.

Maller C (2021) Re-orienting nature-based solutions with more-than-human thinking, *Cities*. 113.

Marvin S (2016) Volumetric urbanism: Artificial "outsides" reassembled "inside". In Coutard O and Rutherford J (eds) *Beyond the Networked City: Infrastructure Reconfigurations and Urban Change in the North and South*. Abingdon: Routledge, 227–241.

Marvin S and Rutherford J (2018) Controlled environments: An urban research agenda on microclimatic enclosure. *Urban Studies* 55(6): 1143–1162.

Metzger J (2016) Cultivating torment: The cosmopolitics of more-than-human planning. *City* 20(4): 581–601.

Moss T, Voigt F and Becker S (2021) Digital urban nature: Probing a void in the smart city discourse. *City* 25: 255–276.

Nature4Climate. 2021. Five reasons why you should listen out for 'nature tech' this year. https://nature4climate.org/five-reasons-why-you-should-listen-out-for-nature-tech-this-year/ (last accessed August 14th 2024).

Nelson IL, Hawkins R and Govia L (2023) Feminist digital natures. *Environment and Planning E: Nature and Space* 6(3): 2096–2109.

Nesshöver C, Assmuth T, Irvine KN, et al. (2017) The science, policy and practice of nature-based solutions: An interdisciplinary perspective. *Science of the Total Environment* 579(1): 1215–1227.

Nost E and Goldstein JE (2022) A political ecology of data. *Environment and Planning E: Nature and Space* 5(1): 3–17.

Osaka S, Bellamy R and Castree N (2021) Framing "nature-based" solutions to climate change. *WIRES Climate Change* 12(5): e729.

Palmer J (2021) Putting forests to work? Enrolling vegetal labor in the socioecological fix of bioenergy resource making. *Annals of the American Association of Geographers* 111(1): 141–156.

Porcher J (2015) Animal work. In: Kalof L (ed) *The Oxford Handbook of Animal Studies*. Oxford: Oxford University Press, 302–318.

Porcher J and Estebanez J (eds) (2019) *Animal Labor: A New Perspective on Human-Animal Relations*. Bielefeld: Transcript.

Rajan KS (2006) *Biocapital: The Constitution of Postgenomic Life*. Durham, NC: Duke University Press.

Robbins P (2007) *Lawn People: How Grasses, Weeds, and Chemicals Makes Us Who We Are*. Philadelphia, PA: Temple University Press.

Seddon N, Smith A, Smith P, et al. (2021) Getting the message right on nature-based solutions to climate change. *Global Change Biology* 27: 1518–1546.

Sekulova F, Anguelovski I, Kiss B, et al. (2021) The governance of nature-based solutions in the city at the intersection of justice and equity. *Cities* 112(103136): 1–6.

Sheikh H, Mitchell P and Foth M (2023) More-than-human smart urban governance: A research agenda. *Digital Geography and Society* 4(100045): 1–13.

Smith A (2023) Hydroponic capital: Socionatural innovation and the intensification of glasshouse agrifood production. *Economic Geography* 99(4): 363–389.

The Company (2021). *Executive Booklet – UrbanMoss*. Online (last accessed 9th August 2024).

The Company (2024a) Our Vision: A Healthier Future in the Cities. Online (last accessed: 21st August 2024).

The Company (2024b) We Grow Fresh Air. Online (last accessed: 21st August 2024).

The Company. (2024c) Our Ecosystem. Online (last accessed: 21st August 2024).

Tozer L, Bulkeley H, Kiss B, et al. (2023) Nature for resilience? The politics of governing urban nature. *Annals of the American Association of Geographers* 113(3): 599–615.

Tozer L, Hörschelmann K, Anguelovski I, et al. (2020) Whose city? Whose nature? Towards inclusive nature-based solution governance. *Cities* 107(102892): 1–10.

Viitanen J. and Kingston R. 2014. Smart cities and green growth: Outsourcing democratic and environmental resilience to the global technology sector. *Environment and Planning A* 46(4): 803–819.

Wachsmuth D and Angelo H (2018) Green and gray: New ideologies of nature in urban sustainability policy. *Annals of the American Association of Geographers* 108(4): 1038–1056.

Wakefield S (2020) Making nature into infrastructure: The construction of oysters as a risk management solution in New York City. *Environment and Planning E: Nature and Space* 3(3): 761–785.

Welden EA (2023) Conceptualising multispecies collaboration: Work, animal labour, and nature-based solutions. *Transactions of the Institute of British Geographers* 48(3): 541–555.

Wickenberg B, McCormick K and Olsson JA (2021) Advancing the implementation of nature-based solutions in cities: A review of frameworks. *Environmental Science & Policy* 125: 44–53.