Energy Research & Social Science 115 (2024) 103648

Contents lists available at ScienceDirect

Energy Research & Social Science

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

Original research article

Stacked energyscapes: Conceptualizing fossil fuel and renewable energy entanglements in low-carbon transitions

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ARTICLE INFO

Keywords:
Energy transitions
Energy stacking
Energyscape
Inflation Reduction Act

ABSTRACT

Energy transitions are often characterized as discrete progressions away from fossil fuels to renewable energy, typically in different geographic spaces, which result in "winning" and "losing" communities. Policies have been enacted to encourage renewable energy investment in "losing" fossil fuel extractive communities. Such conceptualizations do not sufficiently consider how fossil fuel extraction and renewable energy intersect with and shape each other in these spaces. We introduce the term "stacked energyscapes" to better characterize these interactions. Rather than replacing a fossil fuel-based energy system, we argue that renewable energy is "stacked" atop it, entangling their sociotechnical "energyscapes" together in ways that can both accelerate and slow the transition. We develop this conceptualization based on a review of 149 journal articles, policy papers, and news articles of energy transition case studies, primarily focused on the U.S. We identify and analyze five key domains where stacked energyscapes manifest: land, labor, infrastructure, finance, and policy and regulation. Conceptualizing energy transitions as stacked energyscapes can sharpen understandings of transitions in extractive communities so as to better enable just transitions and reduce the environmental footprint of the energy sector.

1. Introduction

In August 2022, U.S. President Joe Biden signed the Inflation Reduction Act (IRA), the largest and most comprehensive climate bill in the country's history. Amongst other things, the Act extends and renews the clean energy tax credit for existing and new renewable energy projects, a policy that is projected to significantly ramp up utility-scale investments [1]. Notably, the Act prioritizes projects (by applying a 10% credit bonus) that are located in "energy communities," defined as places highly reliant on fossil fuel extraction and/or where coal mining facilities have recently closed [2]. The Act's proponents frame this focus as a way to support energy transition and economic development in coal mining towns that have already faced long-term job losses and economic decline [3,4]. This provision, along with an expansion of federal loans and loan guarantees, has redoubled interest in repurposing old wells, power plants, and degraded mining lands for clean energy inputs and installations [5].

The explicit targeting of extractive communities highlights a common understanding of the energy transition: that it is a shift *from* fossil fuels *to* renewable energy [6]. From this perspective, the central goal of transition is the replacement of "old" energy fuel sources and infrastructure with "new" clean energy sources and infrastructure. This understanding suggests that places that embrace the clean energy economy will benefit from an influx of jobs and tax revenues, and places that reject it will experience a downturn. Moreover, downturns will be especially acute in extractive communities that cannot or choose not to transition - with coal towns in Appalachia as a prominent case [7]. Policymakers and advocates hope that an influx of renewable energy investment can turn extractive regions into new clean energy economies [8].

Yet a broader view of the U.S. energy transition reveals a more complicated picture - not just replacement of fossil fuels with renewable energy, but of mutual existence and synergy. In the Permian Basin in west Texas, for example, increased oil production is being partly powered by electricity from nearby solar and wind farms [9,10]. In the Bakken oil shale in North Dakota, energy firms are investing in a "blue" hydrogen hub that uses locally sourced natural gas in the hydrogen production process [11]. In these regions, and others, the presence of fossil fuel extraction offers some cost advantages for renewable energy developers, with established land arrangements, permitting processes,

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https://doi.org/10.1016/j.erss.2024.103648
Received 10 November 2023; Received in revised form 10 June 2024; Accepted 12 June 2024
Available online 20 June 2024

and skilled workers. At the same time, the shift to clean energy sources may prop up extractive industries in unexpected and counterproductive ways. These interactions extend beyond renewable energy installations to the "mining" of fossil fuel wastes for lithium and rare earths used in solar and wind manufacturing [12]. These dynamic entanglements have been somewhat overlooked in the energy transition scholarship, which, while attuned to the ways that established energy regimes shape emerging ones, has not systematically explored how they intersect and complement one another in specific places.

The aim of this paper is to propose a framework for conceptualizing these intersections in extractive regions where energy communities are situated. We suggest that these regions can be characterized as *stacked energyscapes* of low-carbon transition, where old and new energy production systems overlay and articulate with one another in ways that have not been fully analyzed in transition scholarship. These interactions are contradictory. On the one hand, fossil fuel extractive zones have characteristics that attract clean energy, including vast land parcels, existing infrastructure, a supportive regulatory environment, and a potential labor pool. On another hand, investments in renewable energy installations, hydrogen production, and mineral waste processing can bolster and extend the life of extractive industries. These synergies have significant consequences for local resource-based economies as well as the shape and speed of energy transition as a whole. Understanding them is essential to developing policies and programs that aid energy communities while stabilizing emissions. While our focus here is in the U.S., our analysis raises important factors to consider for facilitating energy transitions in other regions of the world.

Our analysis is based on a review of 149 journal articles, policy papers, and news articles of energy transition case studies. The authors iteratively compiled this list by first searching Google Scholar for literature reviews of the energy transition scholarship and articles within the energy studies literature examining the relationship between fossil fuels and renewable energy. We read these articles to confirm our hypothesis that the intersections of fossil fuels and renewable energy have been under-examined in the literature. Our review also helped us to identify five domains of stacked energyscapes: land, infrastructure, labor, finance, and policy and regulation. Second, we conducted targeted searches of Google Scholar and Google News on the terms "energy transition" and each of the five domains. An annotated bibliography of these articles was compiled by a team of undergraduate and graduate student research assistants, which the authors have used to develop the arguments presented in this paper.

