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Debate

The Monster 'Within': Capitalist Urbanization as Geometabolic Escalation

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ABSTRACT

This article challenges prevailing approaches to urban sustainability by reconceptualizing capitalist urbanization as a planetary process of geometabolic escalation. Hegemonic visions of sustainable cities render invisible the non-city sociometabolic preconditions and consequences of urban life under capitalism. Our dissident theorization brings to the foreground such 'hidden abodes' of capitalist urbanization and their role in the enclosure, operationalization and degradation of the planetary biosphere. The fossil-based metabolic regime of capital, consolidated in the 1870s and planetarized during what this article terms the 'Long Intensification', has transformed cities into strategic nodes within a fossil-powered formation of the capitalist urban fabric. This unevenly extended infrastructural matrix escalates the throughput of matter/energy while discharging toxic waste into the biosphere and generating planetary waves of social dispossession. The analysis reveals the dialectical relationship between throughput ecologies (of metabolic intensification) and exhaustion ecologies (of socioenvironmental destruction) that underpins this process. As carbon-intensive patterns of fixed capital are locked in and extended, cities become 'blazing bonfires' that metabolize colossal quantities of energy while projecting their destructive socioenvironmental impacts onto operational landscapes of appropriation and sacrifice zones of ruination. Meanwhile, rather than facilitating transitions away from fossil fuels, renewable energy has primarily supplemented expanding relays of fossil energy production and consumption, further ratcheting up capital's spatial metabolism of plunder, productivity and pollution. Urban sustainability programmes frequently serve to legitimize new forms of eco-apartheid, creating protected enclaves for privileged populations while preserving imperial circuits of extraction and waste. Drawing inspiration from Mike Davis, the article navigates between analytic despair and utopian possibility to envision *alter*-metabolisms that might interrupt capital's destructive planetary trajectory without succumbing to the false hopes associated with 'renewables capitalism'. This article proposes a radically relational, anti-capitalist reconfiguration of sustainability politics, grounded in degrowth strategies, anti-imperialist sociometabolic relations, democratic control of infrastructures and programmes of ecological repair.

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INTRODUCTION

The idea of the 'sustainable city' has acquired unprecedented importance in contemporary international policy discourse (Angelo and Wachsmuth, 2020). It is a guiding principle for urban planning, policy and design interventions around the world, and has also been codified as a key priority within the United Nations Sustainable Development Goals for 2030 (Parnell, 2016). Sustainable urban development is now widely viewed as a basis on which to reduce the environmental impact of urbanization while providing more inclusive social infrastructures and public goods to the world's increasingly urbanizing population. More generally, sustainable cities are today viewed as a key spatial arena for projects to mitigate the most disastrous impacts of climate change, to increase the adaptive capacities of institutions and populations in the face of environmental crises, and to establish new forms of resource management that 'could transform a rapidly urbanising planet such that it remains within the planetary boundaries conducive to human life' (Kronenberg et al., 2024: 235). Against this background, debates on the meaning(s) of urban sustainability and possible strategies to realize this goal have assumed greater urgency in the geopolitics of international development.

However, as radical critics have argued since the popularization of 'sustainable development' ideas in the UN Brundtland Report (World Commission on Environment and Development, 1987) and the subsequent 1992 Earth Summit in Rio de Janeiro, much of the discursive work around this concept is ideological. It serves primarily to preserve 'business as usual' forms of capitalist plunder, exploitation and pollution while rolling out strategies to 'immunize' populations to endure 'larger doses of inequality and environmental degradation in the future' and to extend the spatial infrastructures of militarized accumulation, climate colonialism and eco-apartheid (Kaika, 2017: 98).[1] This article broadly concurs with such radical critiques of urban sustainability discourse, which we likewise view as an ideological mechanism that further entrenches the metabolic operations of capital while leaving unencumbered the imperial class relations, institutional systems and infrastructural circuitry responsible for the ever-escalating capitalist destruction of life on Earth.

We extend such critiques by offering a distinctive theoretical perspective on the nature of urbanization under what we characterize — building upon Éric Pineault's (2023) conceptualization — as the fossil-based metabolic regime of capital. Our focus is not simply the energy carriers (fossil-based or otherwise) that fuel urban life but the *metabolic regimes* through which energy is extracted, canalized, processed, harnessed, distributed and dissipated to power sociospatial relations and to terraform the planet.

1. See also Angelo and Wachsmuth (2020), Cohen (2020), Davis (2010) Goh (2021), Kaika et al. (2023), Luke (2005), Rice et al. (2023) and Sultana (2025).

As we discuss below, the elemental processes that constitute such metabolic regimes — extraction, circulation, production and waste discharge — are grounded upon spatially extensive infrastructural configurations. These processes assume a historically specific form within the world-ecology of capitalism, leading to a relentless, planet-transforming 'churn' of matter/energy and recurrent waves of infrastructural and landscape transformation (Brenner and Ghosh, 2022; Harvey, 2017; Moore, 2015). Under the fossil-based metabolic regime of capital that was consolidated and planetarized in the period after the 1870s, this 'metabolic churn' has shaped the patterns and trajectories of capitalist urbanization in deeply path-dependent ways, with myriad planetary socioecological implications that require extensive theoretical decoding (Brenner and Ghosh, forthcoming). Our analytical framework thus provides a basis on which to critically assess the role of cities and their extended infrastructural assemblages in futurological visions of 'renewables capitalism', as explored with reference to diverse political-economic arenas in other contributions to this Debate.

Ours is a dissident theorization of the urban question insofar as it rejects many of the epistemological, conceptual and spatial foundations that have underpinned much of the last century of research on urbanization (Brenner, 2019; Brenner and Schmid, 2015). Our approach is focused not only upon city-building processes (agglomeration) but upon the sociometabolic preconditions and consequences of such processes under capitalism, understood in relation to the waves of imperialist extractivism, fixed capital formation, sociometabolic intensification and environmental toxification that have ensued since the systematic yet constitutively uneven industrialization and spatial concentration of capital under the fossil-based metabolic regime (Brenner and Ghosh, 2022, forthcoming). This theorization enables us to situate emergent strategies of 'sustainable' urbanism — including those that promote renewable energy systems within cities — within the imperial geopolitical ecologies of planetary urbanization.

Contending with this geohistorical 'context of contexts' is, we argue, a necessary precondition for any effort to address systematically the limits, challenges and potentials of urban sustainable development, within and beyond the 'front stage' of cities and metropolitan regions that are the primary focus of most urbanists. By contrast, we direct attention to the 'hidden abodes' (Conroy, 2023, 2024; Fraser, 2014) of the capitalist form of urbanization — the non-city zones of appropriation, capitalization and waste expulsion that support urban life. These hidden abodes, we argue, constitute the sociometabolic foundations of planetary urbanization (Bašić et al., 2025; Brenner and Ghosh, 2022; Brenner et al., 2025; Ghosh et al., 2023). Any approach to urban sustainability that fails to confront, dismantle and transcend these imperial geopolitical ecologies is likely to be extremely limited in scope and, worse, to leave uninterrogated and unencumbered capital's voracious, crisis-riven drive towards geometabolic escalation, biospheric plunder and eco-apartheid (Cohen, 2020; Kronenberg et al.,

2024; Varvarousis et al., 2024). Indeed, one of the major challenges for any future programme of 'sustainable' urbanization is to develop strategies to counteract and repair the systematic degradation of land and life, ecosystems and populations, within and beyond centres of agglomeration that is immanent to the metabolism of capitalist urbanization.

This line of analysis dissents from the popular futurological assertion that global capitalism is undergoing a singular 'energy transition' in which putatively 'renewable' energy carriers are progressively supplanting the combustion of hydrocarbons. First, the path-dependencies associated with 'carbon lock-in' — capital's expansive, planet-encompassing investment in carbon-intensive infrastructures of extraction, circulation, production and reproduction — represent a major barrier to any system-wide replacement of fossil energy carriers and the machines, equipment, built environments and spatial arrangements that harness them (Malm and Carton, 2024; Seto et al., 2016). Second, following Jean-Baptiste Fressoz's (2024) analysis, we argue that fossil energy carriers are being more intensively woven into a planetarized infrastructural matrix that continues to lock in and further escalate the spatial metabolism of capital in a tightly symbiotic relationship to (an expanding volume of) non-fossil fuel sources (see also Barak, 2020; Malm and Carton, 2024). In this sense, much of the debate on 'energy transitions' (see, for example, Smil, 2010) is premised upon an insufficiently holistic understanding of the intermeshed, path-dependent, and co-evolving infrastructural configurations of the fossil-based metabolic regime, which continuously metabolize flows of matter/energy in order to ratchet up the volume and velocity of capital circulation.

Nor does this analysis uncover any evidence that cities are the 'leading edge' of a currently foreseeable transition towards a renewables-based capitalism or, for that matter, a more sustainable global energy system. Regardless of their energetic foundations, zones of industrial agglomeration around the world remain tightly articulated to the plunder and pollution of non-city territories and environments, both near and far, contributing to the proliferation of 'exhaustion ecologies' that degrade the web of life and destroy the planetary biosphere. This is the metabolic monstrosity that lies at the core of capitalist urbanization in the fossil-based metabolic regime.

From this point of view, we can more clearly recognize the role of urban sustainability discourse in providing ideological legitimization for strategies to erect protected enclaves for privileged segments of urban populations that seek to insulate themselves from proliferating socioenvironmental threats (including extreme weather and emergent infectious disease) as well as disruptive 'incursions' of climate refugees and other dispossessed, 'surplus populations'. Such strategies are not only fantastical — there are no truly 'safe' spaces on a burning planet — but reactionary insofar as they promote and celebrate what is effectively a city-centric, 'greenwashed' form of eco-apartheid. In the absence of strategies to dismantle the underlying imperial-capitalist relations that have produced contemporary forms of

ecocide, social precarization and mass displacement on a planetary scale, urban sustainability will remain little more than a strategy of 'islandization' that advances the infrastructural lineaments of an 'urbicidal Anthropocene' (Wakefield, 2025). Whatever its energetic basis, any form of urbanism that is premised upon capital's ecocidal spatial metabolism is likely to degrade the planetary web of life, and thereby, to destroy the socioecological preconditions of urban existence. Our analysis concludes with some reflections on the prospects for '*alter*-urbanizations' of degrowth, based on circular metabolic relays and ecologies of repair, regeneration and justice, that might circumvent such dystopian futures.

TWO URBAN METABOLISMS AND THE LIMITS TO URBAN SUSTAINABILITY

In debates on the relationship between urbanization and the climate crisis, putative transitions away from fossil fuels are generally explored at a local or regional scale, with reference to the myriad challenges of adapting or retrofitting inherited built environments to downscale energy consumption, minimize carbon emissions and reduce or recycle waste. In some streams of such discussions, there is also an emphasis on the need for new 'green' or 'sustainable' investments in renewable energy infrastructures, generally in conjunction with strategies to increase urban 'resilience' in the face of proliferating climate- and weather-related disasters.[2] Another stream of debate considers the prospects for establishing a circular metabolism by shrinking the 'ecological footprint' of cities through the localization or regionalization of energy, food, materials and waste flows.[3] While such approaches offer salient perspectives on the urban dimensions of climate and energy politics, they are generally premised upon a 'snowglobe' vision of urban metabolism (Cohen, 2020: 54) that fetishizes 'in-city' or proximate activities and brackets the larger-scale, extended metabolic circuits that animate and result from the spatial concentration of population and capitalist operations (see also Wachsmuth et al., 2016). In this sense, the major contemporary approaches to sustainable urbanism disarticulate cities and metropolitan regions from the multi-scalar metabolic relations and infrastructural relays that have long animated the historical geographies of capitalist development and its socioecological crisis tendencies.

Contemporary urban centres are, in fact, tightly embedded within a world economy and planetary biosphere riven by escalating and overlapping forms of turbulence, disruption and disaster. The cascading socioenvironmental violence unleashed through the contemporary 'polycrisis' is often narrated as an external threat against which cities and (some segments of) their

2. For a critical discussion, see Wakefield (2025).
3. For a critical discussion, see Bassens et al. (2020).

populations must be protected. Increasingly, however, the materializations of contemporary climate and nature emergencies are being 'internalized' within cities and metropolitan regions as their impacts — from novel infectious diseases, extreme weather, toxic air, flooding and megafires, among others — shatter the everyday life-worlds of urban populations, degrade or destroy inherited built environments and threaten essential supply relays.[4] Just as crucially, the devastating sociomaterial impacts of such proliferating crises in the 'global countrysides' (Beckert et al., 2021) of the capitalist world system intensify longstanding forms of depeasantization, immiseration and displacement historically associated with imperial and neo-colonial relations of enclosure and commodification (Araghi, 2009). These processes accelerate the production of 'surplus' populations and their expulsion into large population centres as climate refugees. Such developments drastically intensify stress on local infrastructures of public service provision, which have been severely degraded through previous rounds of neoliberal defunding and underfunding in urban governance systems around the world.

Two decades ago, Mike Davis referred to the threat of avian flu as 'the monster at our door', only to revise that formulation amidst the COVID-19 pandemic with the grim pronouncement, 'the monster enters' (Davis, 2005, 2020). We might extend Davis' metaphor to investigate the monstrous threats cities face in a time of cascading climate and nature emergencies. In fact, the 'monster' — an apt metaphor for the socioenvironmental violence endemic to capital's spatial metabolism — was never relegated to an 'exterior' realm from which cities could have safely insulated themselves. It was only through ideologies and strategies of ecological imperialism that such a misleading proposition could have been embraced across generations of urban scholarship. Indeed, the myth of 'externalization' — the idea that the roots of planetary environmental crisis lie outside cities or are only contingently related to the capitalist form of urbanization — may be *the* urban ideology of our time. As we witness on a near-daily basis in the constantly intensifying ricochet of environmental disasters in metropolitan regions around the world, the zoonotic diseases, floods, heatwaves, megastorms and megafires of our time are oblivious to the supposed boundary between cities and their 'exterior'. And yet, this inherited, city-centric epistemology of the urban (Brenner and Schmid, 2015) — the vision of the city as a bounded settlement type and self-propelled agglomeration

4. Originally developed by complexity theorists Edgar Morin and Anne Brigitte Kern (1999), the notion of polycrisis has been popularized in recent years by economic historian and social theorist Adam Tooze. For present purposes, we adopt the polycrisis concept as a shorthand to describe the multidimensional, mutually reinforcing political-economic and environmental crises of the 21st century. Amidst the many ongoing debates regarding the sources, expressions and politico-epistemological implications of these intermeshed crisis tendencies, we concur with Adam Tooze's (2025) core proposition that 'the ecological crisis now must be the pace-setter and the paradigm of all other critical thinking'.

economy — continues to serve as the ideological foundation underlying major streams of research, discourse and practice on urban sustainability.

The prospect of biospheric breakdown on a planetary scale — the worldwide 'space of catastrophe', in Henri Lefebvre's prescient formulation a half-century ago (Lefebvre, 1976/2009: 246-9) — has always been a ubiquitous horizon immanent to the capitalist form of urbanization. This is because the plunder of non-city territories and the expulsion of waste back into the biosphere are necessary concomitants of industrial city-building processes under modern, fossil-fuelled capitalism. In the early 20th century, Lewis Mumford (1938: 232) recognized this point with his vivid reference to the 'voracious mouth of the imperial metropolis', a formulation that underlined the thoroughly imperial, militarized origins of the modern industrial city and its role in inflicting an 'un-building' (*Abbau*) upon inherited landscapes and, indeed, major segments of the planetary biosphere. But, as with Lefebvre's articulation of capitalist urbanization to a planetary horizon of collapse and destruction, Mumford's account of city building and the vicissitudes of un-building remains but a dissident footnote within the canon of urban social science.

We argue, by contrast, that the transformation and degradation of non-city territories and environments must be understood as 'internal relations' — in the dialectical sense of this term (Levins and Lewontin, 1985; Ollman, 2003) — of capitalist urban agglomeration rather than as secondary or contingent byproducts of this process (Brenner and Ghosh, 2022, forthcoming). It is in this sense that we need to develop an 'urban theory without an outside' — that is, an urban theory that does not demarcate its object of investigation by positing an inside/outside dualism and by reifying concomitant binaries such as city/hinterland, urban/rural, or human/non-human (Angelo and Goh, 2022; Angelo and Greenberg, 2023; Brenner, 2018, 2014).

