Sustainability Transitions Through Fossil Infrastructures Deactivation: A Systemic Approach

Marco Grasso * and Daniel Delatin Rodrigues *

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Article

Sustainability Transitions Through Fossil Infrastructures Deactivation: A Systemic Approach

Marco Grasso* and Daniel Delatin Rodrigues

University of Milano-Bicocca, Italy

* Correspondence: marco.grasso@unimib.it

Abstract: Background: Achieving global sustainability goals requires not only the rapid deployment of clean energy, but also the deliberate deactivation of existing fossil infrastructures. However, the phase-out of coal mines, oil wells, pipelines, and power plants remain an underexplored facet of sustainability transitions. Aim: This feature article synthesizes interdisciplinary perspectives on fossil infrastructure deactivation as a core mechanism for systemic sustainability transitions. We foreground deactivation as a contested socio-political process involving struggles among incumbent industries, allied institutions, and emergent forces of change. Methods: Drawing on political economy, political ecology, transition studies, and critical infrastructure research, we integrate literature and real-world case insights. Key themes include the structural lock-in of fossil fuel 'networks', the agents and their alliances that resist or drive phase-outs, the discursive battles over legitimacy and justice, and the methodological approaches needed to study and enable deliberate transitions. Results: We find that fossil fuel phase-out is rarely a natural consequence of new technology alone – it must be actively governed and fought for. Cases from Germany's coal exit to oil bans in California, climate litigation against fossil majors, and grassroots efforts from Ecuador to the United States illustrate both the possibilities and challenges of deactivation in practice. Conclusion: Embedding fossil infrastructure deactivation at the center of sustainability transitions can illuminate pathways for action that are socially just and politically feasible. A sustainability transition requires not only adding green opportunities and alternatives but strategically retiring the entrenched systems of extraction and production of fossil fuels in ways that address power imbalances and equity concerns. This article offers a comprehensive framework for understanding and advancing fossil infrastructure deactivation as a critical lever towards a sustainable future.

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1. Introduction

Global efforts to promote sustainability transitions have overwhelmingly focused on building renewable energy capacity [1], yet far less attention has been paid to the active phase-out of existing fossil infrastructure [2]. Even as solar and wind power surge, coal mines, oil wells, pipelines, and refineries continue to operate, locking in carbon emissions for decades to come. In fact, global carbon dioxide emissions from fossil fuels reached a new all-time high in 2024 [3]. The fossil industry and its allies persist in expanding production, pouring investments into what researchers have termed "carbon bombs" – mega-projects capable of emitting over a gigaton of CO_2 each [4]. As United Nations Secretary-General António Guterres starkly observed in mid-2023, for every dollar the industry spends on oil and gas exploration, a mere four cents goes to clean energy and carbon and storage. He admonished that the fossil fuel industry and its 'enablers' – from financial institutions to public relations firms – bear a 'special responsibility' to stop obstructing the global shift to renewables [5].

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These realities underscore an uncomfortable truth: technical solutions alone are insufficient for sustainable futures if existing fossil-centred socio-economic systems remain intact and entrenched.

Momentum is growing for a strategic emphasis on fossil infrastructure deactivation as a complement to clean energy innovation [6,7] – and we suggest an analytical differentiation between these two broad strategies to sustainability. Scientists and climate advocates increasingly argue that meeting the Paris Agreement goals necessitates winding down operating coal, oil, and gas facilities on an aggressive timeline [8–11]. Yet deliberate fossil fuel phase-out has proven to be politically and socially challenging. Efforts to date have been halting and fragmented, revealing a critical gap in both research, policy and political action. Most transitions literature assumes that carbon-intensive infrastructures will inevitably decline 'automatically' once cleaner technologies become competitive [12]. But incumbent fossil fuel interests form a resilient and stable network of power that resists phase-out through economic leverage, institutional lock-in, and cultural narratives [13]. This 'fossil network' – a hegemonic coalition of companies, government agencies, investors, and ideologues – works to perpetuate fossil fuel dependency and delay its dismantling [14,15]. The persistence of this network helps explain why even unprecedented climate protests and youth movements have so far failed to bend global emissions curves downward. Despite mounting scientific evidence and public pressure, the world remains on a trajectory far off a sustainable path, with projections of 2.5–2.8°C warming implying catastrophic impacts [11].

Focusing on fossil infrastructure deactivation reframes decarbonization as not just a question of adopting new solutions, but of retiring the old and avoiding the new proposed. This article addresses this crucial reformulation, synthesizing insights from various disciplines and situating them within the current conflictual dynamics around fossil fuels. Our aim is to examine the socio-political, spatial, and institutional processes that underpin the deliberate phase-out of fossil energy systems [17]. In particular, we highlight the contentious dynamics at play: on one side, diverse agents are mobilizing to deactivate fossil infrastructures; on the other, entrenched interests strive to prolong the life of those assets. These antagonistic interactions – the push and pull between dismantling forces and stabilizing forces – is central to understanding how a sustainability transition can [or cannot] unfold.

We proceed by first establishing a conceptual framing for fossil infrastructure deactivation, drawing on literatures of energy transitions, political economy, political ecology, and critical infrastructure studies. Next, we provide case-based insights from recent real-world efforts to phase out fossil fuels – ranging from national coal exits to subnational oil bans and grassroots initiatives – illustrating the multi-dimensional challenges of deactivation. We then analyze agent-based and contentious dynamics, examining the networks of agents that resist or propel phase-outs, and the practices and narratives they deploy to either justify delay or demand sustainability transitions. After that, we offer methodological reflections on how researchers can better study these phenomena, including new approaches to capture questions of power, justice, and agency in transition processes. Finally, we conclude by synthesizing the findings and discussing the implications for the broader concept and practice of sustainability. By linking environmental imperatives with social and political analysis, we underscore that managing a rapid fossil fuel phase-out is not only a technical endeavor but a profoundly socio-political project – one that lies at the heart of a just and sustainable future.