The next section of the paper distinguishes the term "stacked energyscapes" and its contribution to the energy transition literature. In section 3, we analyze five domains of stacked energyscapes - land, infrastructure, labor, finance, and policy and regulation - where synergies between fossil fuel and renewable systems manifest. These five domains are not an exhaustive list, but what we view as foundational elements to initiate discussion around the concept of stacked energyscapes. We conclude with suggestions for future research to apply and strengthen this term to other domains, such as technology and geopolitics.

2. Stacked energyscapes: Theoretical foundation

That fossil fuels continue to play a role in the transition to renewable-based power systems is a well-recognized phenomenon. Energy analysts commonly use the term "energy mix" to indicate the number and percentage of different energy sources in a system at any given time [13]. Somewhat less commonly, energy planners will use the more specific term "electricity stack" to refer to the aggregate supply curve of different energy generation sources in the power system [14]. In this understanding, the grid operator sets the curve based on the marginal cost of the different sources, with the lowest-cost sources deployed first to meet expected demand. Applying this understanding of "stacking" to energy transition suggests that *cost* is the most important driver of moving from fossil fuels to renewable energy; as renewable sources become cheaper, they will migrate to the bottom of the electricity stack and be used first.

Yet it is also well-recognized that transition is shaped by more than energy costs alone. This argument is central to the literature on sociotechnical transitions. This work understands energy systems as sociotechnical systems [15] that are embedded in society. Society gives meaning to technical systems while technology mediates the ways in which society functions [16]. Energy *transitions* can thus be described as a transition from one sociotechnical system to another [17]. Using a multi-level perspective framework, scholars have analyzed how entrenched values and institutions that govern a sociotechnical system - known as a sociotechnical "regime" - interact with "niche" innovations and the sociotechnical "landscape" to destabilize incumbent regimes and, eventually, establish a new regime [18]. This approach underscores the need to attend to the sociotechnical dimensions of energy planning in addition to economic dimensions.

Importantly, transitions are not always clean breaks with past sociotechnical regimes [17,19]. Rather, an energy sociotechnical system at any particular moment is comprised of an accumulation of different energy sources and their associated institutions, regulatory frameworks, and even infrastructure. This composition, in part, reflects the nature of transitions as both a "moving toward" a new sociotechnical system and a "moving away" from a previous one - processes that occur in fits and starts, leaving elements of the old regime in place even after a transition is seen to have occurred [20]. Eitan and Hekkert [21] call this continued influence of past sociotechnical systems on current ones a "path dependent lock-in," emphasizing the risks and benefits that this presents for rapid energy transition. Indeed, they suggest that established energy players can manipulate lock-ins for their own benefit - for example, incumbent firms that use profits from fossil fuel projects to diversify into renewable energy [22–24]. The end result is a kind of contradictory energy system, characterized by elements from both fossil fuel and renewable energy regimes that compete for supremacy, yet can also be highly entangled.

Energy geographers, meanwhile, have analyzed the spatial dynamics of sociotechnical energy transitions - what some scholars, building the multi-level perspective and geographical understandings of landscape, call an "energyscape." Delina [25] defines an energyscape as "not only the energy technologies, infrastructure and systems but also the structural arrangements and institutions that make up an entire ecology of what can be called an energy sociotechnical system." Howard et al. [26] add a spatial component, calling energyscapes "the complex spatial and temporal combination of the supply, demand and infrastructure for energy within a landscape." Building on these definitions, we might think of an energyscape as a *place-based manifestation* of a sociotechnical system; energyscapes embody and serve as nodes in the broader system, but also mediate and shape the system through their own place-based socionatural characteristics (this is similar to how geographers have understood other "scapes", such as hydroscapes - see [27]). As the broader system undergoes transition, energyscapes embodying the old fossil fuel regime may continue to persist or expand, even as new renewable energyscapes proliferate. A growing body of research shows how old and new energyscapes can be inextricably linked through, for example, the extraction of certain minerals (cobalt, lithium, rare earths) in one place that allow for the manufacturing and installation of clean energy in another [28,29]. Scholars have also examined how community identity and place attachment in extractive energyscapes can generate both resistance to and receptiveness toward renewable energy development [30].

Relatively unexplored in the literature, however, are the multiple ways that fossil fuel and renewable energyscapes intersect and reinforce each other *in specific places* - a phenomenon we call "stacked" energyscapes. This sociotechnical understanding of "stacking" is very different from its use in energy planning, and has roots in earlier literature on rural household transitions. This literature emerged as a critique of the concept of the energy ladder [31], popularized in the 1980s, which argued that as households develop, they will often transition away from "traditional", biomass-based energy sources for cooking and heating toward "modern", primarily fossil fuel-based energy sources. However, studies have found that instead of discretely moving from one rung of the ladder to the next, households often "stack" energy choices, using a variety of fuels from traditional and modern energy systems, as the economic conditions of households improve [32]. This is a deliberate choice by households, based on the cost of fuel and stoves but also technical characteristics of stoves and cooking practices, cultural preferences, and health impacts [33]. Applied to energyscapes, "stacking" highlights both the deliberate choices that underpin how fossil fuel and renewable energy systems intersect, and that these choices are shaped by place-based technologies, values, preferences, and capabilities.

