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A Not-So-Just Transition? Examining the Effects of Coal Sector Decline on Life Expectancy in U.S. Counties

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ABSTRACT

Driven by climate and energy policy priorities in national and global contexts, coal phase-out is expected to improve public health outcomes by reducing human exposure to air, water, and soil pollution and decreasing the number of workers in dangerous mining conditions. However, the transition may also increase economic distress in mining communities leading to poorer health outcomes—possibly offsetting the benefits of phasing out coal. We examine this hypothesis by assessing the relation between coal production, working hours per miner, coal mining employment, and life expectancy in 3076 U.S. counties (97.9% of all U.S. counties) from 2012 to 2019. We develop and apply a novel spatial modeling approach that combines the high-dimensional half-panel jackknife fixed effects estimator with the spatial lag of X model and examine whether increases and decreases in each predictor are associated with life expectancy. We find that an increase in coal mining employment in adjacent counties increases life expectancy in the focal county in the short and long run and vice versa for a decrease in employment, and that decreases in miner labor hours in adjacent counties increase life expectancy in the short and long run in the focal county. We also find that effects differ in Appalachia compared to the rest of the country—where increases in coal production are associated with decreases in life expectancy and is also where the effects of coal mining employment are concentrated. These findings suggest that both increasing and decreasing reliance on coal can negatively impact population health, and that these competing exposures underscore the importance of a Just Transition away from fossil fuels.

1 | Introduction

Coal produces various forms of air, water, and soil pollution throughout its lifecycle. These exposures from coal are associated with a wide range of adverse population health outcomes, such as cardiovascular disease, asthma, lung cancer, preterm birth, mental illness, and mortality (Gohlke et al. 2011; Hendryx et al. 2020; Henneman et al. 2023; Shindell et al. 2018). The totality of these consequences has generated calls for a transition away from coal use.

Coal employment has been on the decline in the U.S. for nearly a century, while total production peaked in 2008 (see Figure 1), according to the U.S. Energy Information Agency's (EIA 2024a) Annual Coal Report and employment statistics from the Mining Safety and Health Administration (2025). These trends largely reflect the industry becoming more capital-intensive. As underground mining stagnated and declined, surface mining increased for much of the second half of the 20th and early 21st centuries, leading to a peak in 2008. The industry has also shifted spatially over time. For the first

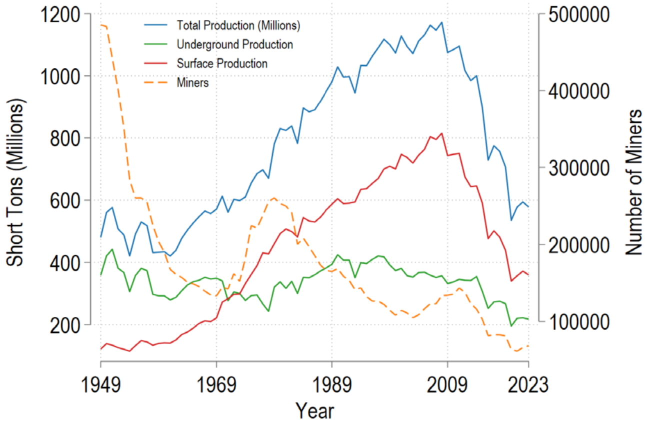

FIGURE 1 | Coal production and employment, 1949–2023.

half of the 20th century, the coal industry was primarily concentrated in Appalachia but shifted to Wyoming as surface mining was less labor-intensive and has lower levels of sulfur (EIA 2025b). As of 2023, Wyoming is now responsible for the largest volume of coal production of any state (approximately 40% of total U.S. production). Given these trends, the decline of the coal industry is uneven across the U.S., with Central Appalachia experiencing a 64% decrease in production compared to 40% for the rest of the country (Bureau of Business and Economic Research 2022).

Although coal production is on the decline, it still makes up approximately 12% of total primary energy production—a similar share to that of renewable energy (EIA 2024b). Coal is considered economically important to many communities. Its decline and the impact that this has on these communities is an important issue in the energy transition literature and for policymakers (Crowe and Li 2020). A growing movement to combat the harmful impacts of the energy transition is the call for a "Just Transition", which argues for an equitable transition to renewable energy (Carley and Konisky 2020). Specifically, this framework recognizes that the transition away from fossil fuels will burden communities historically reliant on these industries, such as coal, for employment and government revenue (Wang and Lo 2021). Proponents emphasize the principles of respect and dignity for vulnerable groups, fairness in energy access and use, social dialogue, democratic consultation with relevant stakeholders, the creation of decent jobs, social protections, and the need to promote more equitable labor practices within the energy sector (Pathak et al. 2022; Wang and Lo 2021).

Although conceptions of Just Transition consider the economic stress resulting from shifts in the energy sector, the health effects resulting from the economic stress produced from the transition remain understudied. Without question, the Just Transition framework does focus on addressing the adverse population health impacts that workers and communities face from the fossil fuel industry (Wang and Lo 2021). However, this framework has come under attack on epistemic, substantive, and political grounds. Epistemically, the framework has been criticized for relying excessively on a narrow set of scientific expertise which downplays and can even marginalize the lived experiences of communities on the ground (Sovacool et al. 2025). Bidwell and Sovacool (2023) also contend that epistemic differences in the approach to community acceptance of energy technologies can muddy visions of energy futures and obscure meaningful tensions around justice perspectives and the degree of desired change. Substantively, critics argue that it has not sufficiently considered the adverse population health impacts from economic stress stemming from fossil fuel sector phase-out in these communities (i.e., an economic bust)[1] or that the framework discourages collective, disruptive, and non-capitalist forms of infrastructural transformation (Bouzarovski 2022). Politically, the concept has been perceived by some, such as those in the labor movement, as a tactic legitimating "climate delayism" (Harry et al. 2024); others have argued that the concept has been mobilized to weaken global climate policy targets (Jenkins et al. 2020) or relies too much on top-down interventions from the nation state rather than those bottom-up from local actors (Routledge et al. 2018), such as community groups, local hospitals and health professionals, or unions.

To offer a more epistemically coherent, substantive, and politically diverse perspective, we augment the Just Transition framework to include a Social Determinants of Health component. The Social Determinants of Health framework posits that the local environment is an important determinant of population health across five domains: economic stability, education access and quality, health care access and quality, neighborhood and built environment, and social and community context (U.S. Department of Health and Human Services n.d.). In the context of coal mining, the economic stability and neighborhood environment are likely the most salient to consider. This augmentation of the Just Transition framework to include Social Determinants of Health allows us to theorize and analyze how both the reliance on coal mining and the current transition away from coal mining influences county-level life expectancy in the U.S. We hypothesize that there are three primary pathways by which mining may impact life expectancy and the overall health of communities: (1) community exposure to air, water, and soil pollution (i.e., the production pathway), (2) hazardous working conditions (i.e., mining labor time pathway), and (3) job security or loss (i.e., the employment pathway).

We use coal mining data from the U.S. Energy Information Agency (2024), the most authoritative dataset related to coal in the U.S., to assess whether these three pathways are associated with changes in county-level life expectancy from 2012 to 2019. Employing a novel modeling approach developed by the authors—a combination of the spatial lag of X model with the half-panel jackknife fixed effects estimator—we model the increases and decreases in these processes in both focal and adjacent counties and test for asymmetry to determine the extent to which the effects of coal phase-out are similar in magnitude to times when counties increase their reliance on coal. We find that increases in coal mining employment are associated with increases in life expectancy and decreases in coal mining employment are associated with decreases in life expectancy. These results support our hypothesized employment pathway and suggest that declining mining employment amplifies economic distress in mining communities. We also find that decreases in miner labor hours in adjacent counties increases life expectancy in the short-and-long-run in the focal county, suggesting that decreasing exposure time for workers produces meaningful