2. Conceptual Framing: From Energy Transition to Sustainability Transition through Infrastructure Deactivation

Mainstream approaches to energy transition often emphasize technological substitution, the idea that renewable energy will simply displace fossil fuels over time [1,6,17]. In contrast, we argue for focusing on infrastructure deactivation: the purposeful shutdown and dismantling of fossil-fuel-based systems as an indispensable component of sustainability transitions. This shift in focus is needed because fossil infrastructures are not passive objects that fade away once cleaner options arrive; rather, they are active socio-political systems embedded in economies, politics, and governance. Political ecologists, anthropologists and geographers remind us of that those infrastructures like pipelines, power plants, and oil rigs are not merely technical artefacts, they rather

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encode and reinforce power relations, resource access, and patterns of development [18–24] In other words, fossil infrastructures form the backbone of what has been called a carbon lock-in: a self-perpetuating alignment of technologies, policies, capital investments, and cultural norms that together hinder the emergence of sustainable alternatives [25]. Fossil fuel phase-out, therefore, cannot be achieved by new investments alone; it also requires the disruption of the entrenched fossil fuel regime.

A growing body of literature conceptualizes the fossil fuel system as a kind of entrenched power structure or 'bloc' [26]. Grasso and Delatin Rodrigues, for example, describe a "fossil bloc"[15] – a coalition of fossil fuel companies, supportive government institutions, financial actors, and affiliated elites forming an "impenetrable barricade of interests" to maintain the status quo [27]. This perspective highlights that continued fossil fuel dominance is not an accident of slow technological diffusion, but the result of deliberate efforts by fossil incumbents to protect their power and influence. Fossil infrastructures serve as centers of accumulation and political patronage, especially in petrostates and resource-rich economies [14,22]. They generate revenues, employment, and geopolitical leverage, which in turn incentivize powerful actors to oppose their decommissioning. From oil subsidies and tax breaks to lobbying networks that shape policy, the institutional architecture surrounding fossil energy actively works to prolong its own existence (reinforce, self-reproduction) [28,29]. Thus, any meaningful attempt at deactivation must grapple with this entrenched incumbency: the policies, financial arrangements, and cultural and institutional norms that keep fossil systems alive well past their expiration date [30,31].

At the same time, critical infrastructure studies and political ecology provide a spatial lens on this issue, especially regarding the Global South. In many developing regions, fossil fuel projects are tightly interwoven with questions of national development, sovereignty, and post-colonial state-building [32]. For instance, oil and gas exports can underpin government budgets and debt repayments; coal plants may be justified by chronic energy poverty. Calls to strand these assets can thus trigger fears of economic stagnation or loss of autonomy. Hernandez and Newell [2023] document how even ostensibly green initiatives [like lithium mining for batteries in South America] can entrench extractive logics under a new guise [33]. This illustrates a broader point: global sustainability efforts intersect with historical inequities and development aspirations. Demands to halt fossil extraction in the Global South raise issues of climate justice – who bears the burden of transition – and may face resistance unless coupled with robust support for alternative development pathways. [34] Recognizing these geopolitical and justice dimensions is crucial to any comprehensive framework of fossil infrastructure deactivation. It underscores that sustainability transitions must integrate environmental imperatives and the rights to development and equity for less-industrialized nations.

Conceptually, then, fossil infrastructure deactivation can be seen as a process of socio-technical regime destabilization toward sustainability [35]. It involves undoing deeply embedded systems of fossil energy provision and the social contracts built around them. Scholars of sustainability transitions have begun to explore concepts like 'exnovation' – the purposeful removal of harmful technologies – as a complement to innovation. Unlike spontaneous market turnover, exnovation demands political will, strategic interventions, and inclusive planning [36]. It involves asking difficult questions: How do we decommission coal plants or oil fields in ways that minimize economic shocks and worker displacement? How can institutions dismantle assets that still have private value but pose a public climate cost? What new governance arrangements can facilitate the wind-down of an industry? These questions push sustainability transition theory beyond techno-economic modeling into the realm of power struggles, compensation schemes, and social dialogue.

In summary, fossil fuel phase-out is not an automatic outcome of building more renewables. Itis a transformative project in its own right, one that entails disrupting entrenched networks of agents and meanings. Fossil infrastructures persist not only because alternatives are insufficient, but because they are actively upheld by what we might call a 'fossil complex' of interests, ideologies, and institutions. Their deactivation, therefore, must be understood as both a material and political act:

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shutting down mines and rigs, as dismantling the power structures that support them]. Crucially, it must also be a just act: attention to who wins or loses from phase-out will determine its viability. In the next section, we turn to concrete cases that illustrate how these dynamics unfold in practice – highlighting both breakthroughs and obstacles in recent efforts to deactivate fossil infrastructure around the world.

3. Case-Based Insights: Global Trends in Fossil Fuel Phase-Out

While full fossil fuel phase-out remains a global challenge, recent cases provide instructive insights into the drivers and constraints of fossil infrastructure deactivation. These examples – spanning industrialized and developing contexts – demonstrate how political, economic, and societal forces converge in attempts to retire fossil assets. By examining them, we can discern emerging patterns of success and conflict in pursuing sustainability transitions.

Germany's Coal Exit

Germany's effort to end coal-fired power offers a high-profile example of negotiated deactivation. Long dependent on lignite [brown coal] mining, Germany in 2020 set a statutory plan to phase out coal by 2038. Subsequent political shifts accelerated this timeline: in 2022, the government reached a deal with energy giant RWE to exit coal in the key mining region of North Rhine-Westphalia by 2030 [37]. This compromise illustrates a crucial aspect of managed fossil infrastructure deactivation that balances climate urgency with incumbent interests. The agreement will prevent an estimated 280 million tons of CO_2 by shuttering plants early [37]. Yet it came at a controversial cost: the demolition of Lützerath, a small village sitting atop lignite reserves, to allow RWE to maximize extraction before the deadline [37]. Lützerath became a flashpoint where climate activists drew a red line, arguing that any further coal expansion undermines the very purpose of the phase-out. In early 2023, mass protests including prominent figures like Greta Thunberg converged on the village, even as police cleared the occupation. The German case shows a tension inherent in fossil infrastructure deactivation: a negotiated early exit can still be experienced as unjust or insufficient by grassroots movements. It shows the importance of how deactivation is pursued: whether it is simply a top-down technocratic decision or part of a broader social dialogue about justice. Germany's case also highlights regional disparity: the coal phase- out deal was facilitated by financial packages for affected workers and regions, underscoring that economic support and alternative livelihoods are vital components of a sustainability transition.

