

# Natural Gas Gathering and Transmission Pipelines and Social Vulnerability in the United States

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## **Abstract**

Midstream oil and gas infrastructure comprises vast networks of gathering and transmission pipelines that connect upstream extraction to downstream consumption. In the United States (US), public policies and corporate decisions have prompted a wave of proposals for new gathering and transmission pipelines in recent years, raising the question: Who bears the burdens associated with existing pipeline infrastructure in the US? With this in mind, we examined the density of natural gas gathering and transmission pipelines in the US together with county-level data on social vulnerability. For the 2,261 US counties containing natural gas pipelines, we found a positive correlation between county-level pipeline density and an index of social vulnerability. In general, counties with more socially vulnerable populations have significantly higher pipeline densities than with less socially vulnerable populations. In particular, counties in the top quartile of social vulnerability tend to have pipeline densities that are much higher than pipeline densities for counties in the bottom quartile of social vulnerability. The difference grows larger for counties at the upper extremes of pipeline density within each group. We discuss some of the implications for Indigenous communities and others affected by recent expansions of oil and gas infrastructure. We offer recommendations aimed at improving ways in which decision-

28 makers identify and address the societal impacts and environmental justice implications of  
29 midstream pipeline infrastructure.

30

31 Keywords: Environmental Justice, Energy, Infrastructure, Indigenous Peoples, Complex Systems

## 32 **Plain Language Summary**

33 Recent years have seen a wave of oil and gas development in the United States (US) and  
34 elsewhere. Research on human health and other societal impacts of oil and gas focuses mainly  
35 on upstream activities, including hydraulic fracturing, and on downstream activities, including  
36 refining and electricity production. Gathering and transmission pipelines, which connect  
37 upstream and downstream parts of the supply chain, also have negative impacts but receive less  
38 attention than other areas. No prior research has determined whether negative impacts of  
39 gathering and transmission pipelines fall equitably across society. We analyzed publicly-  
40 available datasets and found that the existing network of natural gas pipelines in the US is  
41 concentrated more heavily in counties where people experience high levels of social  
42 vulnerability than in counties where social vulnerability is low. These results have implications  
43 for environmental justice, which is concerned, in part, with how environmental burdens are  
44 distributed throughout society. We highlight some of the burdens faced by Indigenous peoples  
45 and others who are impacted by ongoing pipeline development. Our work reiterates a need for  
46 researchers and decision-makers to look closely at these impacts, especially in light of  
47 environmental justice policy, to understand the broader societal costs of oil and gas  
48 infrastructure.

## 49 **Introduction**

50 Energy policy in the United States (US) shifted in recent years from a focus on energy  
51 independence toward so-called energy dominance (The White House, 2019). The policy shift  
52 coincided with major investments in pipelines and other infrastructure to support ongoing  
53 extraction and consumption of oil and gas (US Energy Information Administration, 2019). Even  
54 as US policy begins to shift away from fossil fuels, analysts within the federal government  
55 project that oil and gas will continue to supply most of the energy consumed in the US for  
56 decades to come (US Energy Information Administration, 2021). The expansion of oil and gas  
57 infrastructure to support high levels of consumption will increase greenhouse gas emissions  
58 (Kalen & Hsu, 2020; Pascaris & Pearce, 2020), and climate change associated with these  
59 emissions will have long-term implications for the health of people and ecosystems worldwide  
60 (IPCC, 2018).

61

62 Besides the indirect impacts associated with climate change, oil and gas infrastructure poses  
63 direct risks to nearby communities. At both upstream and downstream ends of oil and gas  
64 supply chains, communities experience environmental degradation and incur a wide range of  
65 health and safety risks associated with phenomena such as hydraulic fracturing, directional  
66 drilling, worker encampments (i.e., “man camps”), refining, electricity production, and more  
67 (Bullard, 2018; Colborn et al., 2014; Davies, 2019; Kroepsch et al., 2019; Olmstead et al., 2013;  
68 O’Rourke & Connolly, 2003; Rahm et al., 2015; Whyte, 2017).

69

70 In comparison to upstream and downstream regions of oil and gas supply chains, the middle  
71 sections have received less attention from researchers who study environmental and societal  
72 impacts of oil and gas. So-called midstream infrastructure includes vast networks of gathering  
73 and transmission pipelines, pumps, compressors, and storage facilities that link production areas  
74 upstream to downstream oil and gas processing and consumption sites. In the case of

unconventional natural gas, which includes shale gas and coal bed methane, a review by Buse et al. (2019) highlights the research gap, especially as it pertains to socioeconomic and health impacts associated with midstream infrastructure. Strube et al. (2021) summarize a few of these impacts, including spills, explosions, and landslides, but the authors emphasize the difficulty in assessing risks due to confidentiality and security concerns that limit the public availability of data about pipelines.