Stacked energyscapes thus helps fill a gap in understandings of energy transitions by foregrounding the place-based entanglements and synergies between fossil fuel and renewable systems - and in turn, how these synergies may both accelerate and inhibit transition. This approach complements and extends the concept of energy "additions" [34] which, while importantly showing that fossil fuels have continued to grow instead of replacing renewable energy, does not explain how and why the two can mutually reinforce each other. Moreover, while energy geographers are highly attuned to the spatial embeddedness of transitions, ranging from landscape characteristics to historical path dependencies [35], there has been less attention to how new energy systems can be embedded in - or *stacked upon* - existing energy systems in ways that generate synergies. And while energy scholars have introduced the concept of "energyscape" to situate sociotechnical systems in space, the ways that distinct energyscapes intersect, compete, and complement each other are less understood. Stacked energyscapes, in sum, illustrate how fossil fuel and renewable systems become intertwined in far more ways than a cost-based supply curve would suggest; they build on and influence one another in specific places, and in doing so, shape the direction and implications of local and national transitions.

3. Analyzing stacked energyscapes

To analyze stacked energyscapes, we turn an empirical focus to the places where interactions between fossil fuel and renewable energy production are most acute: energy extractive communities. For simplicity's sake, we use the expansive definition of "energy communities" in the IRA, which are statistical areas where "'0.17 percent or greater direct employment or at least 25 percent of local tax revenues [are] related to extraction, processing, transport, or storage of coal, oil, or natural gas,' *and* unemployment is at or above the national average in the previous year" [36]. Many of these communities have been reliant upon fossil fuel extraction for generations, contributing to a strong shared identity and place attachment that can manifest as resistance to energy transition [30]. As such, much of the growing literature on these communities focuses on appropriate policies and strategies to enable a just transition [7,37,38], with a strong focus on attracting renewable energy investment through mechanisms like the IRA.

Yet the story is not as simple as a decline in fossil fuels and the (hopeful) growth of solar and wind. Rather, as our framework suggests, fossil fuel installations and their associated firms, institutions, arrangements, and values (their "energyscapes") may partly remain in place, even as new renewable energy systems proliferate. This stacking does not occur on its own, but results from deliberate decisions made by energy companies, local officials and community members seeking ways to limit disruptions from energy transition while securing its benefits [38,39]. Stacking energyscapes may thus act as a brake on transitioning from fossil fuels while still enabling (and even accelerating) deployment of renewable systems.

Our examination of stacked energyscapes in energy extractive communities focuses on five key domains: land, infrastructure, labor, finance, and policy and regulation (see Fig. 1). We analyze these five components because they have been shown to be significant factors of energy transitions in separate, influential texts in the literature. First, McCarthy [40] highlights renewed interest in *land* - particularly rural land - as a fundamental outcome of the shift from a subterranean to a spatially extensive terrestrial energy system. Second, the importance of *infrastructure* in energy transitions, particularly infrastructure financed by nation states, was emphasized in a special issue in this journal [41]. Third, *employment* impacts are often debated in transition studies [6] and are a central component of IRA investments in energy communities. Fourth, Baker [42] describes the similar *financial* mechanisms and firms that are diversified in both fossil fuels and renewable energy, while Christophers [22] notes that fossil fuel projects can subsidize renewable investments. Lastly, Grubler [43] emphasizes the role of *policy and regulation* in setting the pathways and speed of energy transition, underscoring the importance of consistency and continuity. Below, we examine each of these domains of stacked energyscapes in detail, primarily drawing on case studies in the U.S.

3.1. Land

The first domain, land, is perhaps the clearest and most important to assembling new energyscapes. The spatial extensiveness of renewable energy reconfigures land use practices as well as property rights systems [40,44]. Changing land use practices are also embedded in and shape sociotechnical dynamics in the places where they occur. Within the U.S., there is growing interest in finding lands to situate utility-scale solar projects. Farmlands are a prime target as such lands are typically flat and often located near electricity substations [45]. But, transferring land out of farming is frequently contentious, which incentivizes locating renewable energy in non-farm landscapes [46]. And across much of the world, the non-farm landscapes with the highest solar (and for that matter, wind) factors are rural deserts and plains - the same places that host fossil fuel extraction [47,48].

This is the case in energy communities in the rural U.S. West where stacked energyscapes are proliferating. The plains and scrublands of west Texas that boast one of the nation's highest wind capacity factors sit atop the oil-and-gas producing Permian Basin [49]. North Dakota' Bakken Oil Shale has high wind potential, as does the region above and alongside Wyoming's Powder River Coal Basin [50,51]. One of the best environments for continuous solar generation is in California's San Joaquin Valley, on and adjacent to the Bakersfield oilfields that have been producing for over a hundred years. These regions, long reliant on fossil fuel extraction, are rapidly developing new renewable energy projects [52–54].

Moreover, the different land use requirements of fossil fuels and renewables allows for facilities to be close to each other, or even co-located. This is because extraction, by and large, is a vertical operation targeting subsurface resources, while wind and solar are horizontal operations capturing aboveground resources. Co-location is also made possible by the structure of land ownership in many U.S. states, which bifurcates surface rights and subsurface mineral rights. Owners of subsurface rights - which take precedence over surface rights - may be willing to allow solar and wind development as long as "reasonable use" of the surface for oil and gas drilling is not impeded [55]. This scenario can be highly attractive to oil and gas firms because it allows them to continue operating (potentially even underneath the solar or wind farm by using horizontal or directional drilling[1]), or if the land has never produced or been abandoned, allows them to collect royalties by simply holding subsurface rights. Moreover, owners of surface rights can also earn dependable revenue through leases to solar and wind firms.