Oil Phase-Out Initiatives in California

In contrast to Germany's national policy, some fossil infrastructure deactivation efforts occur at local and subnational levels. California, a U.S. state often seen as a climate leader, has begun to directly target oil production. In 2022, the Los Angeles City Council voted unanimously to ban new oil and gas wells and to phase out all existing oil drilling within city limits over 20 years [38]. This landmark move came after years of campaigning by environmental justice groups in Los Angeles' low-income communities, who have faced health impacts from urban drilling. The ordinance signaled a remarkable shift in a city historically built by oil: it framed continued drilling as incompatible with residents' rights to clean air and safety. However, as with many deactivation efforts, the path has been contentious. Oil companies promptly sued, and in 2024 a state court struck down the Los Angeles' phase-out law on grounds that the city had overstepped its authority [39]. Judges argued that regulating oil operations falls under state jurisdiction, exposing a multi-level governance challenge. In response, California's state legislature passed [and the Governor signed] a law affirming local powers to curb drilling, potentially mooting the court ruling [40]. This back-and-forth exemplifies how legal and institutional frameworks can both enable and constrain fossil infrastructure deactivation. It also underscores the importance of coordination: local and national political authorities all have roles to play, and misalignments can slow progress. California's case is still unfolding: Governor Gavin Newsom has additionally set a goal for the state to phase out all in-state oil extraction by 2045 [40]. Achieving this will require not just declarations but resolving tensions between local initiatives, state law, and powerful industry stakeholders. Nonetheless, the

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Los Angeles experience has been heralded by environmentalists as a potential model for urban regions globally, proving that even entrenched oil hubs can chart plans to wind down extraction in pursuit of public health and climate objectives.

Climate Litigation and Fossil Fuel Liability

Another arena driving fossil infrastructure deactivation is the courtroom. In recent years, a wave of climate litigation has targeted both governments and fossil fuel companies to compel stronger action. Notably, in 2021 a Dutch court made history by ordering Royal Dutch Shell to cut its total CO_2 emissions by 45% by 2030 [from 2019 levels], effectively mandating a rapid downscaling of Shell's oil and gas business [41]. The case, brought by environmental groups and citizens, argued that Shell's ongoing investments in fossil expansion undermined global climate goals and infringed human rights. The Hague District Court's ruling marked the first time a company was legally obligated to align with the Paris Agreement, signaling that continued operation of fossil infrastructure could violate duties of care. [Shell later appealed, and in 2024 the Dutch Court of Appeal overturned the ruling on jurisdictional grounds [42], but the initial judgment remains a landmark in shaping the discourse on corporate responsibility.] Similarly, youth activists in Germany won a groundbreaking decision in 2021 when the German Constitutional Court found the government's climate law partly unconstitutional for deferring emissions cuts too far into the future [43]. The court compelled lawmakers to set clearer, stricter targets for the post-2030 period to protect the rights of younger generations. This judicial intervention forced an amendment to Germany's Climate Protection Act, effectively accelerating the timetable for phasing out fossil-based emissions. These examples show how litigation can serve as a catalyst for fossil infrastructures deactivation: by reframing inadequate phase-out plans as violations of legal or moral obligations, courts are increasingly pushing institutions to confront the need for early fossil infrastructure retirement. Lawsuits in the United States, Australia, and beyond – from cities suing oil majors for climate damages to legal challenges against new coal mines – are likewise putting pressure on the longevity of fossil assets. While not all cases succeed, the litigation strategy has opened a new front in the effort to strand fossil fuels, complementing political and grassroots approaches.

Grassroots Struggles and Deactivation from Below

Often the most direct challenges to fossil infrastructures come from civil society and Indigenous movements on the frontlines. Around the world, community-level opposition has proven capable of stopping or shutting down them, sometimes permanently. In the United States, for instance, sustained grassroots campaigning under the Sierra Club's 'Beyond Coal' initiative and allied local groups has led to the retirement or scheduled closure of nearly half of the coal power plants operating in 2010 [44]. This astounding outcome – over 200 coal plants closed – was not driven by federal policy, but by a constellation of city-level agents, public health advocacy, economic pressure [as renewables became cheaper], and strategic litigation. Organizers credit 'people in communities across America' for uniting to pressure utilities and regulators, demonstrating the power of bottom-up action in decommissioning dirty infrastructure. Similarly, Indigenous and environmental activists in North America mounted fierce resistance to oil pipeline projects, using encampments and non-violent direct action to delay construction. The Keystone XL pipeline, once destined to carry heavy crude from Canada's tar sands, was ultimately cancelled in 2021 after a decade of protests and a revocation of its permit: a major victory for activists and tribal nations who argued the pipeline posed unacceptable climate and water risks [45,46]. In another dramatic form of grassroots action, small groups of climate activists known as 'valve turners' have physically trespassed to manually shut off oil pipelines, temporarily halting millions of barrels of crude flow to draw attention to the climate emergency [29,30]. While illegal and controversial, these acts exemplify the lengths to which citizens frustrated with slow policy progress will go to directly intervene in fossil operations.

The Global South: Diversity of Practices

Global South communities are also forging pathways to constrain fossil fuels. In August 2023, Ecuador held a historic referendum in which nearly 60% of voters chose to halt all future oil drilling in the Yasuní National Park, a UNESCO-recognized biodiversity hotspot in the Amazon rainforest

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[48]. This people-powered decision will leave an estimated 726 million barrels of oil in the ground [49] sacrificing short-term revenues to protect indigenous territories and the global climate. Ecuador's referendum – one of the first instances of a country directly voting to keep known oil reserves unexploited – was the culmination of decades of grassroots and indigenous activism under the banner of 'Keep It in the Ground'. It illustrates how normative shifts and community mobilization can overcome entrenched extractive interests, even in a developing economy reliant on petroleum exports. However, it also highlights the fragility of such gains: following the vote, there have been political pressures and legal maneuvers attempting to delay implementation of the drilling ban [49].

Elsewhere, in Kenya, sustained public protests and court challenges led to the cancellation of a planned coal power plant in Lamu in 2019, preventing a new fossil infrastructure from ever being built [50]. And in Nigeria's Niger Delta, years of community unrest and environmental devastation have pushed international oil companies to begin divesting from onshore oil fields, effectively forcing a gradual shutdown of some operations [51]. These Global South cases emphasize that while grassroots and legal actions can yield significant wins, long-term support – including international climate finance and just transition aid – is crucial to ensure that halting fossil projects does not come at the expense of local development needs. Initiatives like the $8.5 billion Just Energy Transition Partnership to help South Africa retire coal plants with support for workers and communities are a step in this direction [52], illustrating how global cooperation can facilitate national phase-outs.