The recent boom in unconventional oil and gas extraction from shale plays in the US (US Energy Information Administration, 2019; Vengosh et al., 2014) has been accompanied by a wave of proposals for major gathering and transmission pipelines to transport oil and gas to downstream consumers (Strube et al., 2021; Wang & Krupnick, 2015; Waxman et al., 2020). Some of these pipelines have already been built and put into service (e.g., Dakota Access Pipeline). Others are still in planning or construction phases (e.g., Mountain Valley and Keystone XL Pipelines). A small number have been cancelled altogether (e.g., Atlantic Coast and Northern Gateway Pipelines).

The pace of US pipeline development signals an urgent need for research about health, socioeconomic, and other impacts associated with pipelines and other midstream infrastructure. In particular, there is a pressing need to understand the extent to which large-scale (e.g., regional or national) distribution of midstream pipelines may create or exacerbate societal inequities in environmental degradation, exposure to health risks, and other harms. Although individual pipeline projects can place disproportionately high and adverse burdens on racially marginalized and low-wealth communities relative to reference populations in the regions surrounding these projects (e.g., Emanuel, 2017; Emanuel & Wilkins, 2020; Whyte, 2017; Wraight et al., 2018),

there is no research on social inequities associated with the geographic distribution of networks comprising many different pipeline projects.

Inequities in the siting of harmful or polluting infrastructure spurred the modern environmental justice (EJ) movement and led to the development of EJ policies in the US. The US Environmental Protection Agency defines EJ as the fair treatment and meaningful involvement of all people in the environmental decision-making process (US Environmental Protection Agency, 2014). Environmental justice policies in the US aspire to identify disparities in the distribution of environmental burdens and amenities, to address the disparate impacts in various ways, and to remove barriers to participation in environmental decision-making by marginalized peoples (Bullard, 1993, 2018; Emanuel, 2017; Holifield et al., 2017; Johnson, 2019; Mohai et al., 2009; National Environmental Justice Advisory Council, 2000; Schlosberg & Collins, 2014; Whyte, 2011). Agencies within the US government are required by federal executive order to evaluate potential disparities and EJ implications of their regulatory actions, including the authorization of new pipeline projects. However, there has never been an effort to examine EJ implications of the larger networks to which individual pipeline projects typically belong. The practice of evaluating EJ on a pipeline-by-pipeline basis makes it difficult to determine whether a new pipeline could exacerbate or alleviate network-wide disparities in the distribution of environmental and public health impacts. By considering the EJ implications of an entire pipeline network, decision-makers, researchers, and others can gain a fuller understanding of the societal impacts of oil and gas flowing through the network.

To this end, we examined the US natural gas gathering and transmission pipeline network to determine whether the network as a whole raises system-wide concerns about EJ. Specifically, we compared the density of natural gas gathering and transmission pipelines to social vulnerability on a county-by-county basis for all pipeline-containing counties in the US. Social vulnerability is an integrated measure of a community's capacity to prepare for, deal with, and recover from pollution, natural disasters, and other hazards (Chakraborty et al., 2020; Flanagan et al., 2018). It takes into account demographic details about a community (e.g., racial composition, age distribution) and other socioeconomic information (Flanagan et al., 2018). Thus, it is a relevant index for evaluating societal disparities in the siting of hazardous or polluting infrastructure.

Geospatial indices of social vulnerability are already used to study societal disparities related to healthcare, flood risk, and other areas (e.g., Flanagan et al., 2018; Saia et al., 2020). For EJ evaluations of pipeline networks, such indices can shed light on a community's ability to cope with risks and threats associated with spills and leaks, explosions, structural failures, construction impacts, and other factors. Finley-Brook et al. (2018) discuss some of these factors in greater detail, but here we note that between 2001 and 2020, federal safety regulators documented a total of 36 fatalities, 164 injuries, and approximately \$2.5 billion in costs associated with industry-reported incidents from natural gas gathering and transmission pipelines in the US (US Department of Transportation, 2021). These costs include property damage as well as the value of natural gas lost to the atmosphere during incidents. Notably, the costs do not account for the climate implications of methane emissions during incidents, which contribute disproportionately to the greenhouse gas footprint of natural gas supply chains (Brandt et al.,

2014; Pandey et al., 2019). Risks of leaks and other incidents increase as these pipelines age  
(Alzbutas et al., 2014; Hendrick et al., 2016).