At least since the consolidation of the fossil-based metabolic regime (Pineault, 2023; hereafter, FMR) in the last three decades of the 19th century, the geometabolic dynamics of capitalist urbanization have assumed planetary dimensions, at once transformative and destructive. This was a period of systemic, planet-encompassing territorial, infrastructural and socioenvironmental restructuring, marked, *inter alia*, by the rapid, mutually reinforcing expansion of steam-powered transportation infrastructures and telegraph communication (including, decisively, the opening of the Suez Canal in 1869); the emergence of new scales of vertically integrated, fossil-fuelled industrial production in the metropolitan regions of Euro-America; the extension of the imperial periphery through new waves of territorial enclosure, resource extractivism, large-scale infrastructuralization and land-use simplification; a worldwide reshuffling of the geographies of primary commodity and primary energy production; and the consolidation of a global agrifood system (Banaji, 2020; Barak, 2020; Beckert et al., 2021; Campling and Colas, 2021; McMichael, 2014; Friedman and McMichael,

1989; Otter, 2021).[5] Taken together, these intermeshed infrastructural, logistical and territorial transformations contributed to an unprecedented acceleration in the turnover time of major circuits of capital (related to primary commodities as well as manufactured commodities) and, more generally, a drastic escalation in the volume and velocity of *metabolic throughput* on a planetary scale — a massive expansion in the system-wide circulation of matter/energy and labour-power being churned into, transformed and dissipated through infrastructural circuits as value-in-motion (or, more precisely, value-being-*metabolized*).[6]

The *differentia specifica* of this watershed in the geohistory of capitalist urbanization was thus not simply the accelerated agglomeration of industrial capital (Harvey, 1985) or its systematic deployment of fossil energy to discipline the urbanized proletariat (Malm, 2016), but a historically unprecedented transformation of the metabolism of urbanization itself. Within the nascent FMR, the metabolism of city-building processes was no longer primarily a problem of biopolitical management and social reproduction (the biological survival of spatially concentrated populations) but became *a lever for the intensified metabolic throughput of capital* and as such, in Andreas Malm's (2016: 218) apt formulation, 'the bedrock for the biospheric universalization of capitalist rule'. We may thus refer to the 'two metabolisms' of the fossil-fuelled city — that of (1) biopolitical reproduction; and that of (2) the escalating throughput of matter/energy in support of capital's expanded reproduction.

The first metabolism is focused upon the reproduction of the city (a relatively circumscribed zone of concentrated population and built structures); the second involves the expanded reproduction of capital (in which the city serves as a site of metabolic throughput intensification within an extended circuit or 'commodity chain' oriented towards the colonization and operationalization of segments or patches of the planetary biosphere).

5. Our periodization of the consolidation of the FMR is broadly aligned with Jason W. Moore's world-historical characterization of the past two centuries as the period of a 'long fossil boom' (Moore, 2018: 268). In our account, the dramatic expansion in energy production and consumption that marked the post-World War II decades — a conjuncture that is often euphemistically described as the 'Great Acceleration' — was premised on an imperial formation of sociometabolic relations that was forged in the late 19th century. For a critical discussion of the concept of the Great Acceleration, see Bonneuil and Fressoz (2016), Görg et al. (2020) and Pineault (2023). In critical dialogue with the concept of the 'Long Acceleration' developed by Fredrik Albritton Jonsson and Moritz von Brescius (forthcoming), which locates the roots of late-20th century environmental emergencies in sociohistorical transformations during the period between 1870 and 1914, we describe this formation as the 'Long Intensification' insofar as it was premised upon both an accelerated *velocity* and an expanding *volume* in the metabolic throughput of capital (Brenner and Ghosh, forthcoming). Our account centres the role of novel forms and scales of fixed capital in animating the drastically intensified metabolism of capital during this period and subsequently.
6. For useful perspectives on matter/energy throughput intensification under capitalism, see Burkett (2006) and Daly (1985).

The changing relation among these analytically distinct yet operationally intermeshed metabolic moments of capitalist urbanization has myriad implications for questions of conceptualization and periodization (Ghosh and Meer, 2021: 1111–12; Nightingale, 2022) and for deciphering the role of cities within the polycrises of global capitalism. In effect, with the consolidation of the FMR, the metabolic load of industrial agglomerations increasingly involved operationalizing the labour power (and thus the biopolitical reproduction) of a spatially concentrated population to support a progressively *escalating spatial metabolism of capital* within extended circuits of accumulation and biospheric destruction.

Under these geohistorical conditions, the metabolism of capitalist urbanization (in both of the above-mentioned senses) came to encompass not only city-building processes but also the organization and continual restructuring of vast *non-city* realms oriented towards (a) the appropriation of unpaid matter/energy and unpaid/underpaid labour power; (b) the uneven capitalization of extraction, agricultural production and other forms of primary commodity production; and (c) the absorption of escalating streams of pollution and increasingly toxic waste from centres of population and industrial concentration. These variegated, path-dependent dynamics cannot be adequately grasped simply as evidence of a 'metabolic rift' in which cities are thought to disrupt an exterior nature located in the 'countryside' (Foster, 2000). Rather, the processes under discussion here are more precisely theorized as a *metabolic churn*, a multi-scalar, multi-directional dynamic of socioecological restructuring, land-use intensification, infrastructural extension and landscape transformation engendered across the planet (we might speak of planetary 'terraformation') as zones of agglomeration and their non-city zones of support and impact begin to co-evolve even more intensively within an emergent, continually-evolving and conflict-ridden web of energetic/material relays.[7]

This contradictory, ecocidal dynamic of geometabolic escalation underpins the *longue durée* geohistory of capitalism (Moore, 2015), but it is under the FMR that it is progressively intermeshed with the process of capitalist urbanization and thus increasingly materialized in an extended infrastructural meshwork of city/non-city relations. The capitalist urban fabric thereby becomes a planetary matrix in which capital's spatial metabolism of plunder, productivity and pollution is at once organized, channelled and continually intensified.

Under these conditions, even if their geographies are dispersed in territories often located at quite some remove from major metropolitan centres, the various non-city 'hidden abodes' of appropriation, capitalization and waste/toxification that support city-building processes are *constitutive* relations of fossil-fuelled urbanization and its logic of metabolic throughput

7. This argument is elaborated at length in Brenner and Ghosh (2022, forthcoming).

intensification. The proliferating dislocations associated with contemporary forms of biospheric crisis are thus not 'intrusions' into urban life from a putatively exterior realm (labelled, for example, as the 'hinterland', the 'rural', the 'natural', or 'wilderness'). They are better understood as symptoms — and antagonistic expressions — of a *transformed configuration of the capitalist urban fabric* defined by emergent, qualitatively new articulations between zones of agglomeration and their variegated, non-city hidden abodes of productivity, plunder and pollution on a planetary scale. These relations are being tendentially reworked in a context of proliferating social and ecological crises, but also under conditions in which powerful geopolitical forces, myriad state and parastatal institutions and transnational capitalist alliances seek to entrench and further extend the very fossil-fuelled infrastructural matrices whose geometabolic dynamics underpin the major climate and nature emergencies of our time (Christophers, 2024; Malm and Carton, 2024).

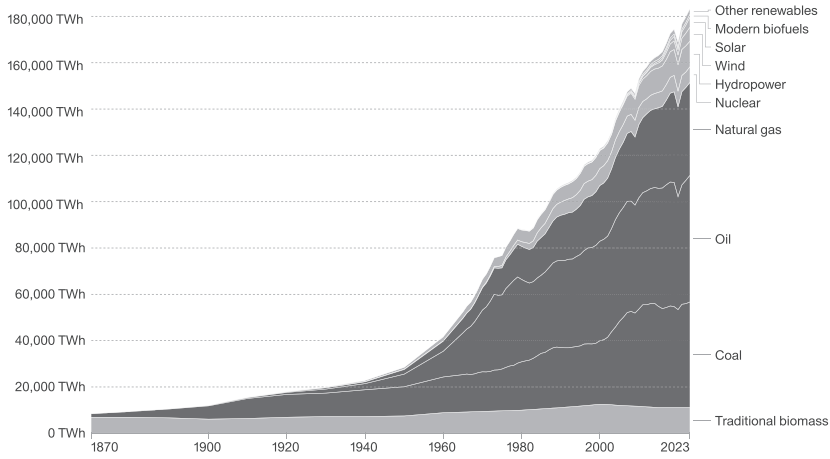
The monster, then, was never 'outside' or even lurking 'at our door'; it has been an internal relation of the capitalist form of urbanization and its 'thano-metabolic' (Gandy, 2023: 2535) drive towards biospheric universalization and degradation. The challenge is to develop a framework of analysis that can illuminate this transformed configuration of the capitalist urban fabric and the multiple determinations through which it mediates, animates and is transformed through proliferating social and biospheric crises. It is on this basis that we might critically evaluate the prospects for delinking from that configuration at any spatial scale or, more generally, restructuring the thano-metabolic relations upon which the FMR is grounded. These are urgent questions to which we return at the end of this article.

ENERGY ADDITIONS AND THE SPATIAL METABOLISM OF CAPITAL

In order to decipher the role of cities and urbanization in contemporary transformations of capital's spatial metabolism, we may begin with some broad generalizations regarding the changing energy mix that undergirded the long fossil boom and continues to define the current geoeconomic conjuncture. As Andreas Malm and Wim Carton (2024) have recently argued, post-COVID capitalism is characterized by a dramatic expansion in the rate of investment in fossil fuel infrastructure coupled with corporate, state and geopolitical-imperial strategies to escalate the rate of economic growth in each of the major regional centres of global capitalism (Euro-America, East Asia and the BRICS countries). These dynamics are quite consistent with longer-term historical trends of symbiotic energy additions (Fressoz, 2024; York and Bell, 2019) that have characterized the FMR since its consolidation and that have substantially deepened since the mid-20th century.

As Figures 1 and 2 illustrate, the ever-intensifying metabolic throughput of fossil fuel-based energy systems has been advanced historically through

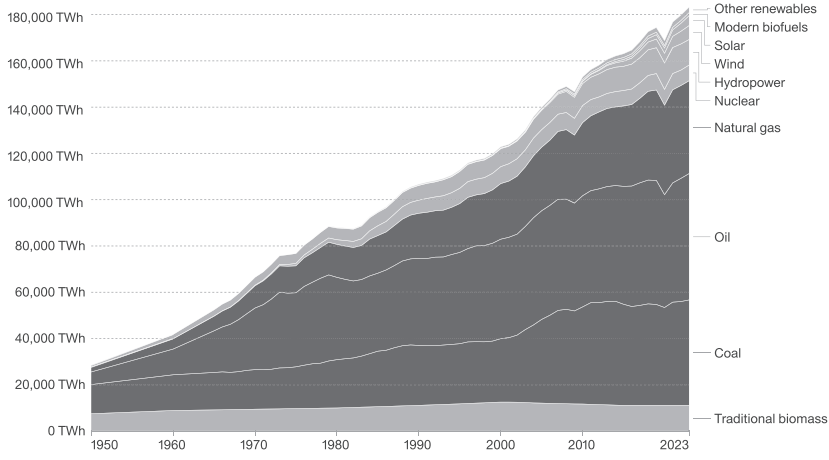
Figure 1. Global Primary Energy Consumption by Source, 1870–2023



Note: Primary energy is measured in terawatt hours. The dark bands correspond to the changing volumes of fossil fuel consumption — coal, oil and natural gas.
Source: Prepared by Willis Kingery based on OurWorldinData.org/energy.

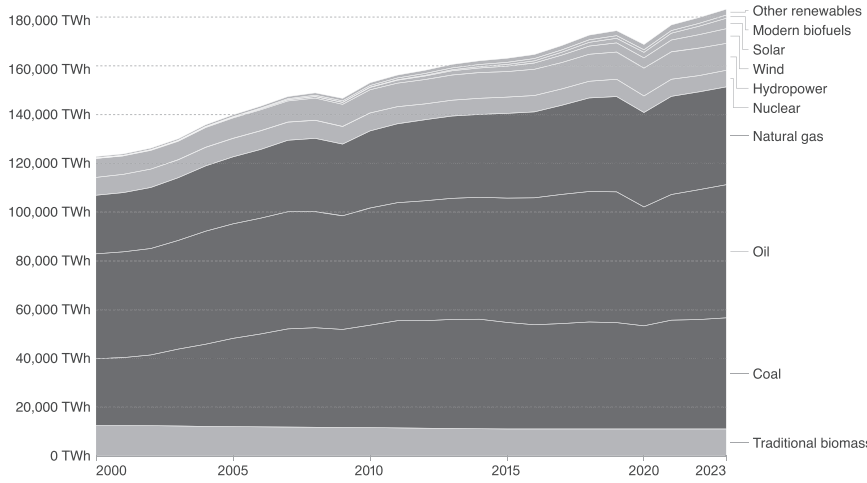
the combination of a shifting mix but expanding *absolute* volume of energy sources that are canalized into, processed, distributed and dissipated through a worldwide infrastructural matrix that materializes capitalist value relations across time and space. These energy sources include traditional biomass,

Figure 2. Global Primary Energy Consumption by Source, 1950–2023



Note: Primary energy is measured in terawatt hours. The dark bands correspond to the changing volumes of fossil fuel consumption — coal, oil and natural gas.
Source: Prepared by Willis Kingery based on OurWorldinData.org/energy.

Figure 3. Global Primary Energy Consumption by Source, 2000–2023



Note: Primary energy is measured in terawatt hours. The dark bands correspond to the changing volumes of fossil fuel consumption — coal, oil and natural gas.
Source: Prepared by Willis Kingery based on OurWorldinData.org/energy.

coal, oil and natural gas, as well as nuclear power (post-1970s) and various 'renewables' (especially post-1990s) such as hydropower, wind, solar and other biofuels. Figures 1 and 2 depict two longer time scales — 1870 to the present (the general period of the FMR); and 1950 to the present (the period generally characterized as the 'Great Acceleration'). Figure 3 depicts the 21st century to date (2000–24). The latter dramatically illustrates that, from a planetary perspective, the supposed 'transition' to renewable energy in recent years has not at all undercut the secular expansion of fossil energy consumption. On the contrary, renewable energy carriers have *supplemented* the continuously expanding production and consumption of fossil fuels. The COVID years were merely a brief interruption in system-wide metabolic throughput intensification, with fossil fuels as its primary energy carrier.

The dynamics of the long fossil boom — which we characterize as the 'Long Intensification' (Brenner and Ghosh, forthcoming) — are unevenly developed across global regions, some of which have indeed undertaken a significant recalibration of their energy systems away from fossil fuels, even as others have drastically intensified their use of fossil-fuelled machines, equipment, buildings and infrastructures. But, despite the widespread adoption of the Paris Agreement in 2015, the evidence on global aggregate trends undermines assertions that a linear 'energy transition' to renewables is underway or likely to transpire in the near future (Smil, 2010). Seen in this light, the narrative of an energy transition is a crude distortion of reality promoted by fossil capital itself and by myriad client states of the carbon majors, including those most centrally implicated in the massive upscaling

of fossil-based primary energy (especially oil) production such as the Gulf states (see Hanieh, this issue, 2025). As Adam Tooze (2025) explains in a review of Fressoz's (2024) recent work (emphasis added):

> When we look more closely at the historical record, it shows not a neat sequence of energy transitions, but the accumulation of ever more and different types of energy. Economic growth has been based not on progressive shifts from one source of energy to the next, but on their *interdependent agglomeration*. Using more coal involved using more wood, using more oil consumed more coal, and so on. An honest account of energy history would conclude not that energy transitions were a regular feature of the past, but that what we are attempting — the deliberate exit from and suppression of the energetic mainstays of our modern way of life — is without precedent.

As Malm and Carton's analysis demonstrates, the dynamics of the Long Intensification have in no way been interrupted or downscaled in the post-COVID era but continue unabated and even appear to be ratcheting up in the current context of escalating geopolitical tension and geoeconomic competition. The precise forms of 'interdependent agglomeration' among myriad energy carriers associated with these dynamics of geometabolic escalation remain a matter of intense geopolitical negotiation and contestation. However, historical trends suggest that the introduction of new forms of hydro, solar and wind power is likely to continue to supplement the secular expansion in fossil energy use while substantially contributing to the longer-term drive of capital to escalate its metabolic throughput in pursuit of endless, profit-driven economic growth.

Renewable forms of energy, then, are further 'revving up' the spatial metabolism of capital 'on top' of the momentum generated through the tendentially expanding deployment of fossil fuels. They have, in effect, created an additional cog in the accelerating gears of capitalist metabolic throughput, contributing to (a) faster *velocity* and expanded *volume* of matter/energy-in-transformation in and through infrastructural relays; and (b) an associated escalation in the discharge of waste — including carbon emissions — into the biosphere. The symbiotic intermeshing of renewable and fossil-based energy carriers is thus serving as a powerful mechanism of capitalist geometabolic escalation rather than as a form of 'greening' that would phase out hydrocarbons or coal. As such, there is no evidence to date that the global expansion of renewable energy consumption or the consolidation of a renewable energy sector, substantially supported through key streams of finance capital, has contributed to a downscaling of metabolic throughput in any major global region.

In sum, then, the generalization of fossil energy carriers (coal, petroleum, natural gas) during the 20th century has massively escalated the demand for non-fossil fuels, including wood, nuclear energy and, most recently, renewables. Expanding energy use has also animated a drastic growth in the extraction of a range of primary commodities (especially wood and biomass) and in the industrial production of synthetic materials (such as steel, concrete, plastics and synthetic fertilizers) that are likewise central to

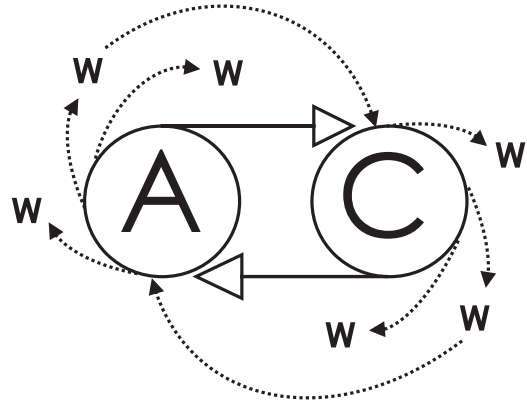
the spatial metabolism of capital (Fressoz, 2024; see also Hanieh, 2021). The unprecedented secular expansion of oil and gas consumption during the last half-century has at once animated and been further impelled by an increased use of coal as well as the integration of new forms of solar and wind power into major circuits of capital. There is thus no linear transition underway towards a renewables capitalism, but a symbiotic intermeshing of supposedly 'green' energy sources with an uninterrupted escalation in the extraction and combustion of fossil fuels.