Across these diverse illustrations, the common theme that fossil infrastructure deactivation is invariably a contested process emerges. Whether through street protests, courtrooms, corporate boardrooms [in the case of shareholder activism], or ballot boxes, the push to deactivate fossil infrastructure encounters pushback from those with stakes in the old order. Yet, the cases also demonstrate that change is possible – sometimes quickly – when societal and political pressure reaches a tipping point. Each successful deactivation or avoided project chips away at the narrative of fossil fuels' inevitability and opens space for more ambitious sustainability action. The lessons from these examples inform the following analysis of the agents and strategies involved in sustaining or deactivatin fossil infrastructures, as well as the narratives they use to legitimize their positions.

4. Practices and Narratives in Fossil Infrastructure Deactivation

Deactivating fossil infrastructure is as much about who drives or thwarts change, and how they frame the narratives, as it is about technical feasibility. In this section, we examine the networks of agents and their practices, their narratives and discourse, and the contentious interactions that together shape the trajectory of deactivation. Understanding these intertwined elements is key to deciphering why some efforts advance while others stall.

4.1. Incumbent Networks and Structures of Endurance

The fossil fuel regime is upheld by a formidable constellation of incumbent agents. At its core are the fossil fuel companies themselves – coal mining firms, oil and gas corporations, shale fuels ventures – which have a direct interest in prolonging the life of their capital-intensive assets. However, these companies do not operate in isolation. They are embedded in what can be described as a wider support network or 'fossil alliance'. This includes financial institutions [banks and investors that finance projects or hold debt/equity in fossil firms], some labor unions [concerned with jobs in extractive industries], technology and service providers [from oilfield services to pipeline construction firms], and elements of the government [politicians, regulatory bodies, state-owned enterprises] that see local, regional and national benefit in fossil revenues or energy independence [27,34]. Media organizations and think tanks and research institutions sympathetic to industry can also be part of this network, shaping public discourse in subtle ways. Together, these agents build and maintain what one might call the 'structure of endurance', the formal and informal system that keep fossil infrastructure running. Examples include subsidies and tax incentives that guarantee profitability to extraction, bureaucratic permitting processes that favor incumbent operators, and political donation circuits that secure influence over policy. These reinforcing loops have created a

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path dependency: a situation where economies and communities become structured around fossil fuel activity, making change disruptive in the short term.

Empirical studies underscore how these networks function. Policy network analysis in countries like Switzerland, for example, shows that climate and energy policymaking tend to be dominated by stable coalitions of elites, often linking industry representatives and officials, which can lead to incremental adjustments rather than transformative change; this shows that even in an ostensibly consensus-driven context, agents closest to the centers of power were able to steer decisions in favor of continuity, while more radical voices were marginalized [55]. Internationally, multilateral forums can exhibit similar dynamics: research on institutions like the IPCC reveals the role of internal 'bridging agents' who strive to maintain consensus – a practice which, while valuable for unified science advice, may filter out more disruptive proposals for fossil fuel phase-out [32]. In effect, incumbents often excel at networked power: leveraging connections across corporate, state, and civil society realms to present a united front against aggressive phase-out policies.

One striking feature of incumbent strategy is how its obstruction to climate action has evolved from outright denial to more insidious forms of delay and diversion. Today, it is common to see fossil fuel companies publicly acknowledge climate change and even endorse 'net-zero' goals, all while pursuing business-as-usual growth. This reflects a shift to what has been termed obstruction through co-optation. Fossil fuel interests frequently adopt the language of sustainability to reframe the narrative and protect their core operations. For instance, major oil companies now emphasize investments in carbon capture or tree-planting offsets, promoting a vision of continued oil and gas use purportedly made clean'. They champion terms like 'energy mix' diversity and 'carbon management' to argue that fossil fuels can be part of the solution, rather than insisting there is no problem [56]. As Lamb et al. [2020] documented, there is a repertoire of 'discourses of climate delay' used by status-quo agents to justify inaction or minimal action [53]. These include arguments about economic realism [e.g. 'we can't disrupt the economy'], appeals to gradualism ['technology will solve this eventually, no need for drastic measures'], and redirection of responsibility [pointing to other countries or sectors as the real problem] [54]. All such discourses contain a grain of truth, which makes them persuasive: yes, jobs matter; yes, developing countries need energy; yes, innovation is happening. But they are deployed in ways that ultimately deflect, delay, or dilute the push for deactivation of fossil assets.

Concrete examples abound. In policy debates, industry groups often invoke energy security and reliability concerns to argue against rapid coal or gas plant closures, warning of blackouts or price spikes if transition moves 'too fast'. They stress that fossil fuels are current indispensable and insist on a slower timeline, during which they lobby for public funding into speculative techno-fixes [like largescale carbon capture and storage] rather than committing to phase-outs [57].

Another frequent narrative is 'fairness' but framed in a way that favors delay: for instance, claims that it would be 'unfair to workers' or 'unfair to certain regions' to dismantle fossil infrastructures without decades of preparation, which in practice becomes an argument to extend the life of those infrastructures without clear end dates. While ensuring fairness is indeed crucial [and central to our argument for a sustainability transition], incumbents sometimes co-opt the 'just transition' vocabulary to oppose any near-term closure plans: essentially using the promise of justice for workers as a shield against climate policy.

4.2. Counter-Agents and Networks of Deactivation

While much of the literature on climate contestation has focused on symbolic and discursive struggles [58], a growing body of empirical research has begun to trace the concrete, procedural, and material mechanisms through which fossil infrastructures are actively deactivated [59,60]: in this sense what is required is move beyond ideological opposition to examine how infrastructures are materially contested, legally obstructed, and politically dismantled to understanding how disruption unfolds in practice.

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One of the clearest aspects is that deactivation is that is not a singular act, but a patterned and strategic practice carried out by networks of diverse agents. Coalitions composed of Indigenous communities, environmental groups, legal advocates, and sometimes sympathetic insiders engage in a range of coordinated actions aimed at interfering with fossil infrastructures, from project siting to financial flows to public legitimacy. Legal injunctions, regulatory delays, coalition-building, and targeted protests are not isolated tactics but interconnected strategies. These practices form a kind of distributed choreography of contestation that incrementally weakens fossil infrastructures and their supporting systems [61,62].