Pipelines concentrated in areas of high social vulnerability raise EJ concerns associated with the  
inequitable distribution of hazards resulting from energy infrastructure. Specifically, the  
concentration of pipelines in these areas suggests that environmental, health, and other burdens  
are shouldered, disproportionately, by communities that have an already limited capacity to carry  
such loads. After examining the US natural gas gathering and transmission pipeline network, we  
discuss the implications for marginalized communities targeted by major pipelines in recent  
years. We then discuss the relevance of these findings for EJ policy and offer recommendations  
to scientists and decision-makers.

## **Methods**

We acquired geospatial data from two different sources. First, we downloaded the social  
vulnerability index (SVI) for 3,142 US counties and county-level equivalents (hereafter counties)  
in shapefile format from the US Centers for Disease Control and Prevention (CDC) website  
(<http://svi.cdc.gov>). The CDC describes SVI as an index to estimate the potential for external  
factors to impact a community's ability to deal with human suffering and financial loss. The  
index ranges from 0 (least vulnerable) to 1 (most vulnerable), and it has a uniform distribution  
among US counties. The uniform distribution is an important property that allowed us to create  
similarly-sized bins of SVI at a later stage in the analysis. We used SVI for 2018, the most recent  
year of data availability when we conducted the analysis.



167 Next, we acquired geospatial data for the US natural gas gathering and transmission pipeline  
168 network. We downloaded these data as a polyline shapefile from the US Energy Information  
169 Administration (EIA), using a version last updated in January 2020  
170 ([https://www.eia.gov/maps/layer\\_info-m.php](https://www.eia.gov/maps/layer_info-m.php)). The shapefile contains information on  
171 approximately 370,000 km of interstate and intra-state pipelines, and, according to the embedded  
172 metadata, is compiled from data submitted to federal regulators and information gleaned from  
173 industry websites and press. The US has approximately 515,000 km of natural gas gathering and  
174 transmission pipelines overall (U.S. Department of Transportation, 2020), which means that  
175 more than 25% of the network is absent from the EIA shapefile. Nevertheless, this file represents  
176 the most comprehensive US natural gas pipeline dataset currently available to the public.

177

178 We processed social vulnerability and pipeline datasets using ArcGIS (Redlands, CA). First, we  
179 overlaid the pipeline shapefile on an equal-area projected map of US counties. We then used the  
180 “Intersect” function to divide the pipeline shapefile into segments within individual counties.

181 Next, we computed pipeline segment lengths (km) by applying the “Calculate Geometry”  
182 function to the resulting attribute table. After computing segment lengths, we used the “Spatial  
183 Join” function to combine the pipeline and county layers into a data table, modifying the  
184 function’s merge rules to compute the sum of pipeline segment lengths for each county.

185

186 Counties that contained no pipeline segments (881 of 3,142, or 28% of US counties) are visible  
187 on the map in Figure 1 but excluded from further analysis. Similarly, pipeline segments located  
188 in open water (e.g., the Gulf of Mexico) are visible in Figure 1 but excluded from further  
189 analysis. We computed the density of natural gas gathering and transmission pipelines,  $\rho_{NG}$ , as

pipeline km per 100 km<sup>2</sup> of land area. The unit conversion places most density values in the whole number range, thus improving readability. The conversion has no effect on statistical analyses or conclusions.

The preceding ArcGIS operations yielded an attribute table that contained the following information for each of the 2,261 US counties with natural gas pipelines: total length of pipeline segments (km), total land area (km<sup>2</sup>), SVI,  $\rho_{NG}$ , and the Federal Information Processing Standard (FIPS) code. The FIPS code uniquely identifies each county and the state in which it is located. We exported the attribute table as a tab-delimited text file for statistical analysis using Matlab (Natick, MA).

We used Matlab's statistics toolbox to test differences in means, medians, and cumulative distributions, and we report p-values from the 2-sample T-test, Wilcoxon Rank-Sum test, and 2-sample Kolmogorov-Smirnov test, respectively. We also used the toolbox to compute Pearson's correlation coefficient and accompanying p-value. Finally, we used Matlab to bin counties by SVI decile in order to select an envelope of counties for further scrutiny if they exceed thresholds of  $\rho_{NG}$  within their respective bins. For exceedance thresholds, we used the 75<sup>th</sup>, 90<sup>th</sup>, 95<sup>th</sup>, and 97.5<sup>th</sup> percentile of counties within each SVI-decile bin. Bins were similarly-sized, each containing between 200 and 245 counties, and the number of counties in each bin varied independently of SVI values.