Meanwhile, despite the increasingly catastrophic impacts of global heating upon planetary life, the carbon majors and their governmental and financial backers are currently making massive investments and constructing new legal-regulatory protections to expand their capacities to extract, process and distribute fossil energy for decades to come, even as some portion of their investment portfolios are diversified to include renewable energy assets (Malm and Carton, 2024). Consequently, any analysis of renewables capitalism is obliged to reckon with two sobering facts: (1) The production of renewable energy during the last three decades has been entirely compatible with a continued expansion and intensification of fossil fuel use while also (2) actively contributing to geometabolic escalation on a planetary scale.

These observations impel us to situate the energetics of capital accumulation within a broader conceptualization of capital's historically specific spatial metabolism. To this end, we build upon Jason W. Moore's (2015) approach to capitalist world-ecology to analyse the transformation of energy/matter under capitalism, not simply in terms of the power density or thermodynamic properties of specific fuel sources — fossil-based or otherwise — but as a medium and expression of the spatial metabolism of capitalist value relations (see also Burkett, 2006). The key issue at stake here is capital's endemic drive to intensify metabolic throughput in pursuit of endless accumulation.

As used here, 'metabolic throughput' refers to the entropic metamorphosis and flow (in the literal sense of *Stoffwechsel*) of matter/energy from the moment of extraction through that of productive consumption to disposal or expulsion. In contrast to the substance-fetishist understandings of throughput that prevail in industrial ecology, we use this concept to decipher the historically specific socioecological dynamics of capitalist value relations and their pulsating, crisis-riven geographies. Thus understood, the metabolic throughput of matter/energy under capitalism is thoroughly mediated by the imperative to increase the productivity of labour *and* the concomitant drive to endlessly ratchet up the extraction and appropriation of unpaid/underpaid work from nature, leading in turn to an equally exponential expansion of (increasingly toxic) waste streams expulsed into the biosphere. Much like the appropriation of unpaid matter/energy from nature (Moore, 2015) and the expropriation of unpaid/underpaid work from 'othered' humans (Conroy, 2023; Fraser, 2014), the 'accumulation of waste' is a negative dialectic at the heart of capitalist value relations (Kadri, 2023; see also

Figure 4. Metabolic Throughput Intensification under Capitalism (A = appropriation; C = capitalization; W = wasting)



Gidwani, 2013). Reflecting on this destructive geometabolic spiral, Moore (2022: 7) posits a 'general law of overpollution' that 'makes increasingly toxic accumulations a "necessary condition" of the endless accumulation of capital'. Therefore, the drive to escalate metabolic throughput under capitalism is not a universal or transhistorical thermodynamic process, but constitutive of specifically capitalist value relations (Burkett, 2006; Burkett and Foster, 2006; Foster and Holleman, 2014).

This drive entails, on the one hand, ceaseless waves of capitalization (C) in which specific configurations of fixed capital are established to ratchet up the volume and velocity of circulation. Just as crucially, the escalation of metabolic throughput by means of capitalization hinges upon 'upstream' waves of appropriation (A) in which progressively larger volumes matter/energy are appropriated from nature, canalized into the circuit of capital and expulsed back into the biosphere further 'downstream' as dissipated, often toxified waste (W). Building upon Moore's (2016) framework, we conceptualize this dialectic of appropriation, capitalization and wasting (A-C-W) as constitutive of the 'gravitational field' of capital's value relations (Figure 4).

This drive towards geometabolic intensification hinges upon a socioecological spiral — a metabolic *churn* — in which 'free gifts' of matter/energy are appropriated from nature and dissipated 'free waste' is projected back into the biosphere over successive systemic cycles of capital accumulation (Battistoni, 2025; Moore, 2015). It is due to the 'bad infinity' of the latter processes (Harvey, 2017) — whose socioecological dimensions are manifested as an endless drive for 'more and more and more' (Fressoz, 2024) — that capitalist urbanization assumes a thano-metabolic form. This entails, in Moore's (2022: 1) formulation, the 'absurd and horrific logic of squandering and devaluing the wealth of human and extra-human life under the law of value'. In other words, even before this appropriation/wasting process (a

dialectic of plunder and pollution) inflicts life-threatening damage upon humanity and induces the progressive extinction of myriad non-human life forms, it contains an immanently life-destroying tendency due to its systemic incapacity to regenerate the biospheric and social preconditions for its own reproduction (Battistoni, 2025; O'Connor, 1998). What results, therefore, is a linear metabolism rather than a regenerative one (Barles, 2010) — a circumstance that is highly consequential as we consider below the prospects for a 'renewables' capitalism and/or post-capitalist alternatives to the FMR, whether based upon a tendentially post-fossil energy mix to support a continued 'bad infinity' of endless accumulation, or *alter*-metabolisms that might interrupt or transcend this thano-metabolic drive and repair the profound damage it has inflicted upon the fabric of social life and the biosphere.

INFRASTRUCTURE, FIXED CAPITAL AND THE RATCHET EFFECT IN THE LONG INTENSIFICATION

Within and beyond urban agglomerations, infrastructure is an essential precondition, medium and outcome of the processes of metabolic throughput intensification outlined above. From a sociometabolic perspective, infrastructure provides a relatively fixed scaffolding through which flows of matter/energy may be extracted, processed, circulated and, eventually, expulsed back into the biosphere as waste. Within the world-ecology of capitalism, infrastructure is not simply an immobile stock that supports flows of matter/energy across the Earth, but operates as a form of *fixed capital* that is dynamically embedded within the gravitational field of value relations, underpinning its socioeconomic imperatives, metabolic pulsations and crisis tendencies (Ekers and Prudham, 2018; Harvey, 1982). Three intermeshed dimensions of these operations and their distinctive geographies may be distinguished as follows:

1. *Infrastructure as produced nature*. Infrastructure as fixed capital congeals earlier rounds of social labour and appropriated matter/energy to create *in situ* spatial configurations — machines, buildings, docks, ports, canals, bridges, dams, roads, energy grids, pipelines, and so forth — that are utilized over successive cycles of capital valorization rather than being immediately exhausted in a single production cycle or directly exchanged as commodities (Marx 1939/1993: 721). Infrastructure as fixed capital thus represents a form of 'produced nature' insofar as, in Michael Ekers and Scott Prudham's (2018: 21) formulation, it entails the 'transformation of various biophysical materials and processes into conditions of production'. The spatial configurations associated with infrastructure as fixed capital materialize social labour (including forms of techno-scientific knowledge and ideology) within built environments, territorialized equipment and terraformed

landscapes that support and animate the metabolism of capital: they are thus 'lively ecologies' that at once embody the social labour required to produce them, facilitate the turnover of commodity and money capital and animate further cycles of socionatural transformation through the continued application of social labour in the churning metabolism of value relations (ibid.).

2. *Infrastructure as a metabolic ratchet*. In the widely debated 'Fragment on Machines' in the *Grundrisse*, Marx (1939/1993: 715; translation modified) posits that fixed capital serves as a 'produced productive force' (*produzierten Produktivkraft*) that 'cannot grow without the raw material it works on also growing'. Consequently, the consolidation of progressively larger-scale configurations of fixed capital requires a 'constant flow' of matter/energy from mines, fields and other sites of resource appropriation to ensure the continuity of capitalist production and stable social reproduction (ibid.: 703). The role of fixed capital in escalating the volume and velocity of biophysical appropriation (of fuel, food and raw material alike) also intensifies the dissipation of waste from the circuit of capital back into the biosphere. In this sense, configurations of fixed capital not only canalize biophysical flows, but operate as levers to ratchet up the system-wide metabolic throughput of capital. As Ekers and Prudham (2018: 22) explain, 'fixed capital formation, understood as the physical congealment of accumulated ecologies and historical-geographical labour processes, goes hand in hand with the expansion, intensification and transformation of material processes of resource flow and waste production'. The 'produced productive forces' associated with fixed capital thereby unleash a 'ratchet effect' that at once locks in specific volumes and velocities of material transformation (*Stoffwechsel*) and engenders their continuous escalation to support the metabolism of valorization — the endless drive toward 'more and more and more' (Fressoz, 2024) that underpins and animates capital's spatial metabolism.[8] Under these conditions,

8. We are grateful to Fredrik Albritton Jonsson for productive discussions of his closely related historical elaboration of the ratchet effect to decipher the birth and consolidation of a fossil economy in 18th- and 19th-century Britain (developed at length in his forthcoming book — see Jonsson, forthcoming). Pineault (2023: 49) develops a broadly analogous account of what he terms 'throughput effects' — 'the command [material stocks] exercise over flows'. As Pineault (2023: 49–50) observes, 'once in existence, the specific form and volume of material stocks further commands and locks in flows that further determine both the mass (scale) and the composition of the throughput'. Despite his use of the somewhat conventional terminology of industrial ecology — stocks and flows — Pineault's account insists, much like our own, that 'the substance of the throughput is more complex than what can be reduced to tonnes and joules … It sheds and dons successive social forms and most imply biophysical transformations'. To this we add that the metabolic throughput is mediated through spatially articulated configurations of fixed capital infrastructure — in our terms, the capitalist urban fabric — the construction and evolution of which are essential to the imperial geopolitical ecologies of capitalism on a planetary scale. Albritton Jonsson's

as Marx (1939/1993: 703) observes, the relays of ever-escalating biophysical appropriation and wasting engendered through the operations of fixed capital come to serve as an 'externally compelling condition' (*äußerlich zwingende Bedingung*) for the reproduction of social life. The drive towards metabolic throughput intensification is woven into the infrastructures of accumulation across the planet. Fixed capital is thus not simply a basis for commodity production but also materializes the power of capital over biophysical processes, territorial organization and socioecological reproduction itself (Mau, 2023).

3. *Infrastructure as a site and medium of socioecological crisis formation*. Even as they canalize and escalate the metabolization of biophysical flows, configurations of fixed capital also figure crucially in the formation and spatialization of crises across the gravitational field of value relations. On the one hand, the channelling of investments into infrastructures — the very creation of 'produced productive forces' in the form of fixed capital — is often a strategy to absorb surpluses that cannot be profitably redirected back into extant circuits of accumulation. Under these conditions, infrastructures may serve to soak up surplus capital while establishing the territorial conditions for a further ratcheting up of metabolic throughput, including accelerated, upscaled relays of biophysical appropriation, capital-intensive industrial processing and wasting/toxification (Ekers and Prudham, 2018; Harvey, 1982). On the other hand, the role of infrastructural configurations and terraformed landscapes as 'socioecological fixes' (Ekers and Prudham, 2018) may unleash a variety of socioeconomic and biophysical crisis tendencies that threaten such 'produced productive forces' with premature devalorization. As the volume and velocity of biophysical appropriation are ratcheted up through the forward-motion of capitalization processes, essential inputs of matter/energy may be systematically underproduced relative to the rising throughput demands of capital. This engenders a declining rate of world-ecological surplus that squeezes profit rates and undermines the viability of extant fixed capital investments (Moore, 2015). Underproduction crises (source depletion) may also be conjoined to crises of overpollution (sink saturation) that proliferate as dissipated, toxified streams of waste erode the biophysical and social preconditions for the production of capital, effectively operating as a brake on accumulation in the form of 'negative value' (Moore, 2015: 268–69; Pineault, 2023: 115, 131). While spatial infrastructures may thus sometimes provide a 'sink for surpluses of over-accumulated capital' (Ekers and Prudham,

historical account likewise directs extensive attention to fixed capital investments (such as mines, canals, railroads, ports, warehouses, factories and buildings), which he productively relates to diverse sociopolitical imperatives, including extractivism, commodity circulation, military logistics and social reproduction.

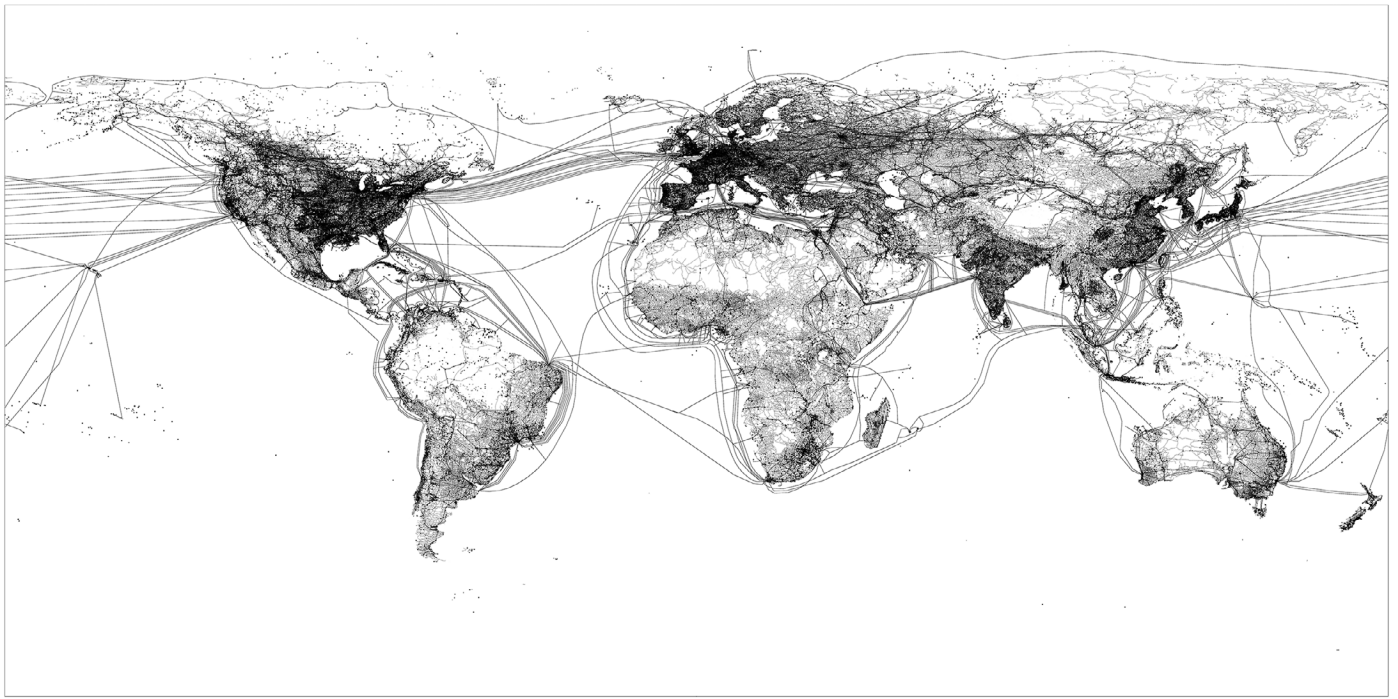
> 2018: 19), they may also operate as arenas and animators of devalorization through various pathways of socioecological crisis formation. Fixed capital configurations are, in this sense, fully ensnared within the core socioecological dynamics, contradictions and crisis tendencies of capitalist value relations.

As a planet-encompassing spatial matrix in which configurations of fixed capital crystallize and evolve, the capitalist urban fabric includes the infrastructural configurations and metabolic relays associated with (a) cities and metropolitan agglomerations; (b) the operational landscapes of capitalized extraction, primary commodity production (mining, agriculture, forestry) and energy processing that support them; and (c) the logistics circuits that channel matter/energy and waste to and from agglomeration centres and other zones of capitalization. It also includes (d) the hidden abodes of biophysical appropriation; and (e) the sacrifice zones of wasting/toxification that support capital's metabolic pulsations within and beyond centres of agglomeration (the imprints of the latter are most evidently materialized in land cover and land use rather than in infrastructural formations). Taken together, these intermeshed zones form an uneven, dynamically evolving geography of infrastructures, engineered land-use configurations, terraformed resource landscapes and plundered ecosystems that supports and continuously ratchets up the metabolic throughput of capital while also intensifying the various socioecological crisis-tendencies unleashed through that dynamic.

The visualization presented in Figure 5, constructed by our Urban Theory Lab collaborator Nikos Katsikis, offers a synthetic representation of this planetary assemblage of interlaced, mutually recursive built environments, infrastructural configurations and sociometabolic relays: it represents the major forms of fixed capital infrastructure and their spatial articulations across the planet, including urban agglomerations, built-up space (impervious surfaces), airports, roads, railways, mining sites (including for minerals, oil and natural gas), electricity grids, energy production plants, pipelines, ports, irrigation systems, dams and submarine cables (Figure 5).[9] This is not an exhaustive visualization; it brackets, for example, subterranean and aerial fixed capital, as well as the accretion of waste landscapes across the planet. Nonetheless, the mottled web of intermeshed agglomerations, operational landscapes and infrastructural relays depicted in Figure 5 conveys the sheer magnitude of fixed capital that has come to be stretched across and embedded in the Earth's so-called 'critical zone' (Latour and Weibel, 2020) over the past two centuries.