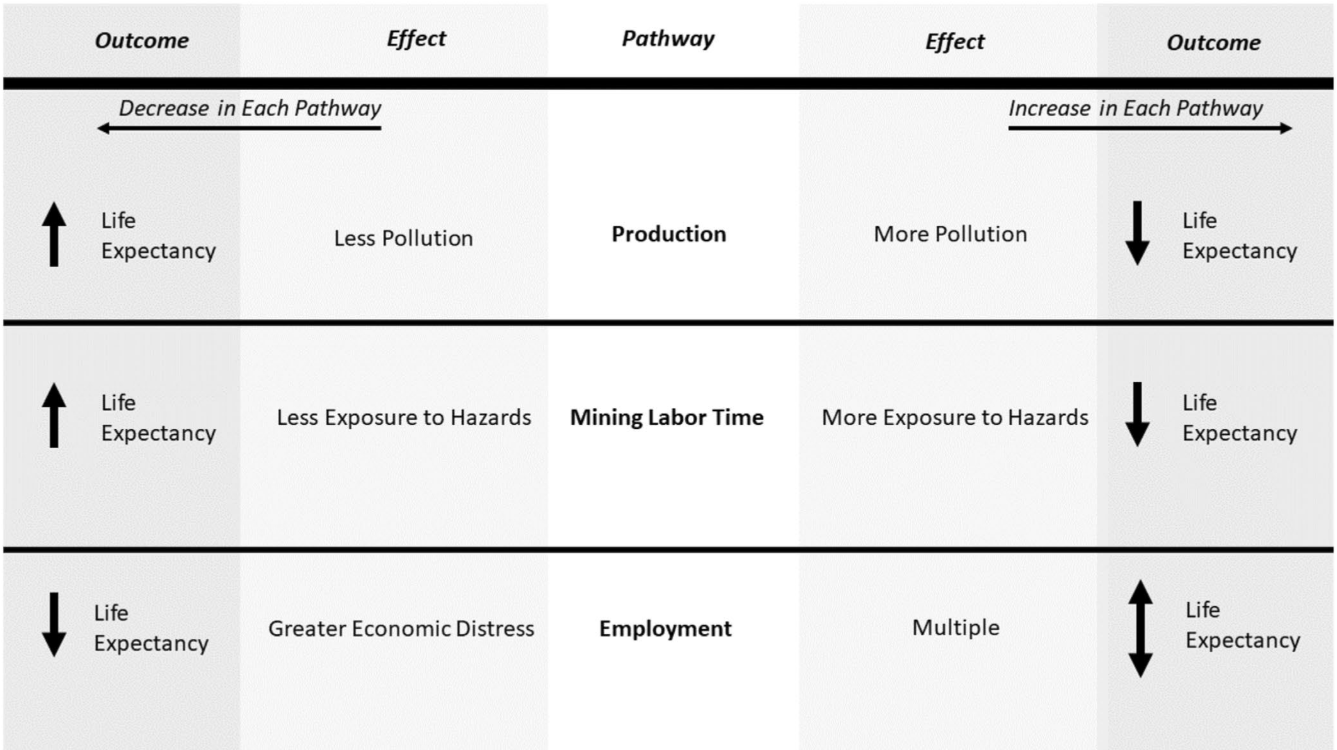

FIGURE 2 | Three pathways through which coal mining impacts life expectancy.

improvements in health outcomes. Although we do not find evidence that changes in total coal production are associated with changes in life expectancy for the whole sample of counties, we do find that increasing coal production is associated with decreases in life expectancy in Appalachia. We also find that the effects of coal mining employment on life expectancy are primarily concentrated in Appalachia.[2] The framework, methodology, and findings in this study make a novel contribution to our understanding of the population health impacts of the current energy transition. We conclude by placing our findings in context with the call for a Just Transition away from fossil fuels.

2 | A Framework to Evaluate the Relation Between Coal Mining and Life Expectancy

Coal produces population health risks across its entire life cycle from mining to disposal (Buonocore et al. 2021; Epstein et al. 2011; Gohlke et al. 2011; Hendryx et al. 2020; Henneman et al. 2023). Here, we specifically focus on the extraction stage of the life cycle (coal mining) and how it impacts life expectancy at the U.S. county-level. We focus on mining because these communities are at the center of the energy transition, and we use life expectancy as an outcome given that it is a well-established indicator of well-being that is widely used in the population health, energy transition, and sustainable development literatures (Dietz 2015, 2023; Dobis et al. 2020; Dwyer-Lindgren et al. 2017; Jorgenson 2014; Thombs 2022b). Therefore, life expectancy provides a natural link between these distinct research threads and builds on the growing body of research examining the relation between the energy sector and population health (Fanning et al. 2022; Roberts et al. 2020; Smith et al. 2013; Steinberger and Roberts 2010; Vogel et al. 2021; Willis et al. 2023).

To evaluate this relation, we augment the Just Transitions framework to include a Social Determinants of Health component that focuses on three aspects of coal mining that we consider upstream social determinants by which coal mining can influence life expectancy. Given that this analysis is contextualized within the current energy transition, we consider not only the effects of increases in coal mining but also the effects of phasing out coal mining. Below, we discuss each pathway, how we expect an increase or decrease in each pathway to affect life expectancy, and why increases and decreases in each process may or may not be asymmetric in their effects (see Figure 2).

The first pathway is what we refer to as the production pathway, which is where air, water, and soil pollution from coal mining produces poor population health outcomes. Prior research shows that people living near coal mines tend to have higher rates of cardiovascular disease, cancer, respiratory disease, and dental disease (Hendryx and Ahern 2008; Hendryx and Luo 2015; Hendryx et al. 2020). Therefore, we expect that increases in coal production lower life expectancy due to higher levels of pollution from mining. Likewise, we expect that a decrease in coal production has a symmetric effect on life expectancy due to lower pollution levels.

The second pathway is related to work as a social determinant of health. We hypothesize that increased mining labor time will decrease life expectancy due to increased exposure to dangerous working conditions that have short-term and long-term effects in the form of mortality and morbidity from mine collapses, fires, coal workers' pneumoconiosis (i.e., black lung disease), chronic obstructive pulmonary disease, and silicosis (Finkelman et al. 2021; Jorgenson et al. 2020). Similar to the production pathway, we expect a decrease in mining labor time

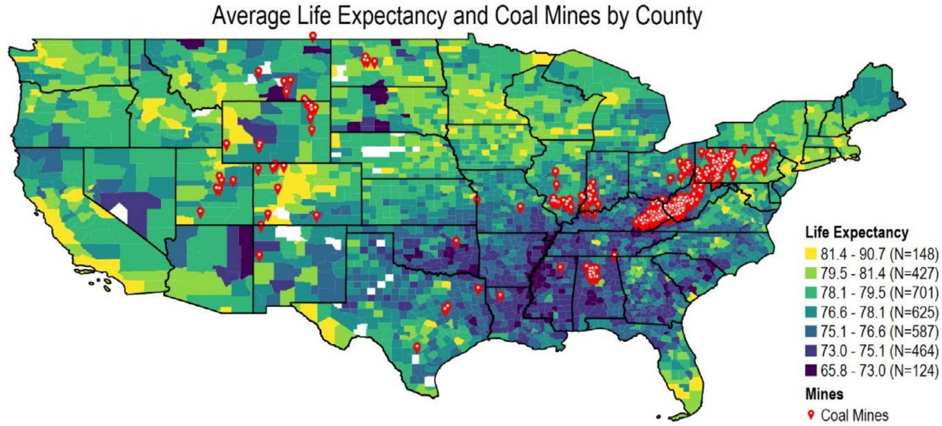

FIGURE 3 | Average life expectancy and coal mines by county. Average life expectancy is the mean from 2012 to 2019. Coal mine locations are collected from the EIA's (2025a) Energy Atlas.

to have a proportionate effect to an increase due to less exposure to dangerous working conditions.

The third pathway examines changes in economic well-being stemming from mining employment. In contrast to the first two pathways, we expect asymmetry. We do not expect an increase in mining employment to be related to life expectancy due to multiple effects that may cancel each other out. For instance, increases in coal employment may increase wages and provide economic security in areas with limited alternative economic opportunities (Lobao et al. 2016). Conversely, the resource dependency and resource curse literatures argue that economies overspecialized in resource extraction tend to have lower economic growth and poorer overall economic outcomes (Douglas and Walker 2017). Resource dependent economies may become over-adapted to industry desires, and extractive industries often crowd out other productive economic activity (Freudenburg 1992; Mueller 2022; Tsvetkova and Partridge 2017). As it relates to coal, studies examining these effects find mixed evidence, suggesting that this association is heterogeneous across regions in the U.S. (e.g., Appalachia compared to non-Appalachian counties) and time (Betz et al. 2015; Lobao et al. 2016).