Shared use of land is less possible in coal regions, as coal mines and infrastructure are more spatially extensive. However, as on oil and gas

[1] At least one solar project, the 150 MW Oberon installation in the Permian, has cut out parking lot-size rectangular spaces in the array for future drill rigs to dig vertically - see [53].

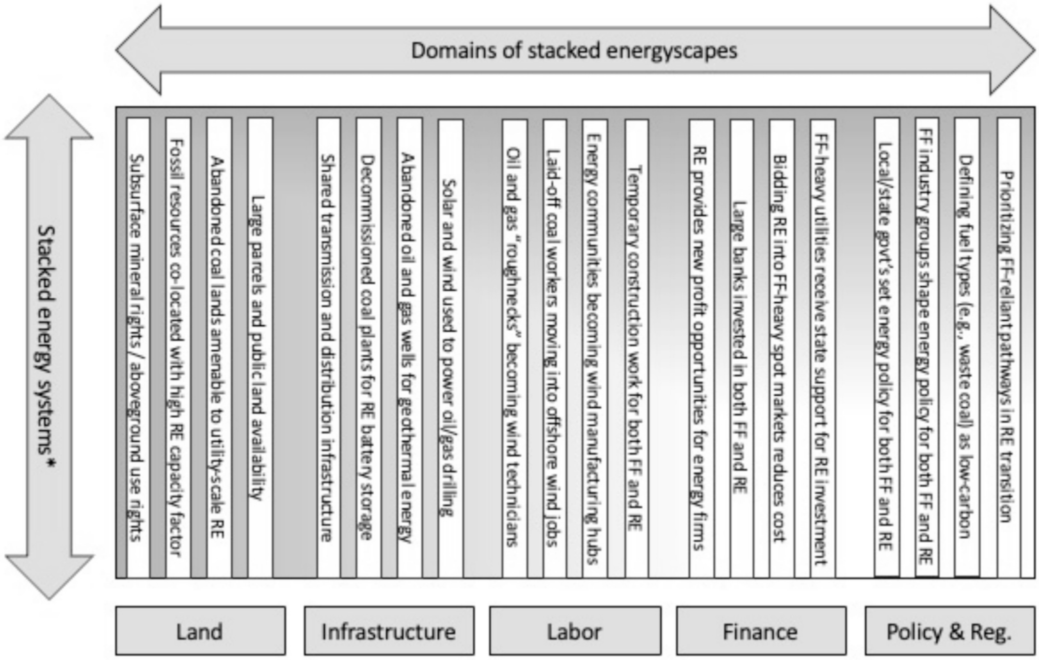

Fig. 1. Stacked energyscapes framework. Each column represents a domain and its characteristics. Vertical shading represents the entangled nature of stacked renewable energy and fossil fuel systems.

lands, siting wind and solar on *abandoned* coal lands has gathered pace over the past decade [56–59]. U.S. law requires coal mining firms to reclaim disused coal lands, which include surface mines, coal processing areas, and coal waste beds. Results of reclamation can be poor [60], and many sites languish with lingering environmental effects [61] - if they receive adequate reclamation funding at all [62]. Yet, while they may not be able to be used for agriculture or recreation, such sites are amenable for wind and solar development - in part because they may be able to make use of existing transmission lines. Recognizing their potential, the U.S. Environmental Protection Agency (EPA) is encouraging renewable energy projects on abandoned and contaminated lands through the *Re*-Powering program [57]. In one of the clearest examples of stacked energyscapes, the U.S. Department of Energy (DOE) recently awarded $90 million to build a 402 megawatt (MW) utility-scale solar facility on 2700 acres of former coal mine lands in central Pennsylvania [63].

Several other factors make land in extractive regions attractive to renewable energy developers. Rural and remote land in the U.S. West tends to be divided into large parcels with few owners that can be leased (and if needed, consolidated) in a relatively straightforward manner [64]. Landowners also tend to be familiar with leasing agreements with fossil fuel extractive firms, such that solar and wind developers find them easier to deal with. Indeed, some of the same "landmen" who plied extractive regions for oil and gas leases now do the same for solar and wind firms [65]. Owners of land with high solar and wind potential increasingly recognize the value of their properties and are pushing back against "lowball" landmen offers that ensnared previous generations of farmers and ranchers sitting atop fossil fuel resources [66].

Perhaps the most important factor is the vast amount of state and federal public land open to wind and solar development. The U.S. Department of the Interior through the Bureau of Land Management (BLM) owns some 380,000 sq.mi. of mostly desert and chaparral in the U.S. West. Traditionally, the BLM has prioritized oil and gas leases on public lands, even in cases where resource potential is low and leases are speculative [67]. However, in the past decade the BLM has encouraged utility-scale wind and solar projects, identifying suitable zones for projects and adopting a "variance" permitting procedure for proposals outside of these zones [68,69]. Under the Biden administration, the BLM set a goal mandated by the *Energy Act of 2020* of approving permits for 25 gigawatts (GW) of renewable energy on public lands by 2025 [70]. A 2023 proposed rule would reduce leasing and generation fees for renewable projects by 80% and streamline the approvals process [71].