9. On this conceptualization of the capitalist urban fabric, see Brenner (2019) and Brenner et al. (2025). This socioterritorial matrix has also been more generically described as the 'technosphere' by Haff (2014) and Zalasiewicz et al. (2017). For discussions of the technosphere concept in relation to urban studies, see Gandy (2022) and Otter (2017).

Figure 5. Fixed Capital Embedded in the Planetary Built Environment



Source: Nikos Katsikis, Urban Theory Lab and TU Delft; for data sources see Appendix.

The interwoven tendrils of this web are the materializations of a series of transformations of fixed capital that, in Marx's (1867/1990: 506) classic analysis of machinery and large-scale industry, ricocheted across the social division of labour during the successive technological revolutions of the 19th century, at once within manufacturing sectors and newly chemicalized terrains of agricultural and livestock production, as well as in the 'means of communication and transport', which he conceptualized as the 'general conditions of the social process of production'. According to Marx (ibid.: 506), the 'feverish velocity' (*fieberhaften Geschwindigkeit*) of emergent forms of steam-powered production engendered recursively 'immense transformations' of fixed capital that were materialized in a new logistics matrix of 'river steamers, railways, ocean steamers and telegraphs'. In the second half of the 19th century, these vast terraqueous networks of steam-powered transportation and communication facilitated the expansion of the imperial periphery, deepened colonial relations of land enclosure and agricultural commercialization, integrated new frontiers of mineral extraction and projected the commodity form across ever greater distances, larger scales and more extended territories. The 'general conditions of social production' were thus materialized within an uneven, planet-girding infrastructural matrix that intensified and accelerated biophysical flows into and out of the circuit of capital. It was this infrastructurally animated process of plunder, productivity and pollution that unleashed the drastically escalating 'un-building' (*Abbau*) of the Earth (Mumford, 1938) throughout the long fossil boom.

In Marx's conceptualization, the increasingly high-velocity and planetarized scope of capitalist operations during this period hinged upon a world-historical transformation in the sociometabolic dynamics of fixed capital formation. This shift is only partially captured in the progressively expanding role of the steam engine as a 'prime mover capable of exerting any amount of force, while retaining perfect control' (Marx, 1967/1990: 506). More generally, in Marx's (ibid.: 506) evocative formulation, the 'feverish velocity' and expanded scale of steam-powered capitalist production and circulation during this period hinged upon the creation of 'machines of Cyclopean dimensions' that could channel 'the huge masses of iron that had now to be forged, to be welded, to be cut, to be bored and to be shaped'. At issue here was not only the 'Cyclopean' scale of the steam-powered machinery, equipment, buildings and infrastructure that were now being deployed to channel and operationalize biophysical flows, but the production of large-scale machines *by means of* large-scale machines — 'machinofacture', in Ernest Mandel's (1975) later terminology — as the technical basis for establishing and maintaining the general conditions of social production. Fixed capital, the product of social labour, was thereby congealed into a fossil-fuelled infrastructural matrix whose elements were recursively intermeshed such that, as Marx (1967/1990: 505) explained, the 'transformation of the mode of production in one sphere of industry necessitates a similar transformation of other spheres'. Under these

conditions, fixed capital infrastructures were at once upscaled to 'Cyclopean' proportions to support the 'feverish' intensification of capital's metabolic throughput and came to operate as prime movers that appeared exterior to the physical capacities and cooperative strategies of workers, confronting them instead as an 'entirely objective organization of production', its material and environmental preconditions (Marx, ibid.: 504, 508).

In effect, Marx's account of machinery and large-scale industry demarcates the lineaments of an emergent formation of capital's spatial metabolism that has underpinned the production of large-scale infrastructures throughout the long fossil boom. Flows of matter/energy are thereby appropriated and canalized from nature on ever-expanding scales, not only to support the production and circulation of commodities and capital, but to establish recursively intermeshed, colossally scaled infrastructures that serve to animate and continuously escalate that process. Marx elsewhere (1894/1991: 756, 757) uses the highly suggestive term 'earth-capital' (denoted variously in his texts in French as *la terre-capital* and in German as *Erde-Kapital*) to describe the embedding and incorporation of fixed capital into the Earth and the concomitant remaking of the Earth itself into a form of intensively terraformed fixed capital.

The essential concept of *la terre-capital/Erde-Kapital* requires more systematic elaboration elsewhere (Brenner and Ghosh, forthcoming). For present purposes, we note simply that the concept of earth-capital resonates closely with our theorization of the capitalist urban fabric and elegantly captures one of the core metabolic dimensions of fixed capital within the FMR. Under these conditions, due to the continuously intensifying ratchet effect, Cyclopean infrastructures come to operate as an objectified spatial matrix that compels and enforces a continued escalation of system-wide metabolic throughput, materializing and extending the power of earth-capital over human and non-human life (see also Mau, 2023). This infrastructural ratchet effect pre-existed the generalized deployment of fossil energy under the FMR, but once systematically woven into the variegated spatial tissue of earth-capital (the capitalist urban fabric) in the second half of the 19th century, its role in escalating the velocity and volume of capitalist metabolic throughput on a planetary scale has been drastically expanded.

The 'Cyclopean' qualities of the nascent FMR, then, flowed not merely from the upscaling of machinery, equipment and infrastructural configurations, but crystallized through the latter's role in metabolizing and canalizing an exponentially expanding volume of appropriated matter/energy and dissipated waste at increasing velocities through its own ever-thickening, fossil-fuelled circuitry. The point is not simply that greater volumes of 'stuff' (matter/energy) were being metabolized more quickly, but that an expansive spatial matrix of interlinked machines, equipment, infrastructures, buildings and territories — the capitalist urban fabric — was being constructed to support and continuously rachet up capital's drive towards metabolic throughput intensification. This was, in effect, an emergent,

planetary crystallization of what David Harvey (2017) has aptly described as capital's drive towards the 'bad infinity' of exponential compound growth. These developments established the infrastructural 'bedrock for the biospheric universalization of capitalist rule' (Malm, 2016: 218) and — as we discuss below — for the planetarization of several core socioecological crisis tendencies unleashed through that process.

THE INFRASTRUCTURALIZATION OF METABOLIC THROUGHPUT

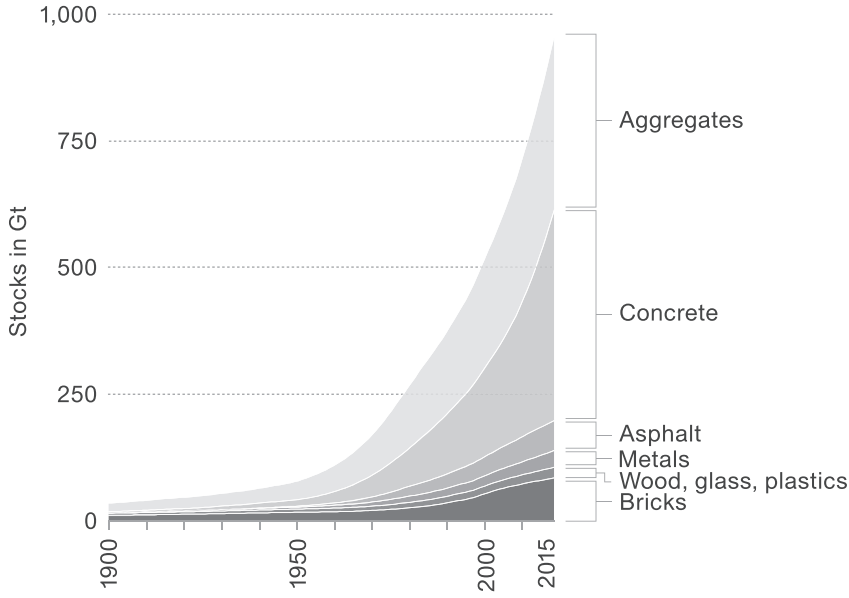
The infrastructural matrices consolidated during the FMR appear today as dense accretions of fixed capital spread unevenly across the Earth's critical zone. It is this process of planetary infrastructuralization whose variegated socioenvironmental impacts are represented in the popular 'hockey stick' data tables that are often used to demarcate the 'Great Acceleration' of the last 70 years of capitalist planetary transformation.[10] Rather than some generic expression of the Anthropocene, this planetary infrastructural assemblage must be interpreted as the uneven and combined spatial artefact of capital's dialectic of plunder, productivity and pollution under the FMR: it materializes and reproduces the power of earth-capital over the social and biophysical conditions of human and non-human life across the planet.

Among their myriad sociometabolic dynamics and impacts, the waves of global capitalist expansion that have unfolded since the 1950s have been premised upon a radical expansion — another round of 'Cyclopean' upscaling — in the sheer quantity and variety of material stock extracted, processed, transported and congealed into infrastructural configurations across the planet. These elements include various forms of biomass, minerals and processed materials (wood, glass, paper, bricks, iron, steel, aluminum, concrete) as well as a range of petrochemicals (especially plastics, asphalt, synthetic fertilizers) that together form the material basis of fixed capital infrastructures across the planet (Hanieh, 2021; Krausmann et al., 2018). As its material composition has been further entangled with large-scale fossil-fuel use, the total volume and weight of physical stocks congealed in the built environment has dramatically increased, closely mirroring the 'hockey stick' graphs of CO_2 emissions, biodiversity loss, mass species extinctions and other key socioenvironmental indicators that are generally associated with the 'Great Acceleration' (Figure 6).

Recent work on material and energy flow analysis (MEFA) at the Institute of Social Ecology in Austria has revealed several salient long-term trends among infrastructural configurations within the FMR. Foremost among these is a dramatic change in the overall portion of material throughput channelled into long-term infrastructures relative to more immediately

10. See, for example, Steffen et al. (2015). For a critical counterpoint, see Görg et al. (2020).

Figure 6. Stocks of Humans, Livestock and Manufactured Capital in Gigatons (Gt)



Note: The original table on which this figure is based included a reference to the stock of humans and livestock relative to the other material stocks listed. However, this amount is so small (less than 1.0 Gt as of 2015) that it is not visible in this format, as noted by Krausman et al. (2018: 136). For this reason, we have removed it from the key and the figure.
Source: Prepared by Willis Kingery based on Krausman et al. (2018: 135).

consumption-oriented, dissipative allocations. Whereas the bulk of material throughput in the early 20th century involved more or less direct consumption and dissipation, with less than 20 per cent congealed into stocks of fixed capital, the total share of stock-building materials had risen to nearly 60 per cent as of 2015 (Krausmann et al., 2017: 1881; 2018: 135). An especially drastic expansion of fixed capital investment occurred after 1980 — over two-thirds of the total volume of stock investment between 1900 and 2010 occurred during the final three decades of this 110-year period (Krausmann et al., 2017: 1882). The escalating accretion of fixed capital infrastructures that are produced through fossil fuels, composed of petrochemical materials and/or depend upon fossil energy for their everyday operations has contributed substantially to the massive growth of CO_2 emissions. The built environments, infrastructural equipment and terraformed landscapes of the planet have thus become progressively more carbon-intensive over the geohistory of the FMR.[11]

11. Whereas Malm and Carton (2024: 120) mobilize the notion of fossil *terre-capital* to reference the subterranean fixed capital outlays required to extract hydrocarbons, we

Whatever their origins and pathways of canalization into infrastructural assemblages, these flows of matter/energy are congealed as fixed capital ('stock', in MEFA terminology) across a dizzying array of land-use, morphological and geographical categories. Consequently, MEFA experts have posited that, during the 20th century, 'socioeconomic metabolism has changed from a throughput system in which most materials are used shortly after extraction to a system in which materials accumulate in stocks' (Krausmann et al., 2018: 136). This period should thus be characterized as 'a century of massive *stockpiling*' (Krausmann et al., 2017: 1884; emphasis added). This stockpiling has been accomplished through the channelling and processing of variegated material flows until they are crystallized into relatively stable infrastructures of fixed capital; these in turn serve to canalize an ever-escalating, largely fossil-fuelled throughput of matter/energy into and out of its own circuitry.[12] However, while the notion of stockpiling is a useful metaphor for capturing the dramatic accretion of processed matter/energy into fixed capital infrastructures under the FMR, it reveals little about the unevenly articulated, geopolitically mediated and militarized pathways of appropriation, capitalization and wasting through which that process has been accomplished. It also renders invisible the variegated, often harmful socioecological impacts of such processes across populations and territories that are positioned differentially within imperial circuits of capital and in the world interstate system (for further discussion, see Görg et al., 2020).

Henri Lefebvre's (1974/1991) powerful critique of spatial fetishism in *The Production of Space* offers a salient epistemological framework through which, despite the aforementioned limitations, MEFA-based accounts of infrastructural stockpiling may be productively articulated to a dialectical understanding of the spatial metabolism of capital under the FMR. In a key passage connecting his 'critique of space' to the analysis of the built environment, Lefebvre (ibid.: 92) considers several seemingly 'transparent' spatial artifacts — a house, a street and a city — and proposes a way to 'rip aside appearances' that make them seem like stable, immovable and functionally self-evident stocks. Rather than being fully legible and intelligible, Lefebvre (ibid: 93) proposes that each is in fact a medium and matrix of determinate, yet often obscure sociometabolic flows and energetic relationships that far transcend its material expression in the built environment:

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suggest a broader conceptualization. In our terms, fossil earth-capital encompasses the entire assemblage of fixed capital inscribed into the Earth (including terrestrial, oceanic/maritime, fluvial and subterranean space) that supports fossil energy metabolism — including the intermeshed moments of extraction, circulation, consumption and/or waste discharge (Brenner and Ghosh, forthcoming).

12. In the 21st century, this tendency toward stockpiling shows no signs of abating. On the contrary, during the last two decades, there has been a marked acceleration in the flow of materials, with a rate of growth comparable to that of the middle decades of the 20th century, a process that would appear still further to lock in the dynamics of metabolic throughput intensification that have underpinned the entire geohistory of the long fossil boom.

> Now, a critical analysis would doubtless destroy the appearance of solidity of this house, stripping it … of its concrete slabs and its thin non-load bearing walls … and uncovering a very different picture. … Our house would emerge as permeated from every direction by streams of energy which run in and out of it by every imaginable route: water, gas, electricity, telephone lines, radio and television signals and so on. Its image of immobility would then be replaced by an image of … a nexus of in and out conduits. By depicting this convergence of waves and currents, this new image … would at the same time disclose the fact that this piece of 'immoveable property' is … at once a machine calling for massive energy supplies and an information-based machine with low energy requirements …. Comparable observations … might be made apropos of the whole street …. Or apropos of the city, which consumes … truly colossal quantities of energy …

We may productively apply the methodological procedure Lefebvre outlines in this passage not only to individual artefacts in the built environment, such as buildings or streets, but also to the vast infrastructural assemblages associated with the 'stockpiling' processes of the last century on a planetary scale, as partially visualized in Figure 5 above. From this point of view, the most salient aspect of the last century of infrastructuralization is not simply the accretion, extension and recursive intermeshing of carbon-intensive fixed capital configurations, but perhaps more consequentially, the colossally escalating biophysical relays of matter/energy and waste that are metabolized through these matrices of earth-capital. As understood here, therefore, the infrastructural matrices materialized in the capitalist urban fabric under the FMR are, in effect, a planet-spanning 'nexus of in and out conduits' (Lefebvre, 1974/1991: 93) that at once supports and escalates capital's distinctive sociometabolic dynamics, with their constitutive moments of plunder, productivity and pollution, and their associated crisis tendencies of underproduction (source depletion) and overpollution (sink exhaustion) (see Figure 4 above). In effect, under the FMR, earth-capital is planetarized: it is not simply incorporated into patches of the Earth from which minerals and fuel are extracted or biophysical resources are appropriated, but is transformed into an Earth-encompassing spatial matrix designed to universalize the rule of capital over the entire biosphere.

Just as crucially, Lefebvre's approach to the 'critique of space' enables us to explore the uneven spatial patterning, jagged developmental pathways and variegated social impacts of these infrastructural matrices, and to track their articulations to the evolving geopolitical economy of capitalism and its mediations through historically specific forms of class struggle, inter-imperial and inter-state rivalry, inter-capitalist competition, nationally or regionally circumscribed state spatial strategies and relays of ecologically uneven exchange.[13] In this sense, the planetarization of the capitalist urban fabric is the geohistorical *and* geopolitical materialization of multiplying, highly variable and crisis-riven processes of metabolic throughput intensification and uneven spatial development, leading in turn to the further ratchetingup of strategies to secure various 'fixes' — spatial (Harvey,

13. On the concept of 'state space' see Brenner (2004) and Lefebvre (1976/2009).

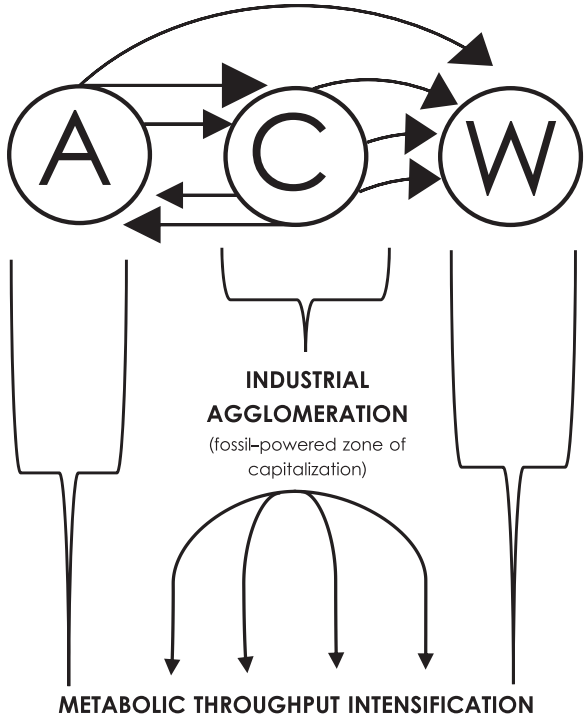
1982), scalar (Brenner, 2019) and socioecological (Ekers and Prudham, 2018) — for capital's proliferating sociometabolic contradictions.