A few caveats apply to the datasets. No counties in Hawaii and only one county in Alaska contained any gathering or transmission pipelines in the EIA shapefile. Thus, the results apply

mainly to the 48 contiguous states. Also, the CDC did not compute 2018 SVI for one county (Rio Arriba, NM) due to a US Census data collection error (<https://www.census.gov/programs-surveys/acs/technical-documentation/errata/125.html>). The county, which contained 56 km of pipelines, was excluded from analyses involving SVI. Finally, we analyzed the existing natural gas pipeline network in 2020. We caution against direct comparison of our results and conclusions with recent work by Strube et al. (2021), which analyzes a sample of proposed new gas transmission pipelines.

## Results

The US natural gas gathering and transmission network comprises approximately 515,000 km of gathering and transmission pipelines, and approximately 370,000 km of that network is shown here (Figure 1). Approximately 280,000 km of pipelines are located on land, traversing 2,261 US counties (72% of all counties). Only one county is located outside of the contiguous 48 states (Kenai Peninsula, AK). Each county contains, on average, 125 km of pipeline, and half of the counties contain at least 64 km of pipelines. Twenty-six counties have at least 1,000 km of pipelines, and 36 counties contain some amount of pipeline but less than 1 km total. The mean density of natural gas gathering and transmission pipelines,  $\rho_{NG}$ , is 6.1 km of pipeline / 100 km<sup>2</sup> of land area for the 2,261 counties. Half of the counties have  $\rho_{NG}$  of at least 3.7 km / 100 km<sup>2</sup>. The distribution of  $\rho_{NG}$  for all pipeline-containing counties skews positive (right).

Gathering and transmission pipelines are located in counties throughout the full range of SVI (Figure 1). Even so, pipeline density is not distributed uniformly among US counties with respect to SVI. In particular,  $\rho_{NG}$  is significantly greater for counties in the highest quartile of SVI (i.e., counties with the most vulnerable populations) than for counties in the lowest SVI quartile (i.e., counties with the least vulnerable populations). Specifically, counties in the highest

quartile of social vulnerability have a mean  $\rho_{NG}$  value of 7.5 km / 100 km<sup>2</sup>, which is significantly greater than the mean  $\rho_{NG}$  value of 4.5 km / 100 km<sup>2</sup> for counties in the lowest quartile of social vulnerability ( $p < 0.001$ ). The median  $\rho_{NG}$  values also differs significantly between the highest and lowest quartiles of social vulnerability ( $p < 0.001$ ). The group of 881 counties without any gathering or transmission pipelines did not differ significantly from the group of pipeline-containing counties in terms of mean  $\rho_{NG}$ , median  $\rho_{NG}$ , or the shape of the SVI cumulative distribution.

For pipeline-containing counties in the top quartile of social vulnerability, the distribution of  $\rho_{NG}$  is shifted to the right of the  $\rho_{NG}$  distribution for counties in the bottom quartile of social vulnerability (Figure 2). Because of the positive skew in  $\rho_{NG}$ , the difference in  $\rho_{NG}$  between the two groups grows larger at higher quantiles of  $\rho_{NG}$ . For example, the difference in  $\rho_{NG}$  is less than 1 km / 100 km<sup>2</sup> for counties that have relatively low densities of pipelines within their vulnerability quartiles, but the difference grows to more than 20 km / 100 km<sup>2</sup> for counties that have relatively high densities of pipelines within their vulnerability quartiles. At the upper extreme, pipeline densities are greater than 50 km / 100 km<sup>2</sup> for 1% of counties in the top vulnerability quartile, whereas the top 1% of pipeline densities for counties in the bottom vulnerability quartile range from approximately 27 km / 100 km<sup>2</sup> to 40 km / 100 km<sup>2</sup> (Figure 2). Table 1 summarizes the differences in key descriptive statistics for the two groups, and it provides upper and lower bounds for each group's 95% confidence interval. The upper bound of the confidence interval highlights the large differences in  $\rho_{NG}$  experienced by counties at the high-density end of each group's distribution.

For all pipeline-containing counties in the US,  $\rho_{NG}$  and SVI are correlated (Pearson's  $r = 0.14$ ,  $p < 0.001$ ). The relationship between  $\rho_{NG}$  and SVI is driven mainly by counties that have relatively high  $\rho_{NG}$  for their SVI (Figure 3). For example, counties in the top 25% envelope of  $\rho_{NG}$  (defined

as counties in the top 25<sup>th</sup> percentile of density for a given range of SVI) have a correlation between  $\rho_{NG}$  and SVI that is much higher ( $r = 0.33$ ,  $p < 0.001$ ) than the correlation for all pipeline-containing counties ( $r = 0.14$ ,  $p < 0.001$ ). The correlation coefficients grow