Yet, these new solar and wind projects are still shaped by the BLM's relationship to fossil fuel extraction on public lands. The IRA includes a provision that 2 million acres of public lands must be offered for oil and gas leases before leases are issued for solar and wind - a carve-out added by West Virginia senator (and scion of a coal family) Joe Machin [72]. The IRA also requires the BLM to hold quarterly lease sales that result in an oil and gas lease. These measures are in addition to existing subsidies and tax incentives for fossil fuel extraction on public lands [67]. Whether these oil and gas-friendly additions to the IRA actually facilitate more extraction is an open question – since oil and gas firms do not have the capacity to drill on all of their leases [73]– but the ongoing prioritization of fossil fuels inextricably ties solar and wind expansion to the decisions made by these firms.

3.2. Infrastructure

In addition to co-location on the same land, renewable energy and fossil fuel infrastructure are often highly intertwined. Repurposing fossil fuel infrastructure for renewable energy systems not only reduces the cost of projects but can minimize disruptions to human-environmental systems. At the same time, prolonging the life of fossil fuel infrastructure by stacking renewable energy atop it may also perpetuate extractive operations, and thus inhibit transition.

The most straightforward example of infrastructure stacking is shared ancillary infrastructure required of all energy projects, such road and rail connections to deliver and transport materials, and more importantly, electrical infrastructure to transmit power to consumers. In the U.S., high-voltage transmission has traditionally been built to link large coal-fired power stations to industrial and population centers - meaning that the closer wind and solar are to existing lines, the more easily (and cheaply) they can connect. Much of U.S. wind and solar development in the 2010s utilized these existing lines [74]. In recent years, however, many of these high-voltage lines are at risk of over-capacity, creating a long multi-year queue of new renewable projects that lack approvals because they cannot connect to the grid [75]. The development pipeline is further exacerbated by a lack of electrical substations in rural areas with high solar and wind potential [45]. Renewable energy proponents have called for a significant ramp-up in transmission line construction to deal with this bottleneck [76]. These issues are particularly acute in the PJM Regional Transmission Organization, the largest regional electricity grid in the U.S. As of September 2022, there were over 202 GW of renewable projects waiting in the PJM queue. If connected to the grid, this would double the amount of renewable energy capacity operating in the U.S. With an estimated time of four years to be interconnected to the grid, the PJM stopped accepting new renewable energy projects in February 2023 to clear the project backlog and to implement reforms to speed up interconnection times [77].

Meanwhile, an increasing number of renewable energy installations are making use of fossil fuel infrastructure itself, by repurposing decommissioned coal plants into solar, wind, and battery storage facilities [78]. Coal plants are situated on large land parcels that can be populated with solar panels and wind turbines - a strategy being pursued at nine retired plants owned in Illinois owned by Vistra Corp., a power producer [79]. Illinois' Coal-to-Storage Grant Program supports the transformation of coal plants to large battery storage at two other facilities [80]. Similar projects are proposed or underway in states across the U.S. [78]. Even if renewables and storage are not located onsite, retired coal plants can still act as the grid connection point for nearby installations, enabling them to circumvent the connectivity bottlenecks currently plaguing solar and wind developers [81].

Another emerging example is to repurpose abandoned conventional oil and gas wells for geothermal energy. Abandoned wells are those whose owners are unknown and are not currently productive. They are a concern because many are thought to be leaking methane but locating them and "plugging" them to stop leakages is costly. The U.S. federal government has allocated $4.7 billion to the Department of Interior to plug abandoned wells [82], most of which will be allocated to state environmental regulators. The extent to which these funds will significantly aid in plugging abandoned wells is unknown. The Pennsylvania Department of Environmental Protection, the main environmental regulator in the state, estimates that it costs about US$33,000 on average to plug an abandoned well [83]. Yet, it also reports costs as high as US$800,000 to plug one well. The state has identified 25,000 abandoned wells and plugged about 3000 to date [83]. However, it estimates that hundreds of thousands of wells have been drilled in the state since the 1850s, when well drilling began [84]. Given these complications, researchers have been exploring the potential to repurpose abandoned wells for geothermal energy, arguing that it would be less costly than plugging and provide a new clean energy alternative to fossil fuels [85]. To advance the use of abandoned wells for geothermal energy, the DOE initiated a Wells of Opportunity Initiative [86], which, to date, has awarded over $36 million to demonstration projects across the US [87,88].

Distribution infrastructure can also be repurposed, and in some cases, shared outright between fossil fuels and renewable energy. In areas like the Pennsylvania Marcellus, pipelines originally built to transport natural gas directly from wells are being used to deliver renewable natural gas (RNG), defined as methane produced from farm waste, landfills, and wastewater [89]. The ratio of RNG to shale-derived natural gas in U.S. pipelines is small but growing [90]. A more prominent use case of existing pipelines is to transport hydrogen by "blending" it with natural gas, enabling it to be used to both heat buildings and in gas-fired power plants [91]. Only 1600 miles of hydrogen pipelines are currently in operation in the U.S., and are almost all located near the Gulf of Mexico, making utilizing the existing nationwide natural gas network an attractive proposition [92]. Some 26 pilot projects are currently in place, including the DOE's HyBlend project [92]. Still, there are significant safety concerns with hydrogen leaking from pipelines designed for methane, and studies to date show that existing gas turbines may not be able to run on hydrogen-heavy mixes [93]. Skeptical observers suggest that blending hydrogen is simply a clever means to "greenwash" the continued extraction of natural gas, particularly given that less than 1% of hydrogen in the U.S. is produced using renewable energy [94].