CITIES AS 'BLAZING BONFIRES' IN THE LONG INTENSIFICATION

The theorization sketched above enables us to conceptualize the capitalist urban fabric as a spatial forcefield that is produced, reproduced and transformed through the historically evolving articulations of city/non-city relations, which constitute strategically essential, recursively intermeshed vectors of fixed capital infrastructure and, thus, of metabolic throughput intensification and concomitant biospheric degradation under the FMR. Within this framework of analysis, capitalist urbanization is not a linear, universal process of city building, spatial concentration, or infrastructural amalgamation, but a historically evolving, spatially uneven and crisis-riven 'unity-in-difference' (Hall, 1986) forged through the increasingly planet-encompassing interplay of agglomeration processes, the relentless remaking of non-city landscapes and biospheric degradation. The capitalist urban fabric is thus revealed as an emergent totality whose constitutive infrastructural elements are internally variegated, spatially differentiated, recursively interlaced and systemically crisis riven.

Within this radically relational framework, we may revisit the question of how cities and metropolitan regions — the elementary spatial expressions of agglomeration processes — figure within the developmental dynamics and crisis tendencies of the capitalist urban fabric. While we concur with the long-established understanding of cities as key sites and expressions of industrial capital's voracious metabolic appetite (Harvey, 1985; Malm, 2016; Mumford, 1956), we situate them as strategic arenas within the multi-scalar, multi-sited processes of fixed capital formation and metabolic throughput intensification outlined above: they are among the most consequential centres of gravity within the spatial matrix of earth-capital and the value relations it undergirds (Figure 7). Our claim is not that cities and metropolitan regions are the only or even primary spatial 'turbines' of infrastructuralization processes, but rather that they assume enhanced strategic significance in this regard under the FMR in mutually recursive articulation to other key arenas of intensified fixed capital investment — for instance, agro-industrial territories, zones of industrial extraction, energy landscapes and large-scale logistics/communications grids. It is the spatial intermeshing and developmental co-evolution of such (increasingly fossil-fuelled) zones of capitalization that underpins the drastic ratcheting up of capitalist metabolic throughput during the long fossil boom, leading in turn to a major 'state shift' (Barnofsky et al., 2012) in the scale, velocity and intensity of social dislocation and biospheric degradation (see Brenner and Ghosh, forthcoming).

Figure 7. Capitalized Agglomerations in the Gravitational Field of Value Relations (A = appropriation; C = capitalization; W = wasting).



This proposition may be further unpacked with reference to the three primary mechanisms through which, under the FMR, the infrastructural assemblages of cities and metropolitan regions have at once animated and escalated capital's spatial metabolism of appropriation (plunder), capitalization (productivity) and wasting (pollution). While these processes have been articulated unevenly and via distinctive developmental pathways across world regions during the Long Intensification (Görg et al., 2020), the following generalizations are meant to orient more contextually specific modes of inquiry into the vicissitudes of capitalist urbanization during this period of intensive geometabolic escalation, unprecedented infrastructural consolidation and planetary un-building.

First, cities and metropolitan regions are sites not only of massive, built-up infrastructure, but of intensive flows of matter, energy and waste. Indeed, the sheer quantity and variety of materials embedded in the built environment of cities are matched only by the immense volumes of matter/energy that flow through them to support the reproduction of social and economic life. This point is vividly encapsulated in Lefebvre's (1974/1991: 93, italics added) aforementioned observation that 'the city … consumes

… truly colossal quantities of energy, both physical and human, and … is in effect *a constantly burning, blazing bonfire*'. Peter Droege (2011: 108) similarly argues that the 20th-century city has been 'trapped in near total dependency' upon 'toxic and nuclear fuels' and has consequently 'bulked up like a prize-fighter on steroids'. He continues:

> It reached its exalted status as dominant settlement form while making its population complicit in the global trade of oil, coal, gas, and radioactive material — and the related paraphernalia and techniques of delivering the drugs: coal and uranium mines, oil and gas fields, processing plants, pipelines, power generators, distribution networks, massive military connections, overt and hidden political pressure — and the extensive financial systems to procure investments and extract the rising payments and profits ….
>
> By its very nature this energy system supported the rise of cities. Cities bulged as a direct consequence — and poisoned, filled, or drained vast stretches of aquifers, rivers and lakes in the process. Wetlands, bushlands, and grasslands disappeared at growing rates …. The cocktail of anthropogenic carbon dioxide, nitrous oxide, methane, and chlorofluorocarbons that enriches the thin layer of terrestrial air is the global gaseous garbage pool resulting from generations of fossil fuel burning, cement production, and rapacious land management practice. The oceans serve as overflow receptacle. Much of this waste is being generated to support the material growth, management, and mobility of cities — and despite all green aspirations the gaseous stream is growing day by day. (Droege 2011: 108–09)

The 'blazing bonfire' of concentrated matter/energy metabolism in cities is thus inextricably tied to the plunder, operationalization and degradation of variegated non-city landscapes — often located at considerable remove from the site of the conflagration — along with the ongoing toxification of the world's oceans and the atmosphere through various forms of pollution. One team of urban environmental researchers estimated that, as of 2010, megacities (defined as agglomerations with populations exceeding 10 million) consumed over 9 per cent of global energy and 10 per cent of global gasoline while generating 13 per cent of the planet's solid waste (Kennedy et al., 2015).

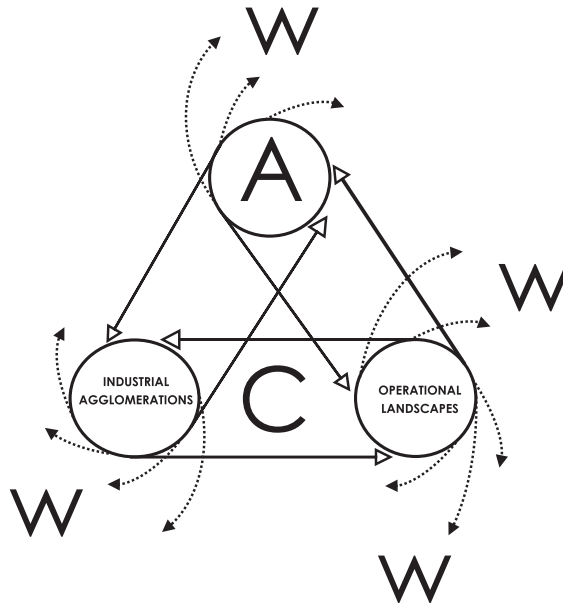
However, this aggregate estimate belies the radical unevenness of resource use and waste generation among and within the largest megacities (the intra-metropolitan dimensions of this observation are especially salient in the Global South). For instance, the total energy and water use of New York City, Los Angeles, Shanghai and Tokyo dwarfs that of Karachi, Dhaka and Kolkata. A similar pattern can be observed in the quantities of waste generated by these two sets of cities (ibid.: 5986). Thus, while there is impressive evidence that the metabolization of energy, matter and waste assumes highly concentrated forms within major metropolitan regions, their precise metabolic parameters (including volumes, velocities and geographies) are profoundly shaped through the path-dependent legacies — and ongoing reconfigurations — of capitalist imperialism and colonialism and their constitutive relations of racialized dispossession, displacement, immiseration and uneven ecological exchange. These differential concentrations of matter/energy in megacities reveal the severe limitations of efforts to evaluate

the metabolic dynamics of global capitalism on the basis of aggregate, city-centric metrics that bracket both the geohistorical contexts and geopolitical legacies that mediate the uneven energetics of megacities *and* the geographically expansive metabolic circuitry and infrastructural configurations that underlie productive, consumptive and dissipative processes *within* cities.

Second, cities and metropolitan regions contribute to the system-wide intensification of metabolic throughput through their role as centres of command-and-control over the financial, logistical and organizational architecture of the FMR itself (see also Luke, 2003). As global city theorists explored extensively in the 1990s and 2000s, the new international division of labour is organized through a disproportionate concentration of decision-making power in a handful of global financial centres, which consequently have come to serve as the command-and-control nodes of a globalized, neoliberalizing world economy (Sassen, 1991; Friedmann and Wolff, 1986; Taylor, 2004). In a broadly analogous manner, we must explore the ways in which the consolidation of a petro-capitalist formation of global capitalism in the post-World War II period has been coordinated from within a worldwide network of strategic urban sites, often co-located in cities that serve as major financial, commercial, military and/or political hubs. These centres of petro-capitalist command-and-control manage the tenuous, conflictual political-economic relations of fossil-fuel extraction, processing and distribution, as well as the ongoing, highly capital-intensive search for new sources, technologies and sites of fossil energy. Many such cities also house the headquarters of the largest fossil fuel corporations (the quintessential example is Houston, which is often characterized as the 'capital city' of oil, see Malm and Carton, 2024; Melosi and Pratt, 2007). This network of petro-capitalist command-and-control centres also includes a range of cities in both the Global North and the Global South that operate as regional, national, or inter-continental energy hubs, concentrating the energy corporations, manufacturing firms, financial institutions, advanced service providers (law, accounting, advertising, consulting), engineering companies, lobbying firms and state bureaucracies that together comprise the energy sector. A subsidiary class of agglomerations that facilitate the organization of the FMR are those 'frontier' cities and towns whose origins and/or expansion are directly conjoined to fossil fuel extraction and the other core processing and distribution operations of hydrocarbon commodity chains. Often located in close proximity to sites of extraction and processing, these cities function as nodal concentrations of the infrastructure, machinery and labour-power (most notably, large-scale refining operations) required for the otherwise spatially dispersed operations of primary energy production.[14]

14. Classic examples of these nodal control centres include various petro-cities and petro-towns in the Amazon basin associated with the Latin American oil boom of the 1960s and 1970s, such as Nueva Loja — colloquially named 'Lago Agrio' ('bitter lake') after Sour Lake, Texas, the oil boomtown where the Texas Company was established in 1902 — in north-

Figure 8. Recursive Capitalization between Industrial Agglomerations and Operational Landscapes in the Gravitational Field of Value (A = appropriation; C = capitalization; W = wasting)



Third, major cities and metropolitan regions animate *non-city* processes of metabolic throughput intensification in which zones of intensive capitalization — operational landscapes — are forged, not only to support urban metabolism, but to advance and escalate the reproduction of capital within broader, ultimately planetary metabolic relays (Brenner and Ghosh, forthcoming; Brenner and Katsikis, 2020). Zones of agglomeration are thus hardly the only spaces in which the ratcheting up of metabolic throughput is animated; they are tightly embedded within a recursively organized meshwork of non-city operational landscapes of capitalized extraction, agro-industrial production, logistics and waste processing that represent additional, highly consequential cogs in the churning gears of capital's spatial metabolism. We interpret the spatial intermeshing and operational coordination of zones of industrial agglomeration (city building) with other arenas of expanding capitalization beyond city limits as a key vector of infrastructuralization that has animated the long waves of accumulation, and concomitant processes of escalating biogeophysical appropriation and wasting, throughout the geohistory of the long fossil boom (Figure 8). Pineault (2023: 92) describes such intermeshings as a form of 'recursivity' in which multiple

eastern Ecuador, which was founded as a company town by Texaco in the 1960s (Sorkin and Calisto, 2016).

arenas of fossil-fuelled, carbon-intensive infrastructure are spatially interlaced and consequently co-evolve over long periods, leading to a cumulative escalation of system-wide metabolic throughput. Just as crucially, we would add, this recursivity engenders *new waves* of investment in fossil-powered machinery, equipment, buildings and infrastructure, within cities and operational landscapes alike, that further lock in the fossil-based spatial metabolism of capital and continuously ratchet up the volume and velocity of metabolic throughput.

In sum, then, city/non-city relations, mediated and animated through large-scale, carbon-intensive infrastructures, are a key spatial vector of the historically specific processes of metabolic throughput intensification unleashed under the FMR. From this point of view, cities and metropolitan regions — and their variegated infrastructural articulations to strategic non-city territories and environments — figure crucially within the dynamics of 'biospheric universalization' (Malm, 2016) through which the metabolism of capital at once feeds upon, terraforms and degrades the planet. This mode of analysis permits the elaboration of a differentiated, multi-scalar sociometabolic portrait of the production and continual reconstitution of the capitalist urban fabric — its mottled, fossil-fuelled infrastructural matrices, its ever-escalating biophysical flows and its proliferating waste streams — in relation to the planetary biosphere from the 1870s up through the present.

THANO-METABOLIC URBANIZATION: THROUGHPUT ECOLOGIES AND EXHAUSTION ECOLOGIES

Here we return to our earlier observations regarding the underlying thano-metabolic tendencies of the capitalist form of urbanization. As understood here, the capitalist urban fabric under the FMR is not only an infrastructural ratchet driving an endless process of metabolic throughput intensification and a concomitant terraformation of the Earth. In so doing, it also induces a maelstrom of crisis tendencies that systematically degrade the conditions for social reproduction and biospheric regeneration across the planet, creating 'exhaustion ecologies' in which environmental ruination, social precarization and the threat of destitution and death are closely conjoined. The capitalist form of urbanization is thano-metabolic in precisely this sense; throughput ecologies and exhaustion ecologies are its mutually constitutive elements.

As the animating lever of metabolic throughput intensification, fixed capital infrastructure has played a strategic role in these thano-metabolic dynamics. The infrastructuralization processes materialized in the capitalist urban fabric under the FMR induce two closely intermeshed, mutually reinforcing forms of exhaustion ecologies — the production of 'sacrifice zones' (Juskus, 2023) and the proliferation of 'sacrifice populations' (Armiero,

2021; Moore, 2022). Whereas both processes have been manifested in specific, relatively discrete sites and pathways of overpollution, biospheric degradation and/or social dislocation, the latter have been progressively intermeshed, intensified and upscaled during the last half-century to trigger what some scholars describe as 'planetary-scale critical transitions' that are likely to engender ruinous implications for the future of the web of life on Earth (Barnosky et al., 2012: 52).

Within sacrifice zones, specific places, their populations and their ecosystems are subjected to concentrated contamination and toxification, generally in patterns that entrench class inequality, environmental racisms, climate colonialism and the destruction of Indigenous life (Juskus, 2023; Sultana, 2024). This occurs through the construction of infrastructural matrices that funnel dissipated waste into specific social geographies and ecosystems. These processes also unfold through the transformation of ecosystems and their constituent elements — soil, land, forests, watersheds, lakes, oceans and the atmosphere — into waste dumps for the toxic discharge and contaminated detritus of capitalist operations. Such ecosystemic expulsions of waste are, however, likewise organized through customized infrastructural relays and assemblages (such as smokestacks, pipes, landfills, sewage systems, and the like) that, by design, treat the biosphere as the 'ultimate sink' (Tarr, 1996) equipped with a limitless capacity to absorb entropic waste.

Lewis Mumford (1938: 1961) advanced an especially stark, urban-theoretical account of such dynamics in the mid-20th century. In his analysis, the 'up-building' of industrial capitalist cities was inextricably linked to a process of 'un-building' manifested across an imagined transect stretching from ruined cities ('necropolis') and contaminated regional hinterlands to degraded rural landscapes, chemicalized fields, toxified ecosystems and polluted oceans. For Mumford, un-building was indeed territorialized in specific places, regions and ecosystems, but it was also an increasingly generalized condition insofar as industrial urbanization subjected major swathes of the Earth's biosphere to comprehensive ruination. In a more recent but closely allied analysis of such issues, Saskia Sassen (2014: 150) charts a globalized pattern of 'dead land, dead water' that has created 'holes in the tissue of the biosphere' defined by 'the expulsion of biospheric elements from their life space and as the surface expression of deeper subterranean trends that are cutting across the world'. In effect, Sassen's account may be read as an elaboration of Mumford's earlier conceptualization insofar as she seeks to decipher what might be envisioned as the planetarization of un-building processes.

This is precisely our hypothesis here. Capital's immanent drive to intensify metabolic throughput and thereby to universalize the gravitational field of value relations across the biosphere, has been inextricably conjoined to a parallel universalization of biospheric ruination — the un-building of the planetary web of life. A planetary 'space of catastrophe' (Lefebvre, 1976/2009) is a ubiquitous prospect within the capitalist urban fabric

because its operational (il)logics of endless intensification systematically degrade, pollute and fail to regenerate its socioecological conditions of possibility. The planetarization of earth-capital and planetary ecocide are thus revealed as mutually constitutive tendencies immanent within capital's spatial metabolism.