Resistance does not merely oppose state authority but often generates alternative forms of governance from below. Particularly in Indigenous-led struggles, resistance operates as a mechanism of land stewardship, jurisdictional assertion, and legitimacy production. These practices do not simply contest extractivism, they produce new political spaces and institutional alternatives. Resistance becomes a proposal of different governance systems that create ruptures in the fossil regime [63].

Far from being removed from policy discourse, many agents of deactivation are deeply engaged with the strategic design of alternative policies and technological pathways. Radical movements are also constructive in their engagement, often possessing expertise comparable to institutional agents. This engagement complicates the dichotomy between insider reform and outsider protest and reveals how contestation can reconfigure policy agendas and open new institutional pathways [64,65].

Another key insight involves the strategic navigation of scale. Many successful cases of disruption involve agents shifting between local, regional, and national scales—e.g., using local permit challenges to trigger broader political debate or leveraging transnational networks to challenge state-led infrastructure. These 'scalar practices' reveal how fossil fuel contestation is inherently multi-level, and how political space can be reconfigured through cross-scalar coordination [63].

Another key characteristic is the 'sequencing' of deactivation. Rather than isolated flashpoints, many interventions follow a cumulative logic: a blockade leads to legal action, which spurs regulatory scrutiny, which in turn may attract financial divestment or political attention. Tracing these processes and events reveals how disruption operates as a chain of interlinked practices, not as a one-off event. Understanding these sequences is crucial to grasp how infrastructures are destabilized over time [65].

These themes illustrate that counter-obstruction is deeply infrastructural, woven through institutional, legal, and material engagements that alter the terrain of fossil politics. Deactivation of fossil infrastructures generally shows the following features: relationally arising from dynamic alliances and oppositions; practical embedded in legal filings, blockades, procedural delays unfolding through processes in time, not isolated acts; mediated through multi-level and cross-jurisdictional actions.

Opposing the incumbent network are a range of countervailing agents seeking to destabilize and ultimately deactivate fossil infrastructures. These include environmental NGOs, grassroots community groups, youth movements, certain progressive policymakers, and increasingly, financial activists [such as divestment campaigners and 'shareholder rebels' in boardrooms]. Over the past decade, a transnational network of anti-fossil actors has gained coherence. Climate justice organizations from the Global North and South collaborate, share strategies, and target common adversaries [for example, coordinating campaigns against a big oil company or a global bank financing coal]. This networked countermovement operates across multiple scales: local groups might fight a single pipeline, while international NGOs work on treaty proposals like the Fossil Fuel Non-Proliferation Treaty [67]. They are linked by a shared goal of leaving fossil fuels in the ground, even if their motivations range from protecting a local river to averting planetary catastrophe.

Social network analyses of climate advocacy illustrate some strengths and challenges of these movements. Jasny and Fisher [2023], studying climate protest coalitions, found that movements bridging multiple issues – for instance, connecting climate action with economic justice, racial equity,

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and Indigenous rights – can attract broader support and forge powerful alliances [68]. The multi-issue alignment [such as the Green New Deal framing] creates a more inclusive narrative for change. However, it can also strain organizational focus and unity, as different factions prioritize different aspects of the struggle. The climate movement is not monolithic; it spans radical system-change advocates and more reformist elements, sometimes leading to tactical disagreements. Nonetheless, the overall trend is an increasingly sophisticated social environment that attacks the fossil fuel problem from all angles – legal, financial, cultural, and political.

One potent strategy emerging from this social environment is climate litigation, which we touched on earlier. By suing both governments and corporations, activists not only aim for direct outcomes [e.g. a court order to shut a polluting facility], but also seek to shift public discourse and investor calculus. A high- profile lawsuit – even if unsuccessful – can spotlight evidence of, say, a company's disinformation campaigns or the inconsistency of climate pledges with expansion plans: this contributes the delegitimation of the fossil fuel industry. Indeed, beyond concrete policies or infrastructure battles, a key objective of climate activists has been to erode the social license to operate [69] of fossil fuel companies – to recast them from engines of progress to perpetrators of harm. Johnstone and Kivimaa [2018] term this 'discursive disruption': activists deliberately challenge the cultural narratives that portray fossil infrastructure as normal or beneficial [16].

Counter-movements also operate within the halls of finance. The fossil fuel divestment campaign – which began on US college campuses about a decade ago – has grown into a global movement convincing universities, churches, pension funds, and even sovereign wealth funds to pull investments from coal, oil, and gas companies. By 2023, institutions managing over $40 trillion had committed to some form of fossil fuel divestment [70]. While the direct financial impact is debatable [many new investors step in to buy those shares], the symbolic and political impact is significant. Divestment normalizes the view that fossil fuels are risky and unethical business. It puts CEOs on the defensive and pressures companies to at least feign climate responsiveness. Shareholder resolutions and activist investors have also scored notable wins – for instance, in 2021 a tiny hedge fund won seats on ExxonMobil's board in a bid to force the oil giant to reckon with climate realities. This kind of insider disruption indicates that even within capitalism's core institutions, agents of deactivation are maneuvering to steer capital away from fossil infrastructure.

4.3. Narratives

Underpinning the clash of agents are dueling narratives and discourses about energy, economy, and society's future. On the side of the resistance to fossil fuel phase out and fossil infrastructure continuity we encounter a spectrum of discourses that accept climate science but propose delay-justifying logics, as described above. All these narratives, often propagated [directly or indirectly] by fossil fuel proponents, serve to legitimize continued fossil infrastructure operation by painting phase-out as either unnecessary, unfair, or impossible.

Conversely, those advocating for rapid transition have crafted counter-narratives that highlight the possibility and desirability of a fossil-free future. These narratives frequently invoke themes of health, justice, innovation, and responsibility. For example, the concept of a 'just transition' originated in the labor movement and has been embraced by climate advocates to stress that protecting workers and communities is fully compatible with – indeed, integral to – bold climate action. Rather than allowing incumbents to monopolize the fairness argument, just transition narratives propose concrete plans for retraining workers, investing in affected regions, and democratizing energy systems. This flips the script: continuing fossil fuel use is portrayed as the more unjust path [due to its climate and health damages], whereas phasing out fossils with support mechanisms is the route to shared prosperity. Another powerful narrative centers on intergenerational justice, epitomized by youth activists who argue that current inaction piles burdens on the young and unborn. This framing proved influential in the German Constitutional Court's decision mentioned earlier [43], and it resonates broadly by casting climate procrastination as a violation of basic fairness across time.