Indeed, infrastructural synergies by and large benefit the persistence of fossil fuel extraction. A clear case is that of solar and wind farms that are constructed primarily to power oil and natural gas drilling. One example, a solar project at California's Belridge oil field, features a 26.5 MW solar array to power drill rigs, and an 850 MW-thermal of solar collectors for steam generation, which is pumped back into the earth for enhanced oil recovery (EOR) [52,95]. A 29 MW solar array also provides electricity for Chevron's Lost Hills facility located next door to Belridge [96]. In Texas' Permian Basin, meanwhile, Exxon Mobil is buying 500 MW of wind and solar power produced at the nearby Sage Draw wind farm and Permian solar facility [9]. Occidental Petroleum, another Permian producer, chose to both purchase nearby solar and build its own solar farm [10]. Extractive firms are also making use of U.S. federal tax credits in the IRA for battery storage projects to purchase or construct hybrid renewables + storage systems to power their operations [97]. Across the board, producers rationalize these investments as a way to reduce their carbon footprint - even as they continue to drill for fossil fuels and release emissions.

3.3. Labor

The perception of job losses in fossil fuel regions is a longstanding and persistent concern. The International Labor Organization (ILO) estimates that low-carbon transition in a 2 °C scenario will lead to a global loss of 6 million jobs in fossil fuel industries by 2030 [98]. Job loss is an especially salient issue for energy communities in the U.S., particularly coal regions in Appalachia [99]. Bringing back the glory days of coal in Appalachia was an important pillar of former President Trump's 2016 election campaign [100].

Yet the same ILO report predicts a global gain of *23 million* jobs in green energy [98]. In announcing his support of the IRA, Senator Joe Manchin highlighted the potential of the Act to create new jobs in Appalachia as well as for the potential for fossil fuel and low carbon energy systems to co-exist as a result of the Act [101]. Scholarly literature, however, tends to treat fossil fuel job loss and renewable energy job creation as spatially distinct processes, with "losing" communities requiring compensation and upskilling [102–104]. The possible movement of fossil fuel extractive workers to renewable energy within energy communities is rarely considered in the literature (see [105] for recent brief treatment of the topic).

The "stacking" of renewable energy labor atop fossil fuel extraction labor is certainly occurring, however. In Texas, amidst an oil and gas downturn, solar and wind developers have targeted laid-off fossil fuel workers (who one executive called "oil and gas refugees") to fill roles in geology, land acquisition, engineering, finance, asset management, and energy contracting [106]. In North Dakota's Bakken, former oil workers on fracking derricks are being retrained as wind turbine technicians at installations nearby [107]. Former coal workers in Wyoming's Powder River Basin are also moving into wind generation [108], with Chinese-owned firm Goldwind specifically recruiting coal miners for a turbine manufacturing facility in the area, and offering free training [109]. Recognizing this trend, staffing companies like Workrise in Texas are contracting with both oil and gas and renewables firms to recruit and train skilled "roughnecks" to work in green jobs [110].

One particular pathway that has received attention is from coal to offshore wind. The Gippsland coal region in Australia, which has experienced ongoing job loss and economic decline, is now the site of a 2.5 GW "Star of the South" offshore wind project touted by the state government as an employment lifeline. The project's developer and state officials recently released a report that specifically identifies transferable skills between coal and offshore wind, with technical, trades, and engineering roles having particularly strong overlap [111]. The Australian government estimates that the project will provide 760 local jobs during construction and 200 ongoing jobs [112]. A very similar process is underway in the North Sea off the northern United Kingdom coast, where former coal workers are being retrained as tradespeople, technicians, and operators [113]. Offshore wind firms have partnered with local and national governments to construct a renewable energy manufacturing hub in Newcastle and the Humber coal valley (plans are also underway to transform a disused coal-fired power plant into an offshore wind battery hub) [114]. Fossil fuel workers in the U.S. also appear to be increasingly seeking out construction and technician jobs in the offshore wind industry located along the eastern seaboard [115].

The quality of green jobs for cast-off workers is a concern, however. A worker on a Texas oil derrick could expect to be paid approx. US$27 per hour with benefits [116]. Utility-scale wind and solar jobs offer comparable but slightly lower wages ($26/ h for wind, $24/ h for solar), while small-scale rooftop solar installation pay starts at a much lower level [117]. Unionization is also low in the renewable energy sector: while some utility-scale roles are unionized, rooftop installer jobs generally are not. Electric battery manufacturers have also sought to limit unionization (for example, Elon Musk's Tesla battery plant) [118]. U.S. states that lean politically progressive have passed legislation to ensure workers are hired locally and paid prevailing wages, and in some cases to require the use of project labor agreements or community benefits/workforce agreements [119]. Such efforts are likely to make clean energy work more attractive to fossil fuel workers, especially if jobs are situated where workers live.

Perhaps the greatest concern is that new renewable energy jobs in fossil fuel regions will not be stable or long-lasting. The majority of utility-scale green energy jobs occur during the project construction phase [45], with operational jobs relatively limited, especially compared to employment in coal, oil, and gas [120]. Workers employed in wind or solar installation construction thus potentially have to move after projects are completed. Manufacturing jobs might offer longer-term employment and are (like generation projects) eligible for subsidies under the IRA, with an additional subsidy for locating in energy communities [121]. Indeed, eleven factories making wind turbines and components have been announced since the IRA's passage, all of which are located in rural areas, and two of which are in regions with fossil fuel economies [122]. It remains to be seen whether job expansion will continue, and moreover, whether workers in fossil fuel regions will be able to permanently transition to these jobs.