Clearly, discrete 'hot spots' of spatially concentrated environmental plunder, contamination and toxification persist, especially in frontline/fenceline, racialized and low-income communities in the Global North, in formerly colonized territories across the Global South and in Indigenous lands around the world. Increasingly, however, the un-building processes in question cannot be grasped exclusively in zonal terms, as territorially demarcated sites or regions, as 'dead zones' within discrete ecosystems, or even as 'holes' in biospheric tissue. Today, earlier areal geographies of sacrifice zones are coalescing and being upscaled to form a sacrificed *planet* that is increasingly prone to the stochastic, mutually reinforcing effects of biospheric destruction. This situation is characterized, *inter alia*, by abrupt, non-linear forms of socioecological crisis that ricochet across territories and environments and ultimately degrade the entire planetary biosphere, turning the web of life into a web of toxification.

Lefebvre's (ibid.) conceptualization of the 'space of catastrophe', inspired by mathematician René Thom's early explorations of catastrophe theory in the 1960s, was precisely an attempt to capture both the stochastic unpredictability of crises and their planet-destroying potential in the geohistorical context of postwar national-developmentalist and globalizing capitalism. The socioenvironmental dimensions and implications of these dynamics are also the focal point of the more recent literature on planetary boundaries, which seeks to demarcate the intermeshed threats to humanity's 'safe operating space' as the relatively stable conditions for human life during the Holocene epoch are dramatically superseded in our time (Rockström et al., 2009; Steffen et al., 2015; Sultana, 2023). There is substantial evidence that the dynamics of capitalist urbanization — including agglomeration processes and their recursive articulations to myriad non-city spaces — figure crucially in the proliferation and intensification of such planetary boundary crossings (Brenner and Ghosh, 2022; Kronenberg et al., 2024).

The processes of infrastructuralization and geometabolic escalation materialized in and animated through the capitalist urban fabric are also deeply implicated in the wasting and ruination of populations that are rendered 'surplus' to capital's demand for wage labour and are correspondingly dispossessed, displaced and/or rendered destitute. As Nick Bernards and Susanne Soederberg (2021: 412) explain, such populations are disposable only *relative* to 'the immediate needs of capital for waged labour at a given place and time'. Marx (1867/1977: 786, 789) thus characterized them as 'relative surplus populations'. Crucially, as Farshad Arraghi has explored at length, the production of relative surplus populations has been embedded within successive imperial 'regimes of forced underconsumption'

(including both Keynesianism and neoliberalism) that boost profit rates (a) by 'cutting into the subsistence requirement of labour power' and (b) through the super-exploitation of nature — especially but not exclusively in the previously colonized, 'developing' world (Araghi, 2009: 120, 122). Through historically specific combinations of imperialist appropriation and ecologically unequal exchange, both strategies degrade and ultimately shatter the socioecological conditions for the regeneration of human and extra-human life (Hickel et al., 2022).

Thus understood, relative surplus populations are not simply a 'reserve army' for waged employment (a circumstance that may likewise drive down the social wage) but are produced through a multiplicity of relations to processes of capital accumulation, including but transcending those directly articulated to the wage nexus. Indeed, in contrast to the forms of infrastructural *recursivity* between centres of agglomeration and non-city operational landscapes that propel the continuous escalation of capital's metabolic throughput, relative surplus populations exemplify the predatory forms of *disarticulation* that likewise shape and animate the capitalist urban fabric (Bair and Werner, 2011).[15] As conceived here, then, much like sacrifice zones, relative surplus populations are not contingent or accidental side-effects of capital's drive to increase metabolic throughput, but are among its constitutive materializations, at once 'the necessary product' and the 'lever' of capital accumulation and thus the 'condition for modern industry' (Marx, 1867/1977: 784, 786). Throughput ecologies and exhaustion ecologies are, therefore, thoroughly intermeshed, co-produced and co-evolving layers within the capitalist urban fabric.

The most fundamental precondition for the production of relative surplus populations is the ongoing, ever-expanding *enclosure* of non-commodified means of social reproduction — variously described as 'primitive' or 'originary' accumulation or as accumulation by dispossession — which subjects populations to the 'mute compulsion' (Mau, 2023) associated with capital's colonization of political ecologies that were previously managed

15. In their theorization of the interrelated processes of inclusion and exclusion (of labour power, among other resources) in the construction of global commodity chains, Jennifer Bair and Marion Werner (2011: 993) define 'disarticulation' with reference to 'dynamic processes that iteratively reproduce the subjects and places included within and excluded from global commodity production'. In a closely analogous sense, the forcefield of capitalist urbanization evolves through the continual, iterative intermeshing of various articulations *and* disarticulations that crystallize historically and regionally specific forms of spatial polarization, peripheralization and ruination at multiple scales — not only operational landscapes, but also sacrifice zones and surplus/wasted populations. The recursive intermeshing of historically evolving spatial arenas of fossil-fuelled metabolic intensification (for instance, in industrial cities, mega-factories, warehousing operations, industrial mining complexes, data centres, factory farms, concentrated animal feeding operations and large-scale logistics systems) is thus inextricably connected to the patterned production of zones of disarticulation — within and beyond these sites — in which the socioecological violence of these processes is projected onto living bodies, ecosystems and landscapes.

through locally specific, collectively organized forms of provisioning and habitation (Araghi, 2009; Sevilla-Buitrago, 2022). As Araghi (2009: 124) explains, such 'expanding "ecological enclosures"' involve a 'privatization of nature and [a] squandering of the ecology of reproduction'. Consequently, even populations that are not directly subsumed within the wage nexus may become substantially dependent upon circuits of capital for their survival. Through processes of dispossession and displacement, and concomitant relations of debt and rent (Soederberg, 2021), such 'wageless' populations are thereby subjected to the violence of forced underconsumption. Due to their disarticulation from infrastructures of public provisioning and social reproduction, relative surplus populations may also be especially vulnerable to the wide-ranging forms of environmental dislocation and toxification induced through capital's strategies to appropriate, canalize, terraform and simplify the biosphere, and due to the proliferating climate and nature emergencies that result from such processes.

As the structural foundations of 'wageless life' (Denning, 2010) and ecological enclosure are conjoined to historically specific regimes of forced underconsumption, capital also seeks to enhance profit rates through various forms of precarization manifested in limited, unstable, or underpaid access to waged work. This predatory tendency within capital's spatial metabolism is manifested, for example, in 'un- and under-employment, hyperexploitative work, lack of a living wage and an increasing inability to meet basic subsistence needs' (Bernards and Soederberg, 2021: 412).

By subsuming an ever-expanding assemblage of biophysical resources (including land, water and forests) under the rule of capital, the 'Cyclopean' spatial matrices and 'produced productive forces' of the capitalist urban fabric actively intensify the formation of relative surplus populations. This relentless process of ecological enclosure generates continuous, if spatially uneven, waves of dispossession and displacement that 'deruralize' the global countryside (Araghi, 2000, 2009), channel former peasants, cultivators, smallholders and agricultural labourers into 'slums' in the Global South (Davis, 2007), and produce myriad 'hinterlands' defined by variegated patterns of precarity, pauperization and destitution in deindustrializing or peripheralized regions of the Global North (Neel, 2018). It is through this conceptual lens that we may interpret the processes of global deruralization that were entrained through the combined effects of rural dispossession (for infrastructural, industrial and urban development) and the expansion of fossil-fuelled capitalist agro-industrialization during the long Green revolution (Araghi, 1995; Patel, 2013) wherein, over several generations, millions of newly pauperized, depeasantized households were expelled into large metropolitan regions and urban peripheries across the Global South (Ajl, 2014; Davis, 2007; Sanyal, 2014).

Crucially, as Alessandra Mezzadri (2019, 2021, 2024,) has argued at length, the concentration of precarized workers in Southern megacities is often contingent upon an externalization of social reproduction costs onto

the 'rural' communities to which many remain connected through circular migration patterns. For this reason, historically specific configurations of the 'urban–rural divide' directly bolster the regimes of forced underproduction that underpin the 'planet of slums' (Davis, 2007). In effect, as Mezzadri (2024: 8; 2019: 38) explains, the 'intergenerational reproductive realm' rooted in rural spaces operates as 'a systemic subsidy to capital' insofar as 'everything is dumped onto the shoulders of workers and their kin, family and community ties'. However, to the degree that such inherited non-city spaces of reproduction are themselves increasingly threatened by the relentless advance of ecological enclosure or destroyed through proliferating climate and nature emergencies, these exhaustion ecologies are likely to become even more brutally hyperexploitative, thus further degrading the conditions of social reproduction for 'wasted populations'. Exhaustion ecologies are, in this sense, dynamically evolving arenas of class struggle in a volatile context of geoeconomic turbulence and proliferating ecological crises.

Alongside the hypertrophic growth of megacities induced through depeasantization processes, exhaustion ecologies have also proliferated throughout zones of industrial extractivism and agro-industrial enclosure, particularly in formerly colonized territories and other global peripheries. Here, semi-proletarianized smallholders have been conscripted into regimes of forced underconsumption through various forms of dispossession and displacement that have severely degraded or destroyed inherited provisioning systems and forms of habitation (Araghi, 2009; Li, 2010). Under the regime of global neoliberalism, closely parallel processes of immiseration have unfolded in deindustrialized or otherwise peripheralized regions of the Global North. In these contexts, precarized, pauperized populations have been conscripted into informalized and/or low-wage employment in erstwhile rural zones (generally associated with extractivism, primary commodity production and basic processing operations) as well as in newly consolidated peri-urban 'slum cities' (often associated with logistics industries, distribution centres, warehousing and other support operations for metropolitan consumption) (Neel, 2018).

Under the FMR, then, the infrastructural ratchet effect engenders not only throughput ecologies that link industrial cities and operational landscapes in a relentless dynamic of geometabolic escalation, but also produces exhaustion ecologies that are materialized in variegated patterns of social dislocation and environmental destruction across the planet. As this process advances, exhaustion ecologies come to serve as a precondition and medium of subsequent rounds of urban transformation: they are, quite literally, materialized in the colossal infrastructural assemblages, terraformed land-use configurations, precarized social geographies and ruined landscapes through which emergent patterns of urbanization are forged. Especially in the wake of global neoliberalization, these exhaustion ecologies are increasingly being consolidated on a planetary scale, at once within

large metropolitan regions, peri-urban fringes, agro-industrial and extractive zones and deruralized landscapes, generally with devastating consequences for social reproduction and biospheric regeneration. While most approaches to 'sustainable' urbanization render such exhaustion ecologies invisible or relegate them to the background of the 'high peaks' of agglomeration economies, we contend that they must be a central focal point of any critical approach to the future of urbanization.

URBAN SUSTAINABILITY IN THE 'WASTEOCENE'

The planetary formation of the capitalist urban fabric established during the Long Intensification is the infrastructural scaffolding within which capital's spatial metabolism is currently organized. Since the consolidation of the FMR, these extended infrastructural configurations have been substantially powered by fossil fuels in symbiotic combination with myriad non-fossil energy sources (Fressoz, 2024). These variegated but predominantly fossil-powered infrastructural configurations have been significantly animated through a matrix of capitalized zones of agglomeration in the imperial core and their non-city hidden abodes of supply and waste, generally located in proximate or distant peripheralized zones. In this sense, the imperial infrastructural matrices undergirding city/non-city relations have been a key lever animating the drastic intensification in the volume and velocity of appropriation (of matter/energy, including fossil energy itself) and waste dissipation (including of carbon) during the last 150 years. As capital's project of biospheric universalization has progressed through successive layerings and extensions of fixed capital threaded through an evolving infrastructural matrix of city/non-city relations, the capitalist urban fabric — the material expression of this still-ongoing process — has become planetarized. Yet its spatial crystallizations, metabolic circuitry and socioecological contradictions have necessarily emerged in regionally specific formations derived, *inter alia*, from the geohistorical legacies of capitalist imperialism, militarized racial empire and climate colonialism (Sultana, 2024; Táíwò, 2022).

The industrial cities of the Euro-American imperial cores figured crucially in the geometabolic dynamics of the Long Intensification, at once as sites of industrial capitalization, as financial and coordinating centres for the fossil economy, as concentrations of carbon-intensive consumption, and as animators of carbon-intensive capitalist operations in non-city zones of extraction, agricultural production, energy processing and logistics systems. Their hidden abodes of appropriation and pollution in proximate and distant peripheralized zones were correspondingly transformed, often in destructive ways, through successive waves of infrastructuralization, landscape simplification, sociospatial dislocation and ecosystem destruction that accompanied the intensified canalization of matter/energy into metropolitan

circuits of capital and its discharge back into the biosphere as dissipated, often toxified waste.

In the colonial/post-colonial peripheries and newly industrializing zones of the world economy, some centres of agglomeration acquired broadly parallel, if largely subordinated, roles in coordinating, hosting or animating some of capital's most carbon-intensive metabolic operations within and beyond their boundaries. Their escalating throughput of matter/energy likewise hinged upon the extensive operationalization of hidden abodes of supply and waste, generally in more proximate, non-city peripheries, whose landscapes and populations were correspondingly churned into and through capital's circuitry of plunder, productivity and pollution. Such peripheralized metropolitan centres thus contributed substantially to a further differentiation and deepening of exhaustion ecologies, both proximate and remote.

These and other cities of the Global South have also been directly shaped through the myriad, non-city exhaustion ecologies induced through the capitalist enclosure and infrastructuralization of the Earth, especially due to their role as concentration points for dispossessed, precarized populations that have been disarticulated from inherited relays of social reproduction attached to the land or have otherwise been displaced due to proliferating climate-induced socioenvironmental crises. The conjoined 'deruralization' and 'depeasantization' processes that produced the 'planet of slums' are inextricably connected to the system-wide intensification of metabolic throughput under the FMR (Araghi, 2000, 2009). For example, the upscaled relays of hyperchemicalized, fossil energy-intensive agricultural production, land-use simplification, groundwater depletion, and waste discharge associated with the Green Revolution co-evolved with the (largely fossil-powered) metropolitan centres of the global North as well as with regimes of forced underconsumption and socioenvironmental degradation within postcolonial megacities, financial centres, port cities, export processing zones, mining hubs, and specialized agro-industrial clusters. In this sense, the urbanization of (industrial) capital, the operationalization of global countrysides to industrialize primary commodity production, the mass displacement and dispossession of erstwhile peasants in the imperial periphery, the degradation and destruction of ecosystems and the informalization of urban life in Southern megacities must be understood as internally related moments of capital's metabolic operations (Ghosh and Meer, 2021).

Capital's drive towards metabolic throughput intensification under the FMR has imposed ever-increasing demands on the planetary biosphere in the form of tendentially escalating, if unevenly distributed, waves of biophysical plunder and toxic pollution. As we have discussed, biospheric universalization and biospheric ruination are immanent, mutually constitutive moments within capital's planet-transforming spatial metabolism. These dynamics have been powerfully mediated through imperial formations of ecological enclosure, forced underconsumption, and ecologically unequal exchange that have subjected peripheralized territories and precarized,

pauperized, and/or racialized populations to the most destructive impacts of capital's metabolic operations. Indeed, even as capital seeks to organize nature as a standing reserve from which limitless supplies of matter/energy ('free gifts') may be extracted and into which boundless streams of dissipated waste ('free garbage') may be expulsed, its ecocidal spatial metabolism produces a cascade of unevenly distributed exhaustion ecologies and planetary boundary-crossings that are materialized in the form of wasted landscapes and populations — a 'wasteocene' of degraded life and biospheric destruction (Armiero, 2021). In this way, the spatial infrastructures of the urban fabric have not only undergirded and animated capital's churning metabolism, but have directly contributed to the mutilation of significant swathes of the planetary web of life.[16] In short, the very strategies of infrastructuralization that capital has mobilized to secure spatial, scalar and socioecological fixes for its continued operations are destroying the biophysical preconditions for accumulation and, ultimately, for the reproduction of life itself.

This is the evidently grim planetary context in which contemporary strategies and struggles around urban sustainability are embedded. The evolution and mainstream adoption of urban sustainability agendas since the 1970s has been animated by several intermeshed regulatory challenges — including, most prominently, urban sprawl (in the Global North) and informalization (in the Global South) — related to the territorially differentiated patterns of urbanization and imperialist appropriation over the last century (Angelo and Wachsmuth, 2020). However, the post-1990s reframing of worldwide debates on urban sustainability around the overarching *problematique* of climate change reflects the widely embraced belief that, despite their otherwise distinct developmental pathways, positionalities in the world economy, and forms/degrees of exposure to environmental hazards, cities are an especially impactful arena in which to mobilize diverse forms of environmental planning, policy, engineering and design (Angelo and Wachsmuth, 2020).

The foregoing analysis of capitalist urbanization and metabolic throughput intensification within the FMR provides a geohistorical framework within which to deconstruct emergent debates around urban sustainability (along with cognate explorations of urban resilience, urban environmental design, and urban renewable energy). While we broadly concur with the proposition that urbanization processes should be a central focus of strategic responses to contemporary climate and nature emergencies, our account strongly rejects the city-centric epistemology and methodological localism

16. According to one influential recent assessment, no less than six of nine planetary boundaries have now been transgressed, a circumstance that is likely to trigger increasingly more extreme 'systemic disruptions' that further erode or obliterate the 'safe operating space' within which the human species has reproduced itself for over ∼10,000 years since the dawn of the Holocene epoch (Richardson et al., 2023).

that underpin mainstream urban environmental discourse, politics and strategy.