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In many cases, alternative narratives and discourses also draw on local and indigenous knowledge to challenge dominant paradigms. For instance, Indigenous communities opposing pipelines often frame the issue not just in environmental terms but as a defense of sacred lands and treaty rights, introducing a discourse of sovereignty and stewardship that contests colonial extractive models. In the Global South, climate campaigners increasingly articulate the need for a 'Global Green New Deal' or similar, emphasizing that wealthy countries must support developing ones in leapfrogging fossil fuels: a narrative of solidarity and reparative justice on the world stage. This counters the delay narratives that poorer nations must rely on fossil fuels for growth; instead, it posits that with fair financing and technology transfer, clean development is achievable and desirable for all. Indeed, at recent UN climate negotiations, coalitions of vulnerable nations and civil society have successfully pushed to put 'fossil fuel phase-out' in official texts, overcoming a long-standing taboo [70]. The fact that the phrase even appeared [albeit watered down to 'phase-down' of coal at COP26] signals a crack in the discursive armor that fossil fuels once enjoyed in global diplomacy.

It is important to note that the battle of narratives and discourses is not just abstract rhetoric – it shapes policy outcomes. Public opinion and voter attitudes can be swayed by how issues are framed. For example, if deactivating a coal plant is presented solely as an environmental necessity, it may face local opposition over job fears; but if packaged as part of a 'regional renewal' program with new economic opportunities and community engagement, it stands a better chance. Likewise, national leaders are more likely to enact bold policies if there's a compelling narrative of national pride or competitive advantage in doing so. Narratives also influence institutional thinking: the International Energy Agency's [IEA] notable shift in 2021 to state that no new fossil fuel projects are compatible with 1.5°C [71] came after years of advocacy challenging the IEA's previously conservative scenarios. In short, narratives are a form of power. Those who can successfully frame the story of the sustainability transition will to a large extent guide its pace and form.

In summary, the agent-based and discursive dynamics surrounding fossil infrastructure deactivation reveal a complex interplay of power and persuasion. On one side, incumbent networks deploy both material influence and narrative tactics to slow down the loss of their assets. On the other, a diverse coalition of change agents pushes to accelerate phase-outs, armed with both disruptive tactics and inspiring visions of a post-fossil future. This 'chess match' of agents and ideas will determine whether society can overcome inertia and vested interests to proactively retire fossil fuels in time to avert climate catastrophe. The next section examines how researchers and practitioners can better analyze and engage with these dynamics – that is, what methodological tools are needed to capture the full complexity of deactivation processes and to inform effective strategies for change.

5. Methodological Reflections: Researching Deactivation in a Complex World

Studying the deactivation of fossil infrastructure presents unique methodological challenges. Traditional approaches in energy research – often grounded in technical-economic analysis or aggregated modeling – struggle to fully capture the political, social, and cultural complexities of deliberate deactivation. In this section, we reflect on how scholarship can adapt and innovate methodologically to illuminate the processes discussed above. We highlight both the limitations of dominant methods and promising approaches that can provide deeper, more actionable insights into fossil infrastructure deactivation as a socio-political phenomenon.

5.1. Limitations of Conventional Approaches

Much quantitative energy and transition modeling implicitly treats the decline of fossil assets as a smooth, optimization-driven outcome – for example, integrated assessment models might 'retire' coal plants in a scenario once they become uneconomic or when carbon prices reach a certain threshold. While useful for macro-level projections, such models abstract away the very forces that often impede or accelerate real-world phase-outs: lobbying, community resistance, policy lock-in, and the vagaries of political will. Techno-economic models tend to assume rational agents and

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efficient markets, thereby underestimating how power imbalances or institutional inertia can cause misalignment between what 'should' happen for cost-optimal mitigation and what does happen. For instance, modelers might be puzzled at why a country continues to build coal plants despite cheap solar: therefore a richer methodological lens is needed to examine the institutional interests or geopolitical considerations driving such decisions.

Another common approach is the case study of individual transitions [say, how a particular city closed its coal plant]. While invaluable for detail, isolated case studies can fall short in generalizability and in understanding cross-scale interactions. They might tell us what happened in one instance but not fully why it succeeded there and failed elsewhere. Comparative methods can improve on this by identifying patterns across cases, yet even then, if analyses remain confined to formal variables [e.g. policy types, economic indicators] they might miss under-the-radar dynamics like informal networks or narrative frames.

Quantitative social science tools [like regression analysis on factors influencing policy outcomes] also meet limits in this context due to data availability and the uniqueness of many deactivation processes. There are only so many instances of, say, an oil ban to include in a dataset, and each might be context-dependent. Moreover, key concepts like 'political will' or 'institutional lock-in' are hard to quantify. This is not to dismiss statistical or model-based research: rather to note that, on their own, they risk offering an overly sanitized view of sustainability transitions, one that might mis-identify levers of change. Paradoxically, a purely econometric analysis might conclude that GDP per capita correlates with coal phase-out, recommending growth and technology as solutions, while missing that in reality a grassroots mobilization or court case was the tipping factor.

5.2. Towards a Pluralistic and Reflexive Methodology

Given these challenges, we are in dire need of a more pluralistic methodological toolkit to study fossil infrastructure deactivation [72,73]. This involves mixing methods and embracing both qualitative and quantitative lenses [74,75], as well as engaging more directly with stakeholders and marginalized perspectives. Below, we outline several approaches that show promise.

Network Mapping and Political-Economy Analysis

To unravel the fossil network, researchers can employ social network analysis and political economy mapping. This might include mapping corporate board interlocks, campaign finance flows, or relationships between regulators and industry groups. Such methods make power structures visible, for instance, revealing that key decision-makers in energy policy attend the same forums funded by fossil companies, or that a handful of banks underwrite the majority of coal financing. Network analysis has been used to show how certain actors occupy central bridging roles that, if redirected, could realign policy networks toward phase-out [76,77]. Conversely, identifying choke points in the network [e.g. a minister or agency that consistently blocks reform] can inform activist and advocacy strategies. However, it is important to emphasize that this does not simply mean presenting static images of these networks. It is necessary to track the evolution of the network over time and the conflicting interactions between networks regarding a fossil infrastructure.