Regardless of whether coal mining improves economic well-being, mining-dependent communities often have limited economic alternatives to resource extraction and phase-out can cause social and economic disruption (Svobodova et al. 2022). Not only does the loss of mining jobs impact miners directly, but mining sector decline has spillover effects into the regional economy and other service sectors that support mining and mining communities, such as prospecting, surveying, and mapping (Black et al. 2005; Lobao et al. 2016). Job loss can lead to economic distress, which is associated with increases in stress, poor mental health, social isolation, suicide, and substance misuse and may offset the improved population health impacts from coal phase-out and energy sector busts (Ananat et al. 2017; Frasquilho et al. 2016; Monnat 2018; Thombs 2022b; Thombs and Willis 2025; Willis et al. 2025). Scholars in development studies, political science, and energy studies have termed this process "social disarticulation", where pressures on a community to change their economic structure, find new employment, or relocate, dismantle the vibrant patterns of social organization, interpersonal ties, and kinship groups that tie communities together (Bidwell and Sovacool 2023; Milgroom and Ribot 2020; Sovacool and Valentine 2011). Thus, we hypothesize that a decrease in employment has a larger magnitude impact on life expectancy in the adverse direction compared to the impact of an increase in employment on life expectancy.

Below, we first describe the data we use to operationalize each pathway and describe the novel spatial modeling approach we developed and applied to the data. We subsequently assess the effect of an increase and decrease in each pathway on life expectancy in U.S. counties. Further, we examine the extent to which these effects differ by region of the U.S., as prior literature highlights the historical role of coal and the different mining practices in Appalachia compared to the rest of the country.

3 | Data and Methods

3.1 | Data and Sample

Our dependent variable is county-level life expectancy at birth obtained from the Institute for Health Metrics and Evaluation (2022) (see Figure 3). To facilitate the use of spatial econometrics, we use a balanced panel data sample of 3076 counties (97.9% of all counties) from 2012 to 2019 (8 years) for the 48 contiguous U.S. states and the District of Columbia (24,608 observations). Within the contiguous U.S., 31 counties with missing life expectancy data were excluded from the analyses (Nebraska: 12; Texas: 8; Colorado: 3; Montana: 3; North Dakota: 2; Idaho: 1; Nevada: 1; and New Mexico: 1).

Our three independent variables of interest are total coal production, labor hours per miner, and coal mining employment. We aggregated to the county-level from mine-level data obtained from the U.S. Energy Information Agency (2024). Total coal production data are measured in million short tons. Labor hours per miner are calculated by aggregating labor hours from each mine to the county-level and dividing them by county-level mining employment (and expressed in thousands of hours per employee). Lastly, coal mining employment is calculated by aggregating the average number of workers at each mine (refuse, underground, and surface) to the county-level and dividing it by the total number of jobs available in the county (BEA 2024).[3]

To model and test for asymmetry, we follow standard practices in the literature (Shin et al. 2014; Thombs et al. 2022) and decompose each relevant variable into partial sums around a threshold of zero:

$$x_{i,t}^{+} = \sum_{j=1}^{t} \Delta x_{i,t}^{+} = \sum_{j=1}^{t} \max\left(\Delta x_{i,t}^{+}, 0\right)$$

$$x_{i,t}^{-} = \sum_{j=1}^{t} \Delta x_{i,t}^{-} = \sum_{j=1}^{t} \min\left(\Delta x_{i,t}^{-}, 0\right)$$

where $x_{i,t}^{+}$ represents the partial sum of the positive changes in x, and $x_{i,t}^{-}$ is the negative partial sum of x. After estimating the model, we use a Wald test to determine whether the coefficients of the two sums are equivalent. If they are statistically different then there is evidence of asymmetry. We generate the partial sums with the community contributed *xtasysum* command in Stata (Thombs 2022c).

We include control variables that capture county-level demographic and economic characteristics: the percentage of the population with health insurance, the percentage of the population that is non-Hispanic white, the percentage of the population over 65, the percentage of the population with a bachelor's degree, an index of economic distress consisting of median household income, the poverty rate, and the employment population ratio.[4] We constructed the economic distress index using Anderson's (2008) generalized least squares index construction method, which we implement using the community contributed *swindex* command in Stata (Schwab et al. 2020). This approach uses a weighting scheme that gives more weight to less correlated measures and less weight to more correlated measures. We originally included the county-level Gini coefficient, but its inclusion gave median household income a negative weight, suggesting that income inequality did not add new information. Therefore, we omitted this variable from the final model.

The control variables are taken from the American Community Survey's 5-year estimates and imported into Stata using the community contributed *getcensus* command (Center on Budget and Policy Priorities 2023).[5] The last year of each 5-year period is treated as the annual observation for that specific year in the dataset. For example, the values for the year 2022 correspond to the five-year estimates for the 2018–2022 period.

The summary statistics for the dependent and independent variables are presented in Table 1. On average, coal producing counties have a lower life expectancy of 1.6 years compared to the typical U.S. county. They also tend to be more economically distressed (0.464 index score relative to the national average of 0), less educated (17% with a bachelor's degree relative to the national average of 21%), and have a higher percentage of residents who are white (90% relative to the national average of 84%). Coal producing counties also tended to experience a decline in all three key coal sector measures over the 2012–2019 period (see Table 2), with coal mining employment decreasing the most often of the three measures (52.54% of the time).

3.2 | Econometric Modeling

We estimate models using the half-panel jackknife fixed effects (HPJ-FE) estimator (Chudik et al. 2018), implemented via Thombs (2023) community contributed *xthpj* program in Stata. Although the traditional two-way fixed effects estimator is the workhorse approach in the panel data modeling literature, its use has three potential limitations in the context of this study. First, it assumes the regressors are strictly exogenous, meaning that there is no feedback between the dependent variable and the regressors (Chudik et al. 2018), and this is likely an unrealistic assumption given that it is possible that life expectancy (and worse health in general) impacts economic conditions. The failure to account for this dependency may lead to biased results (Chudik et al. 2018). Second, the two-way fixed effects estimator can perform poorly when the number of units is large relative to the time dimension, largely due to the well-known Nickell bias that is produced when a lag of the dependent variable is included in the model (Nickell 1981). Chudik et al. (2018) further show that the estimator is biased if any of the regressors are weakly exogenous, regardless of whether a lag is included in the model. Third, the two-way fixed effects estimator does not account for spatial autocorrelation, which can produce spurious results (Pace and LeSage 2010). Accounting for spatial autocorrelation is important in the context of this study because county-level exposures do not necessarily align with population locations (Casey and Willis 2024), and people employed in the coal industry are not necessarily employed in the county that they live in. Given that we are not using individual-level data, the inclusion of spatial lags is necessary to proxy for these processes.

To address these issues, we expand upon the HPJ-FE estimator developed by Chudik et al. (2018). The HPJ-FE is a simple extension of the traditional fixed effects estimator and works by taking the full sample and splitting each panel in half. Using the beta estimate for the full sample (β) and the two-halves (β^{a} and β^{b}), the estimate of the half-panel jackknife beta is $2\beta - ½(\beta^{a} + \beta^{b})$. To address the issue of spatial autoregression, we include spatial lags of the independent variables in the models. The inclusion of spatial lags of the regressors is known as the spatial lag of X (SLX) model and performs well relative to alternatives such as the spatial Durbin or spatial autoregressive models (Rüttenauer 2022). The SLX model has the additional benefit of being simpler than other spatial models and can be combined with more traditional panel data modeling approaches that use ordinary least squares.

We estimate a dynamic model (an autoregressive distributed lag model with the lag of the dependent variable) to capture long-run effects that transpire over time. We also allow for

TABLE 1 | Summary statistics.