3.4. Finance

Energy systems require significant financial investment. The dynamics of low carbon financing is an emerging area of research interest. This research highlights that the material form of energy investments – fossil fuels or renewables – may be less important than investing in whichever option yields steady returns [22,123]. As such, "stacking" investments in *both* fossil fuel and renewable energy projects may be the best strategy for guaranteeing profit.

While the relationship between the energy and finance sectors has long existed, it gained importance with efforts to deregulate the energy sector in the late 1990s. As the industry restructured, companies turned to the finance sector for new sources of funding support [124]. The state continues to play a significant role in such relationships by shaping the regulatory landscape and by providing funding to support low carbon energy transitions. Luke and Huber [125] refer to the co-constitutive relationships amongst the state, energy and finance sectors as "electricity capital."

Various scholars have highlighted the contradictory nature of electricity capital in the context of renewable energy transitions. The electricity sector is characterized by high fixed costs and multi-decadal project financing to support the costs of generating assets and infrastructure. Fossil fuel companies may oppose or attempt to slow the development of renewable energy projects because large investments in renewables will likely devalue fossil fuel assets [40]. As such, the fossil fuel sector will want to recoup their investments before renewable energy systems gain a significant market foothold [126]. Along this line of thinking, Eckhouse [127] argues that the looming threat renewable energy poses to fossil fuel systems may speed up more flexible forms of fossil fuel extraction, such as hydraulic fracturing. On the other hand, the renewable energy sector may function as a "spatial fix" for the electricity sector as investing in renewable energy projects could provide new market opportunities to ensure a steady flow of profits for the energy sector [128].

In fact, despite calls to stop investment in new fossil fuel projects to mitigate climate change [129], recent NGO analyses have found that large banks continue to invest in fossil energy. One report by a coalition of environmental groups led by the Rainforest Action Network found that investment in fossil fuel projects reached US$5.5 trillion from the world's largest 60 banks since the Paris Agreement was signed [130]. The second report by Ceres and the Transition Pathways Initiative analyzed planned investments in the energy sector for the top six US banks and found that the banks' planned investments do not align with strategies to achieve the Paris Agreement target of limiting global warming to 1.5 °C [131]. Yet, based on International Energy Agency (IEA) estimates, global investment in clean energy is forecast to exceed fossil fuel investments in 2023 [132]. Geographers have also posited that the global banking system can play an influential role in financing low-carbon energy pathways, particularly in infrastructure development, if it were to more systematically integrate the possibilities of climate change into its investment planning [133].

Within the U.S., the renewable sector is already having demonstrable impacts on the economics of electricity provision, again in ways that rely on fossil fuels. In states that participate in regional electricity markets that rely on providing electricity through market bidding, the renewable sector has contributed to displacing electricity from higher cost energy sources, namely coal and nuclear [124]. The extent to which this transformation results in emission reductions is yet to be determined as nuclear is often regarded as a low carbon, high risk energy source. Additionally, because the marginal cost of renewable energy is essentially zero, bidding renewable energy into spot markets has helped to lower peak energy costs [124]. It is worth noting that renewable energy would unlikely be successful in such markets without the support of favorable state policies and financial assistance [125]. In states that have not restructured their electricity sectors, traditional vertically integrated utilities that continue to rely on fossil fuels as their primary energy source are still able to benefit by investing in renewable energy projects in other states with restructured electricity markets [124].

3.5. Policy & regulation

In his "cautionary tales" of energy transitions, Grubler [43] emphasizes the importance of policy and regulation as a means of providing continuity in energy transitions. Other scholars highlight the need to integrate components of justice into energy transition policy for the transition to meaningfully reverse historic patterns of uneven development, particularly in extractive communities [134]. Thus, policy and regulation is an important dimension to evaluate for better understanding the stacking of fossil fuel and renewable energyscapes in the process of energy transition.

The U.S. energy regulatory system is a patchwork landscape comprised of federal, state, and local regulations. The federal government generally regulates interstate transmission of energy and the production of energy on federal lands. Most other aspects of regulation are devolved to the states who set policy agendas and control permitting processes. Local municipalities are also important players in many states through their power to establish zoning laws. Supporters of this approach, namely the fossil fuel industry and business and manufacturing interests, have argued that energy basins have unique geologies that states, not the federal government, are best equipped to understand and regulate [135]. Yet, these same interests have often argued in favor of preemption laws, which would limit the authority of local governments to regulate the energy sector [136].

As such, state legislatures are influential players in setting U.S. energy policy for both fossil fuel and renewable energy. On the one hand, this may be concerning because few states have full-time legislatures and even fewer have non-partisan research agencies that could help provide background research to support policymaking [137]. This may provide an opening for advocacy groups to have outsized influence over shaping regulatory agendas by addressing information deficits. Indeed, this has been an objective of the American Legislative Exchange Council (ALEC), a right of center advocacy group, that helps to facilitate information exchange at the state level by writing "model bills" [138]. On the other hand, research on hydraulic fracturing policy making in the U.S. found that information sharing amongst established groups of state regulatory officials, such as the Interstate Oil and Gas Compact Commission, rather than ALEC, have been more influential in shaping state regulatory agendas [139].

Yet, private governance plays a key role in shaping *if and whether* to regulate aspects of the energy sector. The American Petroleum Institute (API), one of the key advocacy groups for the fossil fuel industry, develops voluntary best practice standards on a host of topics for energy companies to follow. Again in the context of hydraulic fracturing, the fossil fuel industry pointed to API standards as justification for *not* increasing federal regulation of the industry [135]. In the context of renewable energy, various certification schemes were established to produce "sustainable biofuels" [140]. Scholars have documented significant industry influence in shaping these schemes [140].