Ethnography and Qualitative Case Studies

There is a growing recognition that deep qualitative research – including ethnography, interviews, and participant observation – is essential to capture the lived realities and contested meanings around fossil infrastructure deactivation [78,79]. For example, ethnographic studies of communities undergoing a coal plant closure can reveal social attitudes, fears, and hopes that numbers alone won't show. By spending time on the ground, researchers can document the narratives people tell about the infrastructure: is it viewed as a proud legacy or a hated polluter? Who is considered a trustworthy messenger regarding its future? Such insights are crucial for designing sustainability transition policies that resonate locally. Ethnographic work within institutions [like a government ministry] can likewise expose internal dynamics – perhaps mid-level officials supportive of transition, or conversely a culture of delay and risk-aversion. These fine-grained details enrich our understanding of how decisions around deactivation are actually made.

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Discourse Analysis

Building on the importance of narratives discussed earlier, critical discourse analysis allows researchers to systematically study texts and rhetoric – from parliamentary debates and media coverage to corporate PR and activist messaging [58]. By coding and analyzing discourse, one can track how certain frames [e.g. 'clean coal' or 'jobs versus environment'] dominate or wane over time, and how different agents adopt or contest these frames. For instance, a study might analyze speeches in a legislature to see if and when terms like 'fossil fuel phase-out' became politically acceptable, or how often policymakers cite 'just transition' in substantive ways. Understanding discourse helps identify windows of opportunity where the range of acceptable ideas has shifted enough that ambitious policies can be tabled. It also helps in deconstructing delay narratives, thereby empowering communicators to counter them more effectively with evidence and reframing.

Participatory and Action Research

Given that the subject matter has direct stakes for communities and the planet, some scholars advocate for participatory methods that involve stakeholders in co-producing knowledge. This includes techniques like scenario co-development workshops where researchers facilitate sessions with diverse stakeholders [local citizens, workers, officials, activists] to imagine and plan fossil-free futures [80]. Such exercises not only yield qualitative data on perceptions and preferences but also serve as interventions that can shift perspectives and build trust. In the same vein, transdisciplinary action research projects might embed researchers in community transition initiatives, helping to document process while also advising on strategy. These approaches break the barrier between observer and participant, aligning research with real-world problem solving. For instance, a project in a coal town might bring together miners, municipal leaders, and renewable energy experts in a series of facilitated dialogues, generating locally grounded plans for industry diversification –all while researchers study the evolving social dynamics and record insights that could be applied elsewhere.

Comparative and Relational Studies

As mentioned, comparisons across cases are useful, but a methodological twist is to adopt a relational comparison perspective: examining how cases influence each other through learning or cascade effects. The fossil infrastructures arena is ripe for such analysis: for example, how did the success of the Canadian tar sands campaign [killing pipelines] feed into activism against a proposed pipeline in East Africa? Or how did Germany's coal exit plan reverberate in policy discussions in other coal-dependent countries? Tracing these linkages helps reveal a global picture of deactivation momentum [or backlash]. It acknowledges that we live in an interconnected world where ideas and strategies diffuse rapidly.

Positionality and epistemology

Scholars are increasingly aware that research on sustainability transitions has been dominated by Global North perspectives and often technocratic paradigms [81]. To truly understand fossil infrastructure deactivation, especially in the Global South, methodologies must be decolonized and pluralized. This means supporting research led by scholars from affected regions, valuing indigenous knowledge systems on stewardship and land, and questioning one-size-fits-all models of transition. It also means examining what tends to be excluded or rendered invisible in current analyses. As highlighted earlier, things like informal practices [e.g. behind-the-scenes political deals to quietly cancel a project, or even clandestine sabotage] are rarely documented yet may be quite influential [82] Similarly, temporal tactics – such as governments announcing distant phase-out dates to buy time, or companies strategically delaying action expecting policy changes – might slip under the radar of short-term studies. Methodologically, this suggests paying attention to absences and silences: what is not being publicly discussed, which voices are missing in data, and how power might be operating in those gaps.

In conclusion, advancing the study of fossil infrastructure deactivation calls for methodological innovation, integration, and humility. By combining quantitative rigor with qualitative depth, embracing participatory approaches, and consciously bringing in marginalized perspectives,

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researchers can better capture the full mosaic of this transition challenge. Such enriched understanding is not an academic exercise alone: it directly informs how we design policies and movements to navigate the coming phase-out in socially just ways. The complexity and contestation at the heart of deactivation demand that we move beyond one-dimensional analyses and equip ourselves with tools that can see the infrastructure, the people around it, and the power between them all at once [74,83].

6. Key Findings

This article investigates how the deliberate deactivation of fossil infrastructures – understood not merely as a technical or economic measure, but as a deeply political, spatial, and social process – is conceptualized and enacted across a broad body of interdisciplinary scholarship. In doing so, we asked: How do analytical and methodological frameworks explain the socio-political and institutional dynamics of fossil infrastructure deactivation? Who are the relevant agents driving or impeding deactivation, what practices and processes shape their actions and effects, and what discourses and power structures sustain or disrupt the status quo? By synthesizing insights from diverse literatures and real-world cases, we have developed a comprehensive foundation for addressing these questions. Several key findings emerge from our analysis:

Centering Deactivation in Sustainability Transitions

We began by reframing sustainability transitions narrative by shifting from a sole focus on adding renewables to placing the active phase-out of fossil fuels and their infrastructures at the analytical center. This shift uncovers the often-neglected reality that fossil infrastructures do not disappear on their own. As our work showed, fossil systems endure due to a nexus of institutional lock-in, economic interests, and cultural norms. Thus, achieving sustainability transitions is not an automatic co-product of innovation, but rather a project of dismantling entrenched regimes. Sustainability, in this view, entails grappling directly with questions of decline and exnovation, a paradigm change for fields accustomed to studying growth and adoption. We underlined that technical feasibility and cost-efficiency [while necessary] are not sufficient; the crux lies in overcoming political and social barriers to shutting down the fossil-fueled status quo. This perspective contributes to sustainability science by insisting that managing the end-of-life of unsustainable systems is as vital as fostering the birth of sustainable ones.