Major streams of work in this field are animated by ostensibly progressive concerns to improve local energy efficiency; to defend and enhance local provisioning systems for food, water, housing and waste management; and to protect local populations from environmental dangers related to extreme weather events, air and water contamination, and public health emergencies, among other key arenas. Unfortunately, however, because of their myopically narrow focus on 'the' city as the singular, exclusive spatial unit for research and practice on urban questions, most current approaches to urban sustainability bracket the supralocal metabolic relays and imperial geopolitical ecologies that constitute urban life and mediate its socioenvironmental dynamics and impacts within and beyond cities (Wachsmuth et al., 2016). Consequently, they implicitly (or, in some cases, explicitly) endorse the preservation or even intensification of imperialist circuits of appropriation and waste externalization as a necessary precondition for establishing more ecological, green, or resilient forms of urbanism. In effect, such city-centric approaches legitimate the imperial mode of living (Brand and Wissen, 2021), albeit in a modestly ecological or 'green' formation, rather than seeking ways to interrupt or downscale its sociometabolic dynamics, class relations, regimes of expropriation, or crisis tendencies (Ajl, 2021; Thompson et al., 2024).

Still more problematically, many of the most well-intentioned versions of this eco-urbanist position may be readily appropriated in support of blatantly reactionary political projects based upon a city-centric formation of eco-apartheid (Cohen, 2018). For instance, neoliberal political forces have enthusiastically embraced urban sustainability programmes as a means to create zones of exclusion — 'splintered urbanisms', 'premium ecological enclaves' and 'eco-islands'— in which urban space is envisioned as a privatized, techno-infrastructural bastion for the ruling classes in a world of increasing socioenvironmental turbulence, climate breakdown and mass displacement (Bassens et al., 2020; Hodson and Marvin, 2010; Sze, 2015; Wakefield 2025). There is, therefore, a major risk that strategies to achieve sustainability goals within cities may contribute to the further polarization of environmental risk and danger, creating privatized fortresses of (relative) protection, stability and prosperity surrounded by larger landscapes of deepening ecological collapse, toxic contamination and generalized social immiseration — much like the dystopian future depicted in Denis Villeneuve's *Blade Runner 2049*.[17]

Of course, notwithstanding the myriad normative objections to such an exclusionary vision of urban futures, there are also obvious empirical problems with the contention that any city could be insulated or defended from

17. For a generative interpretation of *Blade Runner 2049* along these lines, see Wakefield (2017).

the cascading existential dangers associated with the multiple planetary boundary crossings that are currently underway. As the socioecological and geopolitical impacts of these crises intensify and cascade unpredictably around the Earth in the coming years, decades and, indeed, centuries, the vision of the city as an oasis of sustainability may be revealed as an ideological formula for an 'urbicidal Anthropocene' (Wakefield, 2025).

CLIMATE BARBARISM OR *ALTER*-METABOLISM?

How then, might we more effectively, realistically and solidaristically grapple with the role of capitalist urbanization in the intensifying enclosure, operationalization and degradation of the Earth's biosphere? How might cities, their evolving metabolic relays and their contested regulatory capacities be articulated to emergent strategies to counteract or even supersede capital's spatial metabolism? What role might cities and urbanization processes play in future projects to repair the myriad forms of social injustice and socioenvironmental damage inflicted upon the planetary web of life through capital's drive towards plunder, productivity and pollution?

These are urgent, complex, far-reaching and intensely contested questions that require extensive investigation (Ajl, 2021; Kaika et al., 2023; Krähmer, 2022; Kronenberg et al., 2024; Varvarousis et al., 2025).[18] Here we outline in broad strokes some of the key methodological consequences that flow from the specific theoretical framework elaborated in the foregoing analysis, which offers but one among many possible interpretive inroads into this vast *problematique*. To this end, we return to the work of Mike Davis, whose account of avian flu as the 'monster at our door' we discussed at the outset of this article (Davis, 2005).

With characteristic dialectical nuance, Davis interpreted this 'monster' as an imminent threat to global public health derived from a deadly symbiosis of several, interlinked transformations of global capitalism and the planetary biosphere — including neoliberal geoeconomic restructuring, the defunding of disease prevention infrastructures, accelerated capitalist industrialization (especially in East Asia), deforestation and land-use simplification (especially in conjunction with the expansion of industrial livestock production), and the proliferation of high-density megacities across the Global South. For Davis, the 'great concentrations of urban poverty' in the '*bustees*, *colonias* and shantytowns' of the Global South were one among several strategic arenas — along with industrial livestock factories/feedlots and commodified/commercialized forests — in which planetary transformations and microbiological mutations were intermeshing to establish the conditions for a catastrophic 'viral

18. See also Brenner and Ghosh (forthcoming).

hurricane' that would be 'as terrible as any in science fiction' and leave most Third World cities 'defenceless' (ibid.: 84, 99).[19]

In closing our analysis, we turn to another of Davis' (2010) foundational contributions to radical urban and environmental thought — his influential essay, 'Who will Build the Ark?' — that likewise seeks to illuminate the role of urban centres as strategic sites in which capital's monstrous, planet-encompassing metabolic operations are at once rooted, traversed and escalated — but also, potentially, counteracted, downscaled and rearticulated.[20] Just over a decade after the 1997 Kyoto Protocol, Davis directly engaged with the proposition that cities could form the 'ark' that will rescue humanity from the cataclysms of climate change (ibid.).[21] In a provocative rhetorical manoeuvre, Davis (ibid.: 29) organized his reflections as a 'mental tournament between analytic despair and utopian possibility'. He poignantly characterized this internal debate as 'personally, and probably objectively, irresolvable' (ibid.: 29). Drawing upon Antonio Gramsci's (1920) widely debated slogan from the pages of *L'Ordine Nuovo* from over a century ago (see Haider, 2020), Davis (2010: 29) framed the 'analytic despair' side of this argument under the rubric of 'pessimism of the intellect' and its 'utopian possibility' side through the notion of an 'optimism of the imagination'.

In the years following the Kyoto Protocol, Davis found substantial grounds for deep pessimism. After reviewing a catalogue of scientific evidence associated with what would now be termed planetary boundary crossings, Davis (ibid.: 31–32) offered a scathing overview of the Intergovernmental Panel on Climate Change (IPCC)'s 'heroic confidence' that a kind of 'spontaneous decarbonization' would unfold through postulated future gains in energy efficiency that would supposedly alleviate the need for drastic reductions of carbon emissions. Turning to the 'lost decade' of 2000–10, Davis noted the miserly performance of market-based approaches to carbon mitigation and concluded that these hegemonic models amounted to 'little more than leaps of faith': 'the IPCC, in effect, has bet the ranch, or rather the planet, on a market-driven evolution towards a post-carbon world economy' (ibid.: 33).

Against this background, Davis outlined a series of grim geopolitical and geoeconomic trends that anticipated an exceedingly bleak planetary future. These included the ossification of carbon-intensive infrastructural regimes; the stalling of investments in renewable energy systems; the stagnation or suppression of incipient efforts to limit greenhouse gas emissions; and the accelerated transgression of key global environmental 'tipping points' (ibid.: 32). Davis also drew central attention to the ongoing displacement of pauperized, dispossessed populations in the Global South from historic countrysides and their consequent consignment to precarious conditions

19. See also Wallace et al. (2020).
20. For further elaborations, see Kunkel and Seaton (2023).
21. For further discussion and contextualization, see Angelo and Wachsmuth (2020).

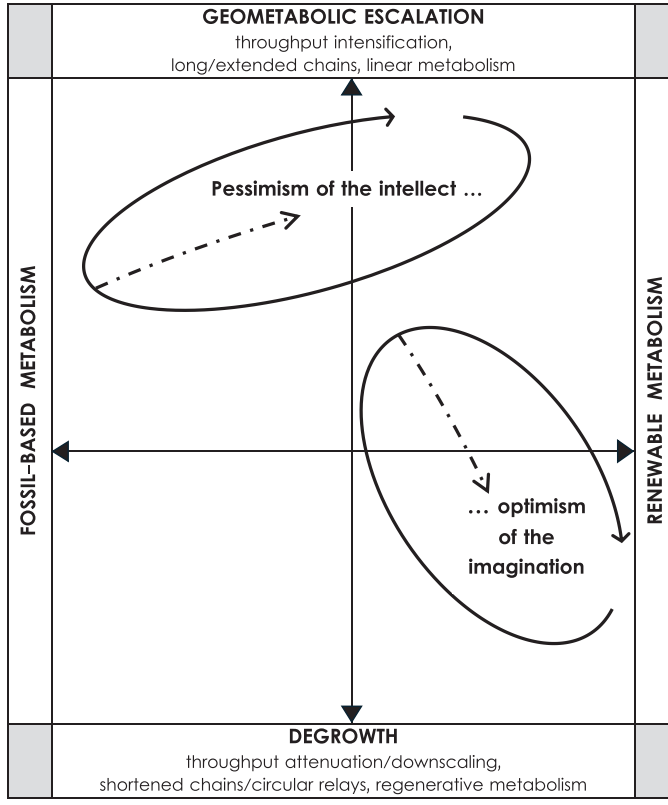
of survival in the 'planet of slums', where they are subjected to the most devastating impacts of climate breakdown despite their negligible role in contributing to it. Faced with 'this planetary deficit of opportunity and social justice', Davis (ibid.: 39, 40) wondered whether 'human solidarity itself may fracture like a West Antarctic ice shelf, and shatter into a thousand shards'.

In excavating a basis for an 'optimism of the imagination' from these calamitous trends and transformations, Davis turned to what he described as a 'classical' vision of the urban derived from the 'utopian ecological critique of the modern city' developed by late-19th and early-20th century socialists, anarchists, bio-regionalists, and communist designers, from Kropotkin and Geddes to the early Soviet Constructivists and the Bauhaus (ibid.: 43). This 'classical' stream of urban-ecological critique rested upon a 'single unifying principle' that, in Davis' view, offers the intellectual and political foundation for contemporary urban responses to climate breakdown, namely 'the priority given to public affluence over private wealth' (ibid.: 43). In Davis' self-described utopian vision of the future city, finite resources and fragile ecosystems would be more effectively managed within a framework of radically democratic urbanism defined by small-scale settlements; comprehensive planning strategies designed to preserve and regenerate supply and waste zones; and a collectivist/communal ethos oriented towards 'public luxury' and the 'socialization of desire and identity' (ibid.: 42).[22]

Davis particularly extols early Soviet Constructivist visionaries such as El Lissitzky and Ivan Leonidov, who, under conditions of extreme resource scarcity, embraced a vision of democratically managed, publicly shared infrastructures for production, social reproduction and cultural life. In the context of early 21st-century planetary environmental crises, Davis proposes to appropriate and rework the early Soviet Constructivist vision of collectivist territorial design into a strategy of eco-socialist urban transformation based on 'the proposition that the egalitarian aspects of city life … provide the best sociological and physical supports for resource conservation and carbon mitigation' (ibid.: 44). Because cities are the 'prime mover' of carbon-intensive forms of life under capitalism, and will likely continue to serve as the 'ground zero' at which diverse planetary socioenvironmental crises and struggles converge, Davis hypothesizes that they may also be a strategic portal through which to confront 'the challenge of sustainable urban design for the whole planet' (ibid.: 41, 44). This could, he suggests, unleash a 'global revolution that reintegrates the labour of the informal working classes, as well as the rural poor, in the sustainable reconstruction of their built environments and livelihoods' (ibid.: 45). While Davis (ibid.: 45) readily concedes that this is probably an 'utterly unrealistic scenario', and cautions against an uncritical 'regression to the utopian', he insists that an 'alter-monde' must nonetheless be pursued which directly confronts and

22. See also Aronoff et al. (2019).

Figure 9. Between Geometabolic Escalation and Degrowth



repairs the planet's 'red zones' of concentrated misery, danger and destruction. The business-as-usual alternative will yield a patchwork of defensively fortified 'green zones', demarcated through monumentalized bulwarks of eco-apartheid, that amount to a '*de facto* triage of humanity' (ibid.: 45).

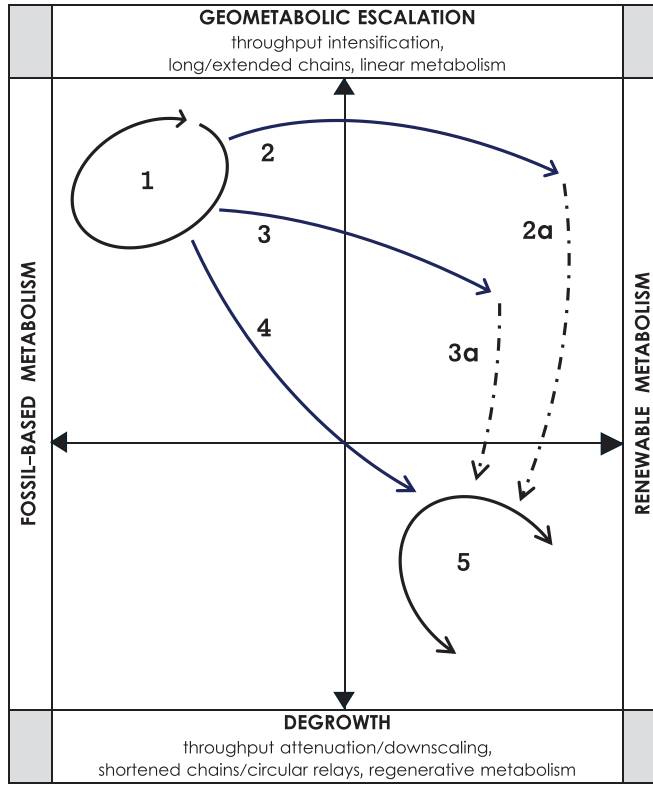
The dialectical spirit that infuses Davis' analysis is at once uncompromisingly grim yet insistently insurgent, if not hopeful. His account resonates with the philosophical orientation of the Soviet Constructivists' western European contemporary Walter Benjamin, who famously conceptualized capitalist modernity with reference to the catastrophic accumulation of suffering, ruination and destruction, yet also viewed the latter as the very soil from which emancipatory struggles would continue to ferment. We take inspiration from Davis' meticulous blending of systematic, analytically grounded pessimism with imaginative, rebellious utopianism and seek to articulate it to our conceptualization of capitalist urbanization during the Long Intensification. Accordingly, Figure 9 situates Davis' (ibid.: 29) 'mental tournament between analytic despair and utopian possibility' within

a conceptual matrix that specifies the key parameters of capital's spatial metabolism and possible pathways that might entrench, escalate, interrupt, or supersede it.

The bubbles associated with each side in Davis' 'mental tournament' demarcate potential trajectories of energo-metabolic, infrastructural and political-economic reorganization that would either reinforce business-as-usual capitalist operations ('pessimism of the intellect') or, alternatively, signal their destabilization or transcendence ('optimism of the imagination'). Pathways associated with the 'pessimism of the intellect' lead towards various forms of climate barbarism that further escalate the capitalist spatial metabolism of plunder, productivity and pollution, intensify the forced underreproduction of labour-power and further eviscerate the planetary biosphere. By contrast, the pathways associated with the 'optimism of the imagination' would lead towards a range of '*alter*-metabolisms' that seek to destabilize and ultimately transcend the core geometabolic imperatives of capitalism as well as the lock-in of fossil energy infrastructures. They would channel new forms of investment into publicly owned, democratically managed infrastructures of social reproduction. In so doing, such *alter*-metabolisms would also introduce various strategies of regeneration designed to repair the myriad forms of socioenvironmental injustice and ecological destruction that have been entrenched and planetarized during the Long Intensification.

The horizonal axis in Figure 9 depicts the social metabolism of energy production/consumption along a spectrum extending from fossil-based carriers (left side) to renewables (right side). The midpoint of this axis corresponds to a situation in which global energy use is premised upon an equal division among these variegated fuel sources. As discussed earlier, the contemporary global energy mix is overwhelmingly fossil-based and thus corresponds to a position on the far left of this axis (see Figure 3 above). The vertical axis of Figure 9 outlines possible metabolic trajectories of social relations extending from a capitalist logic of relentless geometabolic escalation, throughput intensification, imperialist extractivism and continuous waste externalization (top) to a degrowth metabolism based upon throughput attenuation, a shift towards a steady-state metabolism and intensive strategies of ecological regeneration and repair (bottom). We may assume that a trajectory of profit-driven throughput intensification is likely to involve extended supply chains supported by large-scale infrastructural configurations, long-distance logistical circuits and deepening forms of ecologically unequal exchange, along with a linear, non-regenerative metabolism of waste expulsion and toxification. By contrast, a degrowth *alter*-metabolism is likely to involve a downscaling and deceleration of throughput, a tendential regionalization of imperialist/extractivist infrastructural circuits and the establishment of more circular, agroecological, regenerative relays of material supply, food production and waste recycling, as well as a significant societal commitment to socioecological repair within

Figure 10. Possible Patterns and Pathways of Sociometabolic Transformation (1)



and beyond the zones of industrial intensification that animated the Long Intensification.