Variable	Full sample (3076 counties)				Coal producing counties (214 counties)			
	Mean	SD	Between SD	Within SD	Mean	SD	Between SD	Within SD
Life expectancy	77.355	2.553	2.541	0.254	75.767	2.620	2.612	0.263
Production	0.279	5.668	5.610	0.816	4.003	21.146	20.961	3.094
Production (Pos.)	0.039	0.433	0.344	0.262	0.564	1.547	1.189	0.994
Production (Neg.)	−0.091	1.552	1.210	0.971	−1.301	5.749	4.424	3.683
Labor hours/ employee	0.122	0.501	0.479	0.145	2.638	4.322	4.077	1.456
Labor hours/ employee (Pos.)	0.027	0.179	0.146	0.103	0.395	1.149	0.916	0.696
Labor hours/ employee (Neg.)	−0.045	0.279	0.227	0.163	−1.321	2.888	2.426	1.574
Employment	0.184	1.323	1.266	0.384	1.708	0.896	0.722	0.534
Employment (Pos.)	0.028	0.320	0.261	0.184	0.356	0.551	0.407	0.373
Employment (Neg.)	−0.092	0.833	0.722	0.415	−0.596	0.835	0.582	0.600
Economic distress	0.000	1.000	0.985	0.175	0.464	1.012	1.002	0.156
Health insurance (%)	87.429	5.625	5.016	2.549	88.198	5.377	4.492	2.969
BA (%)	20.620	9.169	9.060	1.420	16.961	7.567	7.487	1.196
White (%)	83.714	16.240	16.181	1.409	89.991	12.254	12.250	0.831
Over 65 (%)	17.375	4.455	4.312	1.123	17.145	3.055	2.871	1.062
Spatial Lags								
Production	0.280	2.395	2.370	0.347	1.728	3.047	2.996	0.590
Production (Pos.)	0.040	0.225	0.183	0.131	0.318	0.512	0.393	0.329
Production (Neg.)	−0.093	0.695	0.546	0.430	−0.693	1.133	0.848	0.754
Labor hours/ employee	0.127	0.359	0.352	0.066	1.040	0.639	0.616	0.174
Labor hours/ employee (Pos.)	0.027	0.101	0.083	0.059	0.202	0.244	0.167	0.178
Labor hours/ employee (Neg.)	−0.045	0.161	0.131	0.092	−0.319	0.360	0.241	0.267
Employment	0.175	0.822	0.794	0.213	1.717	2.350	2.232	0.751
Employment (Pos.)	0.027	0.163	0.130	0.099	0.261	0.498	0.364	0.341
Employment (Neg.)	−0.089	0.531	0.462	0.261	−0.936	1.686	1.412	0.925
Economic distress	0.031	0.801	0.794	0.108	0.468	0.847	0.844	0.089
Health insurance (%)	87.450	4.672	4.081	2.275	88.201	4.289	3.328	2.714
BA (%)	20.656	6.261	6.186	0.971	17.280	4.785	4.714	0.876
White (%)	83.637	13.350	13.326	0.829	90.310	9.147	9.153	0.484
Over 65 (%)	17.344	2.989	2.820	0.994	17.366	2.106	1.851	1.013

Note: For the full sample, total observations = 24,608; $N = 3076$; T = 8, and for coal producing counties, total observations = 1712; $N = 214$; T = 8.
Abbreviations: BA, bachelor of arts; Neg., negative partial sum; Pos., positive partial sum; SD, standard deviation.

TABLE 2 | Frequency (%) of increases, decrease, and no change in each coal measure.

	Increase	Decrease	No change
Production	33.6%	49.6%	16.8%
Labor hours/ employee	40.5%	44.7%	14.8%
Employment	32.8%	52.5%	14.7%

county-specific trends, which proxy for other unobserved time-varying factors that may not be captured by the control variables, such as county-level policy changes or changes in the local disease environment. We initially estimated a model and tested whether each coal-related measure is asymmetric. The Wald tests indicate that the effects are symmetric, except for the indirect effects for coal production and labor hours per miner (see Appendices A and B). Based on this finding, our reported model only includes the partial sums of the spatial lags for the increase and decrease of these variables. This means that the coefficient for the symmetric variables can be interpreted as the effect in absolute terms of an increase or decrease in the variable. We estimate the following model with the partial sums of each coal-related measure:

$$\begin{aligned}\text{Life Expectancy}_{i,t} &= \lambda_1 \text{Life Expectancy}_{i,t-1} + \beta_1 \text{Production}_{i,t} + \beta_2 \text{Labor Hours/Employee}_{i,t} \\ &+ \beta_3 \text{Employment}_{i,t} + \beta_4 \text{Economic Distress}_{i,t} + \beta_5 \text{Health Insurance}(\%)_{i,t} + \beta_6 BA(\%)_{i,t} + \beta_7 \text{White}(\%)_{i,t} \\ &+ \beta_8 \text{Over 65}(\%)_{i,t} + \boldsymbol{WX\theta_{i,t}} + \alpha_{1i} T + \alpha_{2i} + \varepsilon_{i,t},\end{aligned}$$

where λ_1 is the autoregressive coefficient for the lag of the dependent variable, $\beta_1 - \beta_8$ are the direct effects, while $\boldsymbol{WX\theta_{i,t}}$ is a vector of spatial lags modeling the indirect effects. $\boldsymbol{W}$ is a queen contiguity matrix standardized using row normalization. $\alpha_{1i}T$ is the county-specific trend term, α_{2i} controls for county-specific fixed effects that capture time-invariant and average differences between counties (e.g., geography, political, economic, and institutional history), time fixed effects (u_t) control for time-specific factors that vary over time but are constant across counties (e.g., recessions, changes in federal policy, innovations in medical technologies), and $e_{i,t}$ is the error term. The long-run effect is calculated by dividing each coefficient by $1-\lambda_1$(Pickup 2015; Thombs 2022a).[6]

4 | Results

The results are reported in Table 3.[7] The direct effect is the change in life expectancy associated with a change in a variable within a county, while the indirect effect is the change in life expectancy due to changes in a variable in neighboring counties (i.e., the spillover effect). The total effect is the sum of the direct and indirect effects, and the reported standard errors are estimated using the delta method (estimated with the *nlcom* command in Stata).

The results partially support our hypothesized pathways. In particular, we find that increases and decreases in coal mining employment (the employment pathway) and decreases in labor hours per miner (the mining labor time pathway) influence short-and-long-run county life expectancy. However, we do not find evidence that changes in total coal production (the production pathway) are related to changes in life expectancy.

Regarding the employment pathway, the indirect and total effects of an increase and decrease in coal mining employment are statistically significant. The findings indicate that if coal mining employment increases by one percentage point on average in neighboring counties, that life expectancy increases by 0.101 years (95% CI: 0.058, 0.144) in the focal county in the short run and 0.157 (95% CI: 0.089, 0.255) in the long run. The total effect is a 0.115 year increase (95% CI: 0.069, 0.161) in life expectancy in the short run and a 0.178 year increase (95% CI: 0.105, 0.251) in the long run. Given this variable is symmetric, this finding also means that a decrease in coal mining employment leads to a proportional decrease in life expectancy.

Turning to labor hours per miner (the mining labor time pathway), we find that a decrease, but not an increase, in mining hours is associated with changes in life expectancy. More specifically, a 1000 h decrease in working hours per miner in neighboring counties is associated with a 0.100 year increase (95% CI: 0.012, 0.188) in life expectancy in the focal county in the short-run and a 0.155 year increase (95% CI: 0.18, 0.292) in the long-run. The total effect is a 0.099 year increase in the short-run (95% CI: 0.005, 0.194) and a 0.154 year long-run increase (95% CI: 0.006, 0.301) in life expectancy.

We do not find strong evidence that increases and decreases in total coal production (the production pathway) influence life expectancy. The total effects of each are associated with decreases in life expectancy, but the results were imprecise.

4.1 | Appalachia Compared to the Rest of the U.S

Next, we compare the effect of each pathway in Appalachia compared to the rest of the U.S. using an interaction between each pathway measure and an indicator variable (=1 if Appalachia, =0 otherwise) (Table 4). These results indicate that Appalachian counties experience changes in the coal sector differently than the rest of the country. Across the three measures, we find that increases in coal production in adjacent counties have a negative effect on life expectancy in Appalachian counties compared to having no effect in non-Appalachian counties, and that the effect of coal employment on life expectancy is also greater in Appalachia.

For Appalachian counties, we find that a one million short ton increase on average in neighboring counties is associated with a 0.444 year decrease (95% CI: −0.706, −0.182) in life expectancy in the focal county in the short run and a 0.684 year decrease (95% CI: −1.092, −0.275) in the long run. Similarly, if coal mining employment increases by one percentage point

TABLE 3 | Regression analysis of county-level life expectancy, 2012–2019.