Agents on Networks, and the 'Fossil Bloc'

Our exploration of agent-based dynamics highlighted that fossil infrastructure deactivation is fundamentally a contested political process. The incumbent 'fossil bloc' – a term we used to denote the coalition of fossil fuel industries and their allies – operates as a coherent force deploying multiple forms of power [material, institutional, and discursive] to delay or prevent phase-outs. We saw how this bloc manifests through concrete networks: industry lobby groups influencing policy, financial institutions bankrolling expansions, and even cultural institutions normalizing fossil dependence. Opposing them are emergent networks of deactivation: climate activists, forward-looking policymakers, innovative entrepreneurs, and communities seeking environmental justice. These counter-agents have scored significant wins [as illustrated by case studies like Germany's coalitions pushing early coal closure, or civil society litigation forcing government action], yet they face an uphill battle against incumbency. The relational lens proved insightful since deactivation outcomes often hinge on interactions between proponents and opponents. For example, a government may commit to a phase-out only when pressure from below becomes impossible to ignore, or conversely, a well-timed industrial campaign can derail proposed regulations. We conclude that navigating fossil infrastructure phase-out requires a coalition-based strategy: aligning diverse agents [labor, environment, consumers, local governments] into a pro-transition alliance strong enough to counter the fossil bloc's influence. This has direct practical resonance, as building such alliances will be key to implementing policies like coal plant retirements or gas bans in the face of pushback but also to create the ground to renewable energy expansion

Narratives and Practices

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Our work also illuminated the profound role of discourse in shaping the trajectory of fossil infrastructure futures. We found that over the past decade, obstruction of climate action has shifted from outright denial of science to more subtle 'discourses of delay' [13]. These include narratives emphasizing incrementalism, portraying fossil fuels as necessary for economic stability or poverty alleviation or offering techno-fixes that avoid the need for structural change. Such discourses can be dangerously effective in slowing policy momentum, as they resonate with common concerns and uncertainties. They posit that leaving fossil fuels behind is not only feasible but beneficial for society at large, and that the true injustice lies in perpetuating extractive, polluting systems [84–86]. Our analysis suggests that winning the public discourse is a crucial component of achieving policy change. In practice, this means communicators and leaders must continue to expose false solutions [like 'clean coal' myths or unproven carbon capture and storage promises] while uplifting stories of successful transitions and just outcomes.

The battle of ideas actively enables or constrains the political space for deactivation measures; but we also tried to highlight the concrete, procedural, and material mechanisms through which fossil infrastructures are actively deactivated. Deactivation emerges as a patterned, strategic process carried out by diverse agent-networks – including Indigenous groups, legal advocates, and grassroots coalitions – through coordinated practices such as litigation, regulatory delays, and public protest. These practices often generate alternative forms of governance, reconfigure institutional pathways, and operate across multiple scales and phases. Viewed in this light, counter-obstruction is also deeply infrastructural: a dynamic, relational, and temporally sequenced practice that reshapes the terrain of fossil power from within and below.

Methodological Innovation for Sustainability Transitions

We highlighted the need for methodological pluralism and justice-centered research. Dominant quantitative models and top-down analyses, while useful for certain insights, often miss the nuanced human and power dimensions of fossil infrastructure deactivation. We highlighted the need for methodologies that can uncover hidden power relations [through network and institutional analysis], amplify marginalized voices [through participatory action research and global South-led studies], and capture the lived experience of transitions [through ethnography and case studies] [59,60]. In particular, we underscore that research must pay attention to issues of justice – procedural justice [who is heard and involved], distributive justice [who bears costs and who gains], and restorative justice [how historical wrongs and imbalances are addressed]. Methodologies that integrate these facets will produce richer academic knowledge and ate same time can actively inform policy design to ensure no one is left behind in the shift away from fossil fuels. Ultimately, we advocate that the research community approaches fossil infrastructure deactivation with the same transdisciplinary, solutions-oriented mindset that is increasingly applied to renewable energy uptake, recognizing that dismantling unsustainable systems is an arena ripe for experimentation, learning, and innovation in its own right [87,88].

7. Conclusion

The deactivation of fossil infrastructure stands as one of the defining sustainability challenges of our era. It tests our collective ability to break from an unsustainable past and imagine new systems grounded in ecological balance and social equity. This article has argued that such a transformation will not happen quietly or automatically: rather it must be willed, planned, and fought for. Encouragingly, the cases and trends reviewed here show that momentum is building: coal plants are closing, oil drilling is being challenged, and narratives of a post-carbon society are taking root. However, we have also seen how formidable the opposition remains, and how easily progress can stall without continued pressure and imaginative policymaking.

For scholars and practitioners of sustainability, a key implication is that sustainability tranisitons is inseparable from questions of power, justice, and agency. Deactivating fossil infrastructures is not a narrow technical task, it is a broad societal project that must negotiate conflicting interests and values. It requires robust democratic processes, stakeholder engagement, and compensatory

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measures to ensure fairness. It also demands steadfast leadership in the face of inevitable pushback and transient setbacks [such as legal defeats or geopolitical shocks that tempt a return to fossil reliance]. The interdisciplinary approach we have taken – weaving together political economy, ecology, transition studies, and critical infrastructure insights – demonstrates the value of breaking academic silos to tackle such a multi-faceted issue.

Ultimately, advancing fossil infrastructure deactivation is not only about preventing climate catastrophe; it is also about seizing an opportunity to remake our world for the better. A managed deactivation of fossil infrastructures can yield co-benefits: cleaner air and water, green jobs in new industries, and empowerment of communities that have long borne the externalities of extraction. It can also help rectify historical injustices by prioritizing support to those most affected by both climate change and the transition [workers, indigenous peoples, and vulnerable nations]. In this sense, fossil fuel phase-out and fossil infrastructure deactivation are at the heart of the sustainability agenda, where environmental necessity meets social justice.

We conclude with a final thought: as the world strives to limit warming to 1.5°C or 2°C, every coal mine closed and every oil field retired is a tangible step toward that goal, but how we get there matters profoundly. Will it be chaotic, crisis-driven, and inequitable? Or deliberate, orderly, and just? The work of scholars, policymakers, and activists in the coming years will largely determine this outcome. Shedding light on the pathways for sustainability transitions – as we have aimed to do here – can guide the process of deactivation to not only meet climate targets, but to also foster a more sustainable and fair society in the process. The dismantling of the fossil fuel era, daunting as it is, thus becomes a beacon for transformation: a chance to build the foundations of a sustainable world that thrives within planetary boundaries and leaves no one behind.

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