State legislatures and private governance are playing key roles in shaping energy transitions. Some states, most notably Texas, are attempting to outright block transitions away from fossil fuels despite having ample renewable energy resources [141]. Other states are broadly defining energy transition pathways so that fossil fuels could qualify as low carbon fuel sources. In Pennsylvania, concessions to the coal industry have been important to the state's efforts to join the Regional Greenhouse Gas Initiative, a cap and trade program for Northeast and Mid-Atlantic states. Specifically, generating electricity from waste coal has been granted CO_2 allowances under the program [84]. Some environmental groups have raised concerns that such concessions may decrease air quality as waste coal is considered a low-quality fuel compared to other energy resources [142]. The interplay between fossil and renewable energy in Pennsylvania resembles efforts at the federal level to advance low carbon energy transitions. Most notably, Senator Joe Manchin has allegedly agreed to support President Biden's initiative to expand renewable energy transmission lines in exchange for approving new fossil fuel projects, specifically the Mountain Valley Pipeline [143].

Lastly, the API has also established a Climate Action Framework [144] to help shape low carbon futures. The five-point framework advocates for accelerating technology and innovation, particularly in hydrogen and carbon capture and sequestration, mitigating emissions from oil and gas operations, endorsing carbon pricing, advancing cleaner fuels, and improving climate reporting through expanded use of Environmental and Social Governance reporting for oil and natural gas. Based on these examples, renewable energy transition pathways are in many ways predicated on and likely heavily shaped by the continued existence of the fossil fuel industry, supporting cautions previously raised by McCarthy [40].

4. Conclusion

Dominant understandings of energy transitions posit that places that are highly dependent on fossil fuel extraction are at risk of economic stagnation and decline; put differently, that they are the "losers" of transition. This paper describes an alternative and more complex dynamic: that rather than simply replacing fossil fuels, renewable energy sources are being added alongside and atop them. We propose the framework of *stacked energyscapes* to emphasize the interactions and synergies between these old and new sociotechnical energy systems in energy communities where they are situated. These places possess characteristics that facilitate interactions between fossil fuels and renewable energy, including large land parcels, pre-existing infrastructure, access to a skilled labor pool, synergistic financing, and supportive regulatory environments. In these places, in a way not dissimilar to households, energy firms, local officials, energy workers, and community members will "stack" energy systems so as to minimize disruption and maximize benefit. In this way, our paper builds on the concepts of the energy mix [13] and energy "additions" [34] by analyzing how and why established and emerging systems intersect and complement one another. We also contribute to the literature on geographies of transition by highlighting the embeddedness of stacking in specific places and their assorted infrastructure, institutions, arrangements, and values - i.e., their energyscapes.

Moreover, the findings of this paper, which are intended to initiate future primary research, suggest that stacking energyscapes can both ease the path of energy transitions in extractive communities, and also potentially inhibit them. Utilizing the same plots of land and infrastructure for both fossil fuel and renewable systems can minimize environmental disruption, lessen the need for additional costly transmission and transportation infrastructure, and possibly reduce emissions by electrifying extraction. Enabling labor migration between fossil fuel and renewable industries may provide continuity for energy workers. Energy communities that have long relied on extraction may also be more supportive of renewable energy development if it does not fully replace - and even supports - the continuation of the extractive economy. Seen in this way, stacking has the potential to facilitate more just transitions in extractive communities.

At the same time, stacking is also likely to prolong the existence of fossil fuel extraction in these communities, which - as important energy producers - may reduce the pace and scale of energy transition at the local and the national/global scale. Indeed, in a kind of Jevons paradox, the synergies offered by stacking may result in *increased* energy use and emissions. Solar and wind farms deployed to electrify existing oil and gas operations may also enable firms to "greenwash" future expansion. Natural gas pipelines that are repurposed for RNG and "blended" hydrogen may ensure a future for gas production. Fossil fuel firms that are enlisted to draft regulations for "waste coal" and sustainable biofuels will be eligible for subsidies, and they have negotiated numerous concessions for oil and gas leases as a precondition for renewable energy development on public lands. And these same firms continue to invest in profitable fossil fuel projects, providing a stable revenue stream that reduces investment risk in their renewable energy portfolios. These intersections are largely overlooked in the energy transition literature, which may result in unintended consequences that hinder transition objectives.

This paper also opens up other new, underexplored lines of inquiry in the field. These include: how do incumbent firms and institutions in extractive regions enable and/or constrain transitions [145–147]? How do local governments and communities shape (or not) stacking in their administrative regions [37]? What are the justice dimensions and implications of stacked energyscapes - both within energy communities and between places? What other sociotechnical domains of energyscapes - such as technological innovation, distributed generation, and even geopolitics [148] - might experience stacking? And, building on calls for a geographical political economy of energy transitions [149], how does stacking that manifests in specific landscapes influence broader transition trajectories? Overall, we suggest, the concept of stacked energyscapes opens space for more granular place-based, relational studies of transitions that are attentive to the geographical political economic dynamics that shape the speed and scale broader transitions as a whole.

CRediT authorship contribution statement

Tyler Harlan: Methodology, Investigation, Formal analysis, Data curation, Conceptualization, Writing – review & editing, Writing – original draft. **Jennifer Baka:** Methodology, Investigation, Formal analysis, Conceptualization, Writing – review & editing, Writing – original draft.

Declaration of competing interest

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

Data availability

No data was used for the research described in the article.

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