	Short-run effects			Long-run effects		
Variable	**Direct effects**	**Indirect effects**	**Total effects**	**Direct effects**	**Indirect effects**	**Total effects**
Life expectancy$_{t-1}$	0.355** (0.024)					
Production (Pos.)	0.002 (0.003)	−0.120 (0.064)	−0.118 (0.065)	0.003 (0.005)	−0.186 (0.100)	−0.183 (0.100)
Production (Neg.)	−0.002 (0.003)	−0.008 (0.008)	−0.010 (0.008)	−0.003 (0.005)	0.012 (0.012)	−0.015 (0.013)
Labor hours/employee (Pos.)	0.001 (0.013)	0.096 (0.063)	0.097 (0.064)	0.002 (0.021)	0.148 (0.098)	0.150 (0.099)
Labor hours/employee (Neg.)	−0.001 (0.013)	0.100* (0.045)	0.099* (0.048)	−0.002 (0.021)	0.155* (0.070)	0.154** (0.075)
Employment (Pos.)	0.014 (0.007)	0.101** (0.022)	0.115** (0.023)	0.021 (0.011)	0.157** (0.035)	0.178** (0.037)
Employment (Neg.)	−0.014 (0.007)	−0.101** (0.022)	−0.115** (0.023)	−0.021 (0.011)	−0.157 (0.035)	−0.178** (0.037)
Economic distress	−0.082** (0.017)	−0.071 (0.037)	−0.153** (0.040)	−0.128** (0.026)	−0.110 (0.057)	−0.238** (0.062)
Health insurance (%)	−0.002 (0.002)	−0.002 (0.004)	−0.004 (0.004)	−0.003 (0.003)	−0.004 (0.006)	−0.007 (0.007)
BA (%)	−0.032** (0.002)	−0.003 (0.005)	−0.036** (0.005)	−0.050** (0.004)	−0.005 (0.007)	−0.055** (0.008)
White (%)	−0.001 (0.002)	0.011* (0.006)	0.010 (0.005)	−0.002 (0.004)	0.018* (0.009)	0.016 (0.008)
Over 65 (%)	0.009 (0.006)	0.019 (0.013)	0.028 (0.015)	0.013 (0.009)	0.030 (0.020)	0.043 (0.023)
N	3076					
T	6					
Obs.	18,456					

Note: $^{**}p < 0.01$, $^{*}p < 0.05$. Standard errors clustered by county reported in parentheses. Total effects estimated using the delta method. Direct effects for restricted model are reported symmetric (a decrease in the variable is the coefficient × −1).
Abbreviations: Neg., negative partial sum; Pos., positive partial sum.

TABLE 4 | Regression analysis of county-level life expectancy in appalachia and non-appalachian counties, 2012–2019.

	Short-run effects			Long-run effects		
	Direct effects	**Indirect effects**	**Total effects**	**Direct effects**	**Indirect effects**	**Total effects**
Life expectancy$_{t-1}$	0.351** (0.024)					
Production (Pos.)	0.003 (0.006)	−0.105 (0.063)	−0.102 (0.064)	0.005 (0.009)	−0.162 (0.098)	−0.157 (0.098)
Production (Neg.)	−0.003 (0.006)	−0.006 (0.009)	−0.009 (0.011)	−0.005 (0.009)	−0.009 (0.014)	−0.014 (0.017)
Production (Pos.) × APP	−0.022 (0.021)	−0.339* (0.148)	−0.361* (0.153)	−0.034 (0.032)	−0.522* (0.229)	−0.556* (0.236)
Production (Neg.) × APP	0.022 (0.021)	−0.094 (0.058)	−0.071 (0.059)	0.034 (0.032)	−0.144 (0.090)	−0.110 (0.091)
Labor hours/employee (Pos.)	−0.013 (0.021)	0.015 (0.080)	0.002 (0.082)	−0.020 (0.032)	0.024 (0.122)	0.004 (0.127)
Labor hours/employee (Neg.)	0.013 (0.021)	0.081 (0.069)	0.094 (0.073)	0.020 (0.032)	0.125 (0.106)	0.145 (0.112)
Labor hours/employee (Pos.) × APP	0.026 (0.029)	0.160 (0.124)	0.186 (0.126)	0.040 (0.045)	0.247 (0.191)	0.287 (0.195)
Labor hours/employee (Neg.) × APP	−0.026 (0.029)	0.048 (0.093)	0.022 (0.099)	−0.040 (0.045)	0.073 (0.143)	0.033 (0.153)
Employment (Pos.)	0.004 (0.011)	-2.079×10^{-4} (0.028)	0.004 (0.032)	0.006 (0.018)	-3.201×10^{-4} (0.043)	0.005 (0.050)
Employment (Neg.)	−0.004 (0.011)	2.079×10^{-4} (0.028)	−0.004 (0.032)	−0.006 (0.018)	3.201×10^{-4} (0.043)	−0.005 (0.050)
Employment (Pos.) × APP	0.014 (0.019)	0.136** (0.050)	0.151** (0.055)	0.022 (0.030)	0.210** (0.078)	0.232 (0.085)
Employment (Neg.) × APP	−0.014 (0.019)	−0.136* (0.050)	−0.151** (0.055)	−0.022 (0.030)	−0.210** (0.078)	−0.232 (0.085)
Economic distress	−0.083** (0.017)	−0.063 (0.037)	−0.145** (0.040)	−0.127** (0.026)	−0.096 (0.057)	−0.224** (0.061)
Health insurance (%)	−0.002 (0.002)	−0.002 (0.004)	−0.004 (0.004)	−0.003 (0.003)	−0.003 (0.006)	−0.005 (0.007)
BA (%)	−0.032** (0.002)	−0.003 (0.005)	−0.035** (0.005)	−0.050** (0.004)	−0.005 (0.007)	−0.054** (0.008)
White (%)	−0.001 (0.002)	0.011 (0.006)	0.010 (0.005)	−0.002 (0.003)	0.017 (0.009)	0.015 (0.008)
Over 65 (%)	0.009 (0.006)	0.019 (0.013)	0.027 (0.015)	0.014 (0.009)	0.029 (0.020)	0.042 (0.023)

Note: $^{**}p < 0.01$, $^{*}p < 0.05$. Standard errors clustered by county reported in parentheses. Total effects estimated using the delta method. Direct effects for restricted model are reported symmetric (a decrease in the variable is the coefficient × −1).
Abbreviations: APP, indicator variable for appalachia; Neg., negative partial sum; Pos., positive partial sum.

on average in neighboring counties, life expectancy increases by 0.136 years (95% CI: 0.054, 0.219) in the focal county in the short run and 0.210 years (95% CI: 0.081, 0.339) in the long run (and vice versa for a decrease in employment). These effects are statistically equivalent to zero in non-Appalachian counties.

5 | Discussion and Conclusion

This study contributes to our understanding of how the current transition away from coal impacts life expectancy in U.S. counties. We augmented the Just Transitions framework with a Social Determinants of Health lens and argue that there are three primary pathways by which the reliance on, and the transition away from, coal mining impacts life expectancy (the production, mining labor time, and employment pathways). We operationalize these pathways using mine-level data that is aggregated to the county level across the U.S., and we examine to what extent these relations differ in Appalachia compared to non-Appalachian counties, paralleling differences in mining between these regions.

We develop and apply a novel spatial modeling approach and test whether increases and decreases in each pathway are associated with life expectancy and whether these effects are asymmetric. The results provide mixed support for our three pathways. We find strong evidence that increases in coal mining employment are associated with increases in life expectancy and decreases in coal mining employment are associated with decreases in life expectancy. These results support our hypothesized employment pathway, and they suggest that declining mining employment amplifies economic distress in mining communities. Other recent research suggests that fossil fuel sector busts may be associated with increased working-age mortality (Thombs and Willis 2025), and that this finding may be partially driven by increases in deaths from drugs, alcohol, and suicide (i.e., "deaths of despair") stemming from increased economic distress (Carriere et al. 2019; Kerr et al. 2017; Monnat 2018; Zhang and Monnat 2024). Although we hypothesized that increases in coal mining employment could be associated with life expectancy in either direction, the positive association observed here could be due to higher wages and other benefits from employment in areas with limited alternative economic opportunities (Black et al. 2021; Lobao et al. 2016). It could also be a function of the time period being examined, as prior research finds that the relationship between coal employment and economic well-being fluctuates over time (Lobao et al. 2016).

We also find that decreases in miner labor hours in adjacent counties increase life expectancy in the short-and-long-run in the focal county, suggesting that decreasing exposure time for workers produces meaningful improvements in health outcomes. Although we do not find evidence that changes in total coal production are associated with changes in life expectancy for the whole sample of counties, we do find that increasing coal production is associated with decreases in life expectancy in Appalachia. These findings are likely due to Appalachia having more mines and greater mine density than the Western coal region. We also find that the effects of coal mining employment on life expectancy are primarily concentrated in Appalachia, which is likely due to mining being more labor-intensive in this region.

Our findings have significant implications related to the current energy transition. In particular, the results suggest that mining employment loss adversely impacts health. This finding supports arguments made by the Just Transition framework, which calls for a planned transition away from fossil fuels to maximize the social and environmental benefits of the transition. It should be noted, however, that the concept of a Just Transition has become increasingly contested among workers, policymakers, activists, and academics (Banerjee and Schuitema 2022; Ciplet and Harrison 2020; Stevis 2023). What is considered "just" can create tensions among different groups, which can cause initiatives founded on just transition principles to fail to deliver (Banerjee and Schuitema 2022; Cha 2020; Ciplet and Harrison 2020; Sovacool et al. 2022).