On a general level, Figure 9 summarizes several key energo-metabolic articulations that we have discussed above. First, extensive fossil energy production/consumption is intrinsically linked to a dynamic of metabolic throughput intensification, imperialist extractivism and large-scale infrastructural extension (upper left side of the 'pessimism of the intellect' bubble). Second, the integration of renewable energy carriers is fully compatible with capital's continued drive towards geometabolic escalation, large-scale fixed capital investments, imperialist extractivism and biospheric plunder (upper right side of the 'pessimism of the intellect' bubble). Beyond these broad generalizations, Figure 9 also demarcates a space of possibility in which renewable energy sources are articulated to various kinds of anti-imperialist, degrowth and reparative/regenerative projects that interrupt, destabilize, or transcend capital's spatial metabolism of plunder,

productivity and pollution (bottom right corner of the 'optimism of the imagination' bubble).

Figure 10 and Table 1 further elaborate these parameters and possible pathways of transformation within them. In considering these, we must proceed from the premise that the biospheric conditions that prevailed throughout the geohistory of capitalism, including during much of the Long Intensification, have been severely eroded in the early 21st century. This has induced the transgression of myriad environmental tipping points and a concomitant destabilization of human 'life-support systems' (Odum, 1993) across our toxified, hyper-terraformed planet (Barnosky et al., 2012; Richardson, et al., 2023). Consequently, all possible future pathways of sociometabolic transformation will unfold within a 'broken world' (Jackson, 2014; see also Blumenfeld, 2024; Buck, 2021) in which, amidst the proliferating crises of global capitalism, the 'residuals of fossil modernity' will fundamentally shape the prospects for future societal development and extra-human life (Folkers, 2021: 233). This is, therefore, a radically different biospheric conjuncture and geopolitical configuration than that in which the Soviet Constructivists and other radical proponents of the 'classical' vision of the urban commons extolled by Davis developed their interventions in the early decades of the 20th century. It requires an updated, conjuncturally specific understanding of the drastically transformed planetary parameters within which sociopolitical relations, infrastructural configurations and sociometabolic relays could be organized such that a 'safe operating space' (Röckstrom et al., 2009) for human and extra-human life may be preserved for future generations.

This bleak situation is further exacerbated by the massive outlays of carbon-intensive machinery, infrastructure and buildings that underpin the operations of capital and upon which the biopolitical reproduction of planetary social life is largely dependent. Given the colossal formations of earth-capital that are now sunk into such fossil-fuelled, carbon-emitting infrastructural assemblages, the ratchet effect of geometabolic escalation they inflict upon the biosphere and the powerful institutional and military forces that continue to support their continued operation or even expansion, carbon lock-in remains a substantial barrier to any and all strategies of post-carbon (and, indeed, post-capitalist) energo-metabolic and sociopolitical transformation (Malm and Carton, 2024; Seto et al., 2016).

Relatedly, as Malm and Carton (2024) argue, even as socioenvironmental crises intensify in severity, cadence and scale, we appear to have entered an 'overshoot' conjuncture of global capitalism in which hegemonic states and ruling class alliances are actively retreating from incipient, early 21st-century efforts to reduce carbon emissions. Instead, they are increasingly promoting mega-infrastructural strategies — including, most prominently, solar geoengineering and carbon capture/storage — to manage the catastrophic biospheric consequences of escalating carbon emissions. If upscaled and generalized, these technoscientific ventures will require

Table 1. Possible Patterns and Pathways of Sociometabolic Transformation (2).

	Energy metabolism	**Metabolic regime**	**Matrix of city/non-city relations**	**Form of biospheric governance**
Pathway 1: **fossil-fuelled ecocide**	Deepening carbon lock-in; expansion of fossil energy as dominant fuel source driving system-wide metabolic throughput	Plunder, productivity, pollution dialectic animated through an increasingly planetarized formation of the capitalist urban fabric; escalating, linear throughput	Long, extended chains of supply and waste externalization; continued production of exhaustion ecologies within and beyond metropolitan agglomerations	Roll-out of colossal new fixed capital investments to manage the 'overshoot' conjuncture (urban resilience, carbon capture and storage, climate geoengineering); proliferation of urban sustainabilty 'fortresses'
Pathway 2: **hybrid-powered ecocide**	Ongoing carbon lock-in; expansion of fossil energy as major fuel source, with growing symbiotic integration of renewable energy sources to 'top up' system-wide metabolic throughput	Plunder, productivity, pollution dialectic animated through an increasingly planetarized formation of the capitalist urban fabric; escalating, linear throughput punctuated by small, capitalized 'renewables loops' typically limited to major zones of agglomeration in the global North.	Long, extended chains of supply and waste externalization; continued production of exhaustion ecologies within and beyond metropolitan agglomerations, including in 'green' sacrifice zones	Roll-out of new energy infrastructures in conjunction with colossal new fixed capital investments to manage the 'overshoot' conjuncture (urban resilience, carbon capture and storage, climate geoengineering); proliferation of urban sustainabilty 'fortresses'
Pathway 3: **geometabolic idling**	Modest attenuation of carbon lock-in coupled with system-wide expansion of renewable energy consumption	Idling / partial downshifting of throughput; still predominantly linear metabolic relays, but with modest roll-out of metabolic circularity in some regions and territories ('managed decline')	Long, extended chains of supply are partially supplanted by more regionally, embedded metabolic relays in which some waste streams are recycled; continued production of exhaustion ecologies, fossil-based and 'green'	Significant fixed capital investments to manage the destructive impacts of climate breakdown, including major defensive infrastructures around urban centers as well as dispersed strategies of ecological repair and regeneration

(*Continued*)

Table 1. (Continued)

	Energy metabolism	Metabolic regime	Matrix of city/non-city relations	Form of biospheric governance
Pathway 4: **geometabolic drawdown**	Abandonment, sequestration, or retrofitting of 'stranded assets' related to fossil-based fixed capital infrastructure; institutionalized channeling of resources towards a democratically managed renewable energy infrastructure, including for circulation of commodities and people.	Major drawdown of energy consumption and metabolic throughput, especially in the global North / imperial core; roll-out of new forms of metabolic circularity—including regenerative primary commodity production and waste recycling	Recalibration of cities' supply and waste relays to minimize exploitative, destructive, and imperialist forms of externalization; creation of solidaristic, agroecological matrix for provisioning across places, territories, and scales; tendential decentralization of settlement matrix and land use systems	Democratic management of protective infrastructures to insulate vulnerable populations from climate disasters; expansion, upscaling and inter-regional coordination of strategies to regenerate landscapes and degraded ecosystems across the planet; roll-out of various approaches to climate reparations
Pathway 5: ***alter*-metabolisms of degrowth**	Expropriation and shutdown of fossil capitalist infrastructures and fossil energetic relays; termination / sequestration of most fossil-powered, carbon-intensive forms of machinery, equipment, and buildings; and continued roll-out of democratically managed, universally available forms and mixes of renewable energy	Construction of degrowth metabolism based on equal human rights, the dismantling of imperialist systems of plunder and pollution, democratic self-management of the biospheric commons, the regeneration of damaged ecosystems, and the constriction of planetary boundary-crossings	Coordinated, multiscalar reweaving of the inherited urban fabric to support a democratically planned and managed pattern of human settlement, provisioning, land-use, and transport grounded upon renewable energy, agroecological conservation, sustainable / circular metabolic relays, and the regenerative management of supply and waste	Consolidation and extension of democratically managed infrastructures to protect populations and ecosystems from climate disasters; systematic repair and regeneration of damaged landscapes and ecosystems; and the creation of spaces of refuge, provisioning, dignity, and empowerment for climate refugees and other displaced or dispossessed populations

significant new streams of fixed capital investment and major landscape transformations across the planet, further terraforming the Earth's terrestrial surface as well as the atmosphere. Consequently, the variegated formations of the 'new state capitalism' that were forged during the last three decades (Alami and Dixon, 2024) are likely to be further consolidated as dominant political institutions seek out new ways to maintain economic growth while rolling out large-scale, techno-infrastructural 'climate solutions' that are meant to limit or externalize the disruptive impacts of continued carbon emissions and associated sociopolitical dislocations. The geopolitical ramifications and socioenvironmental impacts of such geoengineering and carbon capture/storage strategies remain a matter of intense debate (Buck, 2019; Levien, 2025; Malm, 2019; Sapinski et al., 2021; Surprise and Sapinski, 2023). It seems clear, however, that their widespread embrace and increasing normalization in mainstream (geo)political discourse represents a major mutation in the logics of capitalist climate governance, one that sharply diverges even from those market-based 'climate solutions' that prevailed during the early 21st-century conjuncture in which Davis (2010: 45) considered the limited prospects for a 'journey of hope' towards an 'alter-monde'.

Five distinct pathways emerge from this schematic analysis, understood as energo-metabolic, infrastructural and institutional crystallizations within a 'moving map' of restructuring processes shaped by a turbulent, crisis-riven world economy and an overheated, toxified biosphere. Each pathway is also grounded upon specific relays of city/non-city relations that emerge from — and may significantly rework — inherited infrastructural configurations and geometabolic dynamics. Moreover, each pathway may lay the groundwork for — or block — myriad other pathways. These range from business-as-usual pathways (1, 2) leading to climate barbarism, deepening ecological enclosure and entrenched eco-apartheid ('pessimism of the intellect') to various possible degrowth configurations (4 and 5) in which *alter*-metabolisms would be established that confront 'the challenge of sustainable urban design for the whole planet' (Davis, 2010: 44) through a post-fossil, anti-imperialist, post-capitalist reconfiguration of sociometabolic relations and infrastructural configurations ('optimism of the imagination'). Pathway 3 is a hybrid configuration that, while perpetuating key elements of business-as-usual capitalist plunder and pollution, articulates various forms of energo-metabolic, infrastructural and institutional restructuring that could potentially provide strategic openings for systemic transformations and the eventual creation of a post-capitalist *alter*-metabolism. The sharply angled dotted lines in Figure 10 (2a, 3a) articulated from pathways 2 and 3 to pathway 5 underscore the path-dependency of all trajectories. The prospects for path-shifting changes are likely to become more constrained — but not necessarily closed — with the further lock-in of the sociometabolic relations, infrastructural configurations and institutional arrangements associated with the fossil-fuelled operations of capital.

It is not possible here to provide a more systematic discussion of the pathways outlined in Figure 10 and Table 1, their (geo)political conditions of possibility and their possible implications for societal and biospheric futures.[23] Our analysis suggests, however, that the prospects for emergent programmes of urban sustainability are likely to be forged not only through local conditions, experiments and strategies, but in and through a planetary forcefield of turbulent, politically contested geometabolic, infrastructural and institutional transformations. The remaking of inherited matrices of city/non-city relations will not only involve efforts to redesign urban space and the metabolism of agglomeration, but will also, just as centrally, require a radical reorganization of inherited regimes of energy, food and materials production and supply; systems of circulation and waste management; and still broader questions related to reparations for climate colonialism, the mechanisms of socioecological repair and the prospects for agroecological regeneration, landscape conservation and biodiversity protection.[24]

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Two salient conclusions emerge from this schematic assessment. First, the shift into an overshoot formation of capitalist environmental governance appears to be substantially transforming the geopolitical context in which urban sustainability strategies operate. Under these conditions, supposedly 'sustainable' approaches to urban governance and design are being operationally intermeshed with newly established techno-infrastructures of planetary environmental management, which not only perpetuate but also actively intensify the fossil-fuelled operations of capital and associated forms of neo-imperial plunder and pollution. Consequently, rather than serving as a site of public affluence, resource conservation and ecological design, much less as a lever of transformation towards a post-fossil social metabolism, the 'sustainable' city is in danger of being degraded into an infrastructural and ideological basis for the 'triage of humanity'— just as Davis (2010: 45) feared. Within this framework, the politics of urban sustainability may forge a 'deadly symbiosis' with newly established infrastructures of climate geoengineering to further escalate the imperial mode of living, thus permitting the intensified plunder of 'cheap natures', the extraction of underpaid, precarized labour from various peripheries and the concomitant expulsion of entropic, toxified waste into exhaustion ecologies and sacrifice zones across the Global South.

Given these tendencies and the persistent danger of misrecognizing them due to the ideological veneers of green urbanism, we must

23. For a closely related account, see Ajl (2021).
24. On these issues see, for example, Ajl (2021), Büscher and Fletcher (2020) Paprocki and McCarthy (2024), Sultana (2024), Táiwó (2022) and Vandermeer and Perfecto (2025).

reconceptualize sustainability in radically relational terms and, on this basis, embed its spatial politics within the shifting imperial geopolitical ecologies and metabolic rhythms of capital in a hyperpolarized world economy. Within the current formation of environmental governance, urban sustainability strategies appear to bolster a city-centric regime of eco-apartheid and imperialist extractivism. But, under a different geopolitical rule regime, could the politics of urban sustainability assume a different form in support of an *alter*-metabolic, perhaps even emancipatory transformation? This question might also, of course, be inverted: could a progressive, solidaristic, or emancipatory regime of environmental governance, whether territorial or planetary, not be forged precisely through the development and coordinated upscaling of localized or regionalized *alter*-metabolisms oriented towards degrowth, socioenvironmental justice, regeneration and repair, including within cities and metropolitan regions?

These vexing questions flow directly into our second concluding observation. From our point of view, the horizon of a genuinely solidaristic, emancipatory politics of urban sustainability must be defined by ongoing struggles to create collectively shared, democratically controlled capacities to forge *alter*-metabolisms that would interrupt and supersede the imperialist, fossil-fuelled dynamics of capitalist geometabolic escalation. On the one hand, this entails the development of strategies to disrupt capital's grip on the Earth, its landscapes and its life-forces. Their goal would be to seize control over the infrastructural matrices of earth-capital that continue to enforce a 'mute compulsion' of throughput intensification upon socioenvironmental relations and to enclose social reproduction and biospheric regeneration within its gravitational field. On the other hand, any meaningful project of urban sustainability must forge new infrastructures of production, circulation, social reproduction and waste recycling to organize the metabolism of city/non-city relations — and biospheric processes more generally — in solidaristic, regenerative formations.

The urgency of debates on degrowth stems above all from their wide-ranging, imaginative contributions to such efforts on variegated terrains of socioenvironmental practice, experimentation and transformation — encompassing, *inter alia*, the future configuration of urban life, agrarian environments, systems of resource management and approaches to waste absorption and recycling; pathways towards the democratic self-management and coordination of socioenvironmental relations; as well as strategies to repair the catastrophic damage unleashed upon the biosphere through capital's spatial metabolism. A radical politics of urban sustainability today must thus be fundamentally relational, stretching from the city across the web of life to the planetary biosphere; from imperial centres of agglomeration to the peripheralized geographies, degraded ecologies and brutalized populations of the majority world. Within this relational matrix, the spatial politics of urban sustainability can become not only regenerative and reparative, but also resolutely anti-imperialist.

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APPENDIX

Data sources for Figure 5

Figure 5 was constructed by Nikos Katsikis, Urban Theory Lab and TU Delft, from the following sources:

- *Airports*: Open Flights database; https://openflights.org
- *Built-up space*: GHS-BUILT-S R2023A, GHS built-up surface grid, derived from Sentinel2 composite and Landsat, multitemporal (1975–2030) European Commission, Joint Research Centre (JRC)
- *Submarine cables*: Submarine Cable Map dataset, Telegeography, 2013; www.submarinecablemap.com
- *Dams*: Lehner, B. et al. (2011) 'High-resolution Mapping of the World's Reservoirs and dams for Sustainable River-flow Management', *Frontiers in Ecology and the Environment* 9(9): 494–502. See also www.globaldamwatch.org/grand
- *Electricity grid*: Extracted from OpenStreetMap and Open Infrastructure map; https://openinframap.org
- *Mineral extraction sites*: Mineral Resources Data System (MRDS), United States Geological Survey (USGS)
- *Irrigated areas*: Global Map of Irrigation Areas by Stefan Siebert et al., 2013. Global Map of Irrigation Areas version 5 by Rheinische

Friedrich-Wilhelms-University, Bonn, Germany and Food and Agriculture Organization of the United Nations, Rome, Italy

- *Oil and gas extraction sites*: Global Oil and Gas Extraction Tracker, Global Energy Monitor, February 2025 release
- *Oil and gas Pipelines*: Global Oil Infrastructure Tracker, February 2025 release; https://globalenergymonitor.org
- *Energy production plants*: Global Energy Observatory; Google, KTH Royal Institute of Technology in Stockholm; Enipedia; World Resources Institute, 2019. Global Power Plant Database v1.2.0. Published on Resource Watch (http://resourcewatch.org/) and Google Earth Engine (https://earthengine.google.com/); accessed through Resource Watch (resourcewatch.org)
- *Ports*: National Geospatial Intelligence Agency (NGA). World Port Index, accessed through NGA portal; https://msi.nga.mil/NGAPortal/MSI.portal
- *Railways*: Global Logistics Database, Logistics Cluster, World Food Programme (WFP); https://data.humdata.org/dataset/global-railways?
- *Roads*: Global Roads Inventory Project (GRIP); GLOBIO (Global biodiversity model for policy support); Johan Meijer et al. (2018) 'Global Patterns of Current and Future Road Infrastructure', *Environmental Research Letters* 13: 064006.
- *Urban areas*: Schiavina M. et al. (2023), GHS-SMOD R2023A – GHS settlement layers, application of the Degree of Urbanisation methodology (stage I) to GHS-POP R2023A and GHS-BUILT-S R2023A, multitemporal (1975-2030) European Commission, Joint Research Centre (JRC); http://data.europa.eu/89h/a0df7a6f-49de-46ea-9bde-563437a6e2ba

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