Our results further contribute to this discourse by indicating that ensuring continuation of employment as part of a Just Transition framework may be an effective way to mitigate reductions in life expectancy due to losses of employment from coal mining. Although the resulting economic distress on workers and communities from mining employment loss is fundamental to conceptions of a Just Transition, the health effects resulting from economic distress remain an understudied issue. Failing to account for the health effects could impede the principles of distributive justice (the fair distribution of costs and benefits of the transition) and restorative justice (repairing the harm caused by the transition) that are central to the concept of a Just Transition (Heffron and McCauley 2018; Sovacool et al. 2016). As shown in our results, economic distress translates into adverse health outcomes in the form of lower life expectancy. These findings provide further justification as to why a Just Transition is pivotal for the well-being of communities at the center of the transition. Specifically, our results indicate that maintaining employment, through the development and support of low-carbon industries, is an important strategy to reduce the health impacts of loss of employment. Policies should focus on transitioning workers into low-carbon sectors, increasing labor protections, protecting state and local government revenues from the transition, and investing in social welfare programs to transition a carbon-free economy in a just and equitable manner (Cha et al. 2021).

When interpreting the results of our study, there are two key limitations to consider. The primary limitation of this study is that the data are aggregated to the county-level. Given that individuals may not work in the county in which they live, we sought to address this issue using spatial lags. However, this approach is only a proxy, and it does not disentangle associations at smaller geographical units, let alone infer to the individual-level. As feasible, future research should consider individual-level data to assess how living in proximity to coal mines and working in the sector impacts health outcomes. Furthermore, future research should consider specific causes of death to further develop our understanding of the relation between changes in mining employment and mortality, such as deaths related to drugs, alcohol, and suicide (Case and Deaton 2020; Monnat 2018; Zhang and Monnat 2024), as well as exploring how these associations differ across counties, given the significant heterogeneity in mortality rates across the country.

In conclusion, this study advances our understanding of the population health impacts of the current energy transition in the U.S. Although the coal sector is detrimental to public health, the economic distress stemming from mining employment loss also adversely affects health in regions that rely on the coal industry. By incorporating the Social Determinants of Health lens, these findings speak to the need for a Just Transition away from coal that addresses issues of equity, risks of social disarticulation, the longstanding issue of disinvestment, and lack of economic security and opportunity in mining communities. This study also provides evidence that employment support may be a useful strategy to prevent loss of life expectancy due to unemployment.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Endnotes

[1] Clinicians in these communities have documented their concerns around the growth of extractive economies on population health for decades (Bacigalupi and Freudenberg 1983; Becker 2018; Bougsty et al. 1983).

[2] We define Appalachia according to the definition used by the Appalachian Regional Commission (2024).

[3] The total jobs data for Wise County, Virginia includes Wise County and Norton, VA.

[4] At the request of a reviewer, we include total employment as an additional control variable and find the results are substantively the same (see Appendix C).

[5] The life expectancy estimates are based on modeled data that include post-secondary education, income, poverty, nativity, and population density as covariates (see GBD US Health Disparities Collaborators 2022), so we also estimate models without any control variables. The results are nearly identical and are available upon request.

[6] We estimate additional models without spatial lags and find that the effects are substantively similar with the exception that the coal mining employment variable is statistically significant at the 0.05 level but is similar in magnitude to the results reported in Table 3 (see Appendix D).

[7] As sensitivity analyses, we estimate the same model for life expectancy in four-year intervals (e.g., ages 1–4, 10–14, 15–19, etc.) and find that these effects are consistent across age groups except for the 80–84 group where the indirect effect for mining employment is not statistically significant. These results are reported in Appendices E–G.

References

Ananat, E. O., A. Gassman-Pines, D. V. Francis, and C. M. Gibson-Davis. 2017. "Linking Job Loss, Inequality, Mental Health, and Education." *Science* 356, no. 6343: 1127–1128. https://doi.org/10.1126/science.aam5347.

Anderson, M. L. 2008. "Multiple Inference and Gender Differences in the Effects of Early Intervention: A Reevaluation of the Abecedarian, Perry Preschool, and Early Training Projects." *Journal of the American Statistical Association* 103, no. 484: 1481–1495. https://doi.org/10.1198/016214508000000841.

Appalachian Regional Commission. 2024. "Appalachian Counties Served by ARC." https://www.arc.gov/appalachian-counties-served-by-arc/.

Bacigalupi, L. M., and W. R. Freudenberg. 1983. "Increased Mental Health Caseloads in an Energy Boomtown." *Administration in Mental Health* 10, no. 4: 306–322. https://doi.org/10.1007/BF00823107.

Banerjee, A., and G. Schuitema. 2022. "How Just Are Just Transition Plans? Perceptions of Decarbonisation and Low-Carbon Energy Transitions Among Peat Workers in Ireland." *Energy Research & Social Science* 88: 102616. https://doi.org/10.1016/j.erss.2022.102616.

BEA. 2024. "Regional Data." https://apps.bea.gov/itable/iTable.cfm?ReqID=70&step=1&acrdn=1.

Becker, K. L. 2018. "Help Wanted: Health Care Workers and Mental Health Services. An Analysis of Six Years of Community Concerns From North Dakota's Oil Boom Residents." *Journal of Rural Studies* 63: 15–23. https://doi.org/10.1016/j.jrurstud.2018.08.012.

Betz, M. R., M. D. Partridge, M. Farren, and L. Lobao. 2015. "Coal Mining, Economic Development, and the Natural Resources Curse." *Energy Economics* 50: 105–116. https://doi.org/10.1016/j.eneco.2015.04.005.

Bidwell, D., and B. K. Sovacool. 2023. "Uneasy Tensions in Energy Justice and Systems Transformation." *Nature Energy* 8, no. 4: 317–320. https://doi.org/10.1038/s41560-023-01217-8.

Black, D., T. McKinnish, and S. Sanders. 2005. "The Economic Impact of the Coal Boom and Bust." *Economic Journal* 115, no. 503: 449–476. https://doi.org/10.1111/j.1468-0297.2005.00996.x.

Black, K. J., A. J. Boslett, E. L. Hill, L. Ma, and S. J. McCoy. 2021. "Economic, Environmental, and Health Impacts of the Fracking Boom." *Annual Review of Resource Economics* 13, no. 1: 311–334. https://doi.org/10.1146/annurev-resource-110320-092648.

Bougsty, T., P. Marshall, and E. Chavez. 1983. "Prevalence and Prevention of Mental Health Problems in an Energy-Affected Community." *Administration in Mental Health* 10, no. 4: 272–287. https://doi.org/10.1007/BF00823105.

Bouzarovski, S. 2022. "Just Transitions: A Political Ecology Critique." *Antipode* 54, no. 4: 1003–1020. https://doi.org/10.1111/anti.12823.

Buonocore, J. J., P. Salimifard, D. R. Michanowicz, and J. G. Allen. 2021. "A Decade of the U.S. Energy Mix Transitioning Away From Coal: Historical Reconstruction of the Reductions in the Public Health Burden of Energy." *Environmental Research Letters* 16: 54030. https://doi.org/10.1088/1748-9326/abe74c.

Bureau of Business and Economic Research. 2022. "Coal Production and Employment in Appalachia." https://www.arc.gov/wp-content/uploads/2022/09/2022-09-Coal-Production-and-Employment-in-Appalachia.pdf.

Carley, S., and D. M. Konisky. 2020. "The Justice and Equity Implications of the Clean Energy Transition." *Nature Energy* 5, no. 8: 569–577. https://doi.org/10.1038/s41560-020-0641-6.

Carriere, D. E., M. I. Marshall, and J. K. Binkley. 2019. "Response to Economic Shock: The Impact of Recession on Rural–Urban Suicides in the United States." *Journal of Rural Health* 35, no. 2: 253–261. https://doi.org/10.1111/jrh.12334.

Case, A., and A. Deaton. 2020. *Deaths of Despair and the Future of Capitalism*. Princeton University Press.

Casey, J. A., and M. D. Willis. 2024. "Invited Perspective: Drilling Down Into the Mechanisms Linking Oil and Gas Development to Adverse Perinatal Health Outcomes." *Environmental Health Perspectives* 132, no. 10: 101301. https://doi.org/10.1289/EHP15106.

Center on Budget and Policy Priorities. 2023. "Getcensus."

Cha, J. M. 2020. "A Just Transition for Whom? Politics, Contestation, and Social Identity in the Disruption of Coal in the Powder River Basin." *Energy Research & Social Science* 69: 101657. https://doi.org/10.1016/j.erss.2020.101657.

Cha, J. M., M. Pastor, C. Moreno, and M. Phillips. 2021. "Just Transition/Transition to Justice: Power, Policy and Possibilities." https://dornsife.usc.edu/assets/sites/1411/docs/New_Just_Transition_Report__v4_FINAL.pdf.

Chudik, A., M. H. Pesaran, and J.-C. Yang. 2018. "Half-Panel Jackknife Fixed-Effects Estimation of Linear Panels With Weakly Exogenous Regressors." *Journal of Applied Econometrics* 33, no. 6: 816–836. https://doi.org/10.1002/jae.2623.

Ciplet, D., and J. L. Harrison. 2020. "Transition Tensions: Mapping Conflicts in Movements for a Just and Sustainable Transition." *Environmental Politics* 29, no. 3: 435–456. https://doi.org/10.1080/09644016.2019.1595883.

Crowe, J. A., and R. Li. 2020. "Is the Just Transition Socially Accepted? Energy History, Place, and Support for Coal and Solar in Illinois, Texas, and Vermont." *Energy Research & Social Science* 59: 101309. https://doi.org/10.1016/j.erss.2019.101309.

Dietz, T. 2015. "Prolegomenon to a Structural Human Ecology of Human Well-Being." *Sociology of Development* 1, no. 1: 123–148. https://doi.org/10.1525/sod.2015.1.1.123.

Dietz, T. 2023. *Decisions for Sustainability: Facts and Values*. Cambridge University Press.

Dobis, E. A., H. M. Stephens, M. Skidmore, and S. J. Goetz. 2020. "Explaining the Spatial Variation in American Life Expectancy." *Social Science & Medicine* 246: 112759. https://doi.org/10.1016/j.socscimed.2019.112759.

Douglas, S., and A. Walker. 2017. "Coal Mining and the Resource Curse in the Eastern United States." *Journal of Regional Science* 57, no. 4: 568–590. https://doi.org/10.1111/jors.12310.

Dwyer-Lindgren, L., A. Bertozzi-Villa, R. W. Stubbs, et al. 2017. "Inequalities in Life Expectancy Among US Counties, 1980 to 2014: Temporal Trends and Key Drivers." *JAMA Internal Medicine* 177, no. 7: 1003–1011. https://doi.org/10.1001/jamainternmed.2017.0918.

EIA. 2024a. "2023 Annual Coal Report." https://www.eia.gov/coal/annual/.

EIA. 2024b. "U.S. Energy Facts Explained." https://www.eia.gov/energyexplained/us-energy-facts/.

EIA. 2025a. "Coal Mines." https://atlas.eia.gov/maps/eia::coal-mines-1/explore.

EIA. 2025b. "Wyoming Profile." https://www.eia.gov/state/print.php?sid=WY.

Epstein, P. R., J. J. Buonocore, K. Eckerle, et al. 2011. "Full Cost Accounting for the Life Cycle of Coal." *Annals of the New York Academy of Sciences* 1219, no. 1: 73–98. https://doi.org/10.1111/j.1749-6632.2010.05890.x.

Fanning, A. L., D. W. O'Neill, J. Hickel, and N. Roux. 2022. "The Social Shortfall and Ecological Overshoot of Nations." *Nature Sustainability* 5, no. 1: 26–36. https://doi.org/10.1038/s41893-021-00799-z.

Finkelman, R. B., A. Wolfe, and M. S. Hendryx. 2021. "The Future Environmental and Health Impacts of Coal." *Energy Geoscience* 2, no. 2: 99–112. https://doi.org/10.1016/j.engeos.2020.11.001.

Frasquilho, D., M. Gaspar Matos, F. Salonna, et al. 2016. "Mental Health Outcomes in Times of Economic Recession: A Systematic Literature Review." *BMC Public Health* 16, no. 1: 115. https://doi.org/10.1186/s12889-016-2720-y.

Freudenburg, W. R. 1992. "Addictive Economies: Extractive Industries and Vulnerable Localities in a Changing World Economy." *Rural Sociology* 57, no. 3: 305–332. https://doi.org/10.1111/j.1549-0831.1992.tb00467.x.

GBD US Health Disparities Collaborators. 2022. "Life Expectancy by County, Race, and Ethnicity in the USA, 2000–19: A Systematic Analysis of Health Disparities." *Lancet* 400, no. 10345: 25–38. https://doi.org/10.1016/S0140-6736(22)00876-5.

Gohlke, J. M., R. Thomas, A. Woodward, et al. 2011. "Estimating the Global Public Health Implications of Electricity and Coal Consumption." *Environmental Health Perspectives* 119, no. 6: 821–826. https://doi.org/10.1289/ehp.119-821.

Harry, S. J., T. Maltby, and K. Szulecki. 2024. "Contesting Just Transitions: Climate Delay and the Contradictions of Labour Environmentalism." *Political Geography* 112: 103114. https://doi.org/10.1016/j.polgeo.2024.103114.

Heffron, R. J., and D. McCauley. 2018. "What Is the 'Just Transition'?" *Geoforum* 88: 74–77. https://doi.org/10.1016/j.geoforum.2017.11.016.

Hendryx, M., and M. M. Ahern. 2008. "Relations Between Health Indicators and Residential Proximity to Coal Mining in West Virginia." *American Journal of Public Health* 98, no. 4: 669–671. https://doi.org/10.2105/AJPH.2007.113472.

Hendryx, M., and J. Luo. 2015. "An Examination of the Effects of Mountaintop Removal Coal Mining on Respiratory Symptoms and COPD Using Propensity Scores." *International Journal of Environmental Health Research* 25, no. 3: 265–276. https://doi.org/10.1080/09603123.2014.938027.

Hendryx, M., K. J. Zullig, and J. Luo. 2020. "Impacts of Coal Use on Health." *Annual Review of Public Health* 41, no. 1: 397–415. https://doi.org/10.1146/annurev-publhealth-040119-094104.

Henneman, L., C. Choirat, I. Dedoussi, F. Dominici, J. Roberts, and C. Zigler. 2023. "Mortality Risk From United States Coal Electricity Generation." *Science* 382, no. 6673: 941–946. https://doi.org/10.1126/science.adf4915.

Institute for Health Metrics and Evaluation. 2022. "United States Mortality Rates and Life Expectancy by County, Race, and Ethnicity 2000–2019." https://ghdx.healthdata.org/record/ihme-data/united-states-life-expectancy-by-county-race-ethnicity-2000-2019.

Jenkins, K. E. H., B. K. Sovacool, A. Błachowicz, and A. Lauer. 2020. "Politicising the Just Transition: Linking Global Climate Policy, Nationally Determined Contributions and Targeted Research Agendas." *Geoforum* 115: 138–142. https://doi.org/10.1016/j.geoforum.2020.05.012.

Jorgenson, A. 2014. "Economic Development and the Carbon Intensity of Human Well-Being." *Nature Climate Change* 4, no. 3: 186–189. https://doi.org/10.1038/nclimate2110.

Jorgenson, A., J. B. Fitzgerald, R. Thombs, et al. 2020. "The Multiplicative Impacts of Working Hours and Fine Particulate Matter Concentration on Life Expectancy: A Longitudinal Analysis of US States." *Environmental Research* 191: 110117. https://doi.org/10.1016/j.envres.2020.110117.

Kerr, W. C., M. S. Kaplan, N. Huguet, R. Caetano, N. Giesbrecht, and B. H. McFarland. 2017. "Economic Recession, Alcohol, and Suicide Rates: Comparative Effects of Poverty, Foreclosure, and Job Loss." *American Journal of Preventive Medicine* 52, no. 4: 469–475. https://doi.org/10.1016/j.amepre.2016.09.021.

Lobao, L., M. Zhou, M. Partridge, and M. Betz. 2016. "Poverty, Place, and Coal Employment Across Appalachia and the United States in a New Economic Era." *Rural Sociology* 81, no. 3: 343–386. https://doi.org/10.1111/ruso.12098.

Milgroom, J., and J. Ribot. 2020. "Children of Another Land: Social Disarticulation, Access to Natural Resources and the Reconfiguration of Authority in Post Resettlement." *Society & Natural Resources* 33, no. 2: 184–204. https://doi.org/10.1080/08941920.2019.1590668.

Mining Safety and Health Administration. 2025. "Coal Mining Fatality Statistics: 1900–2024." https://arlweb.msha.gov/stats/centurystats/coalstats.asp.

Monnat, S. M. 2018. "Factors Associated With County-Level Differences in U.S. Drug-Related Mortality Rates." *American Journal of Preventive Medicine* 54, no. 5: 611–619. https://doi.org/10.1016/j.amepre.2018.01.040.

Mueller, J. T. 2022. "Natural Resource Dependence and Rural American Economic Prosperity From 2000 to 2015." *Economic Development Quarterly* 36, no. 3: 160–176.

Nickell, S. 1981. "Biases in Dynamic Models With Fixed Effects." *Econometrica* 49, no. 6: 1417–1426. https://doi.org/10.2307/1911408.

Pace, R. K., and J. P. LeSage. 2010. "Omitted Variable Biases of OLS and Spatial Lag Models." In *Progress in Spatial Analysis*, edited by A. Páez, J. Gallo, R. N. Buliung, and S. Dall'erba, 17–28. Springer.

Pathak, M., R. Slade, R. Pichs-Madruga, et al. 2022. "Technical Summary." In *Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, edited by P. R. Shukla, J. Skea, R. Slade, et al. Cambridge University Press.

Pickup, M. 2015. *Introduction to Time Series Analysis*. Sage.

Roberts, J. T., J. K. Steinberger, T. Dietz, et al. 2020. "Four Agendas for Research and Policy on Emissions Mitigation and Well-Being." *Global Sustainability* 3: e3. https://doi.org/10.1017/sus.2019.25.

Routledge, P., A. Cumbers, and K. D. Derickson. 2018. "States of Just Transition: Realising Climate Justice Through and Against the State." *Geoforum* 88: 78–86. https://doi.org/10.1016/j.geoforum.2017.11.015.

Rüttenauer, T. 2022. "Spatial Regression Models: A Systematic Comparison of Different Model Specifications Using Monte Carlo Experiments." *Sociological Methods & Research* 51, no. 2: 728–759.

Schwab, B., S. Janzen, N. P. Magnan, and W. M. Thompson. 2020. "Constructing a Summary Index Using the Standardized Inverse-Covariance Weighted Average of Indicators." *Stata Journal: Promoting Communications on Statistics and Stata* 20, no. 4: 952–964. https://doi.org/10.1177/1536867X20976325.

Shin, Y., B. Yu, and M. Greenwood-Nimmo. 2014. "Modelling Asymmetric Cointegration and Dynamic Multipliers in a Nonlinear ARDL Framework." In *Festschrift in Honor of Peter Schmidt*, 281–314. Springer.

Shindell, D., G. Faluvegi, K. Seltzer, and C. Shindell. 2018. "Quantified, Localized Health Benefits of Accelerated Carbon Dioxide Emissions Reductions." *Nature Climate Change* 8, no. 4: 291–295. https://doi.org/10.1038/s41558-018-0108-y.

Smith, K. R., H. Frumkin, K. Balakrishnan, et al. 2013. "Energy and Human Health." *Annual Review of Public Health* 34: 159–188. https://doi.org/10.1146/annurev-publhealth-031912-114404.

Sovacool, B. K., P. Devine-Wright, S. Mander, J. Rowley, and S. Ryder. 2025. "Realising a Locally-Embedded Just Transition: Sense of Place, Lived Experience, and Social Perceptions of Industrial Decarbonisation in the United Kingdom." *Global Environmental Change* 94: 103051. https://doi.org/10.1016/j.gloenvcha.2025.103051.

Sovacool, B. K., R. J. Heffron, D. McCauley, and A. Goldthau. 2016. "Energy Decisions Reframed as Justice and Ethical Concerns." *Nature Energy* 1, no. 5: 16024. https://doi.org/10.1038/nenergy.2016.24.

Sovacool, B. K., D. J. Hess, R. Cantoni, et al. 2022. "Conflicted Transitions: Exploring the Actors, Tactics, and Outcomes of Social Opposition Against Energy Infrastructure." *Global Environmental Change* 73: 102473. https://doi.org/10.1016/j.gloenvcha.2022.102473.

Sovacool, B. K., and S. V. Valentine. 2011. "Bending Bamboo: Restructuring Rural Electrification in Sarawak, Malaysia." *Energy for Sustainable Development* 15, no. 3: 240–253. https://doi.org/10.1016/j.esd.2011.05.003.

Steinberger, J. K., and J. T. Roberts. 2010. "From Constraint to Sufficiency: The Decoupling of Energy and Carbon From Human Needs, 1975–2005." *Ecological Economics* 70, no. 2: 425–433. https://doi.org/10.1016/j.ecolecon.2010.09.014.

Stevis, D. 2023. *Just Transitions: Promise and Contestation. (Elements in Earth System Governance).* Cambridge University Press.

Svobodova, K., J. R. Owen, D. Kemp, et al. 2022. "Decarbonization, Population Disruption and Resource Inventories in the Global Energy Transition." *Nature Communications* 13, no. 1: 7674. https://doi.org/10.1038/s41467-022-35391-2.

Thombs, R. 2022a. "A Guide to Analyzing Large *N*, Large *T* Panel Data." *Socius: Sociological Research for a Dynamic World* 8: 23780231221117645. https://doi.org/10.1177/23780231221117645.

Thombs, R. 2022b. "The Asymmetric Effects of Fossil Fuel Dependency on the Carbon Intensity of Well-Being: A U.S. State-Level Analysis, 1999–2017." *Global Environmental Change* 77: 102605. https://doi.org/10.1016/j.gloenvcha.2022.102605.

Thombs, R. 2022c. "Xtasysum."

Thombs, R. 2023. "Xthpj."

Thombs, R., X. Huang, and J. Fitzgerald. 2022. "What Goes Up Might Not Come Down: Modeling Directional Asymmetry With Large-*N*, Large-*T* Data." *Sociological Methodology* 52, no. 1: 1–29.

Thombs, R., and M. D. Willis. 2025. "Impact of Oil and Gas Boom and Busts on Working-Age Mortality in the U.S." *Environmental Epidemiology* 9, no. 6: e438.

Tsvetkova, A., and M. Partridge. 2017. "The Shale Revolution and Entrepreneurship: An Assessment of the Relationship Between Energy Sector Expansion and Small Business Entrepreneurship in US Counties." *Energy* 141: 423–434. https://doi.org/10.1016/j.energy.2017.09.101.

U.S. Department of Health and Human Services. n.d. "Healthy People 2030." https://odphp.health.gov/healthypeople/priority-areas/social-determinants-health.

U.S. Energy Information Agency. 2024. "Annual Coal Reports." https://www.eia.gov/coal/annual/index.php.

Vogel, J., J. K. Steinberger, D. W. O'Neill, W. F. Lamb, and J. Krishnakumar. 2021. "Socio-Economic Conditions for Satisfying Human Needs at Low Energy Use: An International Analysis of Social Provisioning." *Global Environmental Change* 69: 102287. https://doi.org/10.1016/j.gloenvcha.2021.102287.

Wang, X., and K. Lo. 2021. "Just Transition: A Conceptual Review." *Energy Research & Social Science* 82: 102291. https://doi.org/10.1016/j.erss.2021.102291.

Willis, M. D., N. Cesare, M. Harleman, et al. 2025. "Impact of Boom-and-Bust Economies From Oil and Gas Development on Psychiatric Hospitalizations Among Medicaid Beneficiaries." *Environmental Research: Health* 3, no. 3: 35008. https://doi.org/10.1088/2752-5309/ae01ce.

Willis, M. D., L. J. Cushing, J. J. Buonocore, N. C. Deziel, and J. A. Casey. 2023. "It's Electric! An Environmental Equity Perspective on the Lifecycle of Our Energy Sources." *Environmental Epidemiology* 7, no. 2: e246. https://doi.org/10.1097/EE9.0000000000000246.

Zhang, X., and S. M. Monnat. 2024. "Geographically Specific Associations Between County-Level Socioeconomic and Household Distress and Mortality From Drug Poisoning, Suicide, Alcohol, and Homicide Among Working-Age Adults in the United States." *SSM - Population Health* 25: 101595. https://doi.org/10.1016/j.ssmph.2023.101595.

Supporting Information

Additional supporting information can be found online in the Supporting Information section. **Data S1:** ruso70034-sup-0001-DataS1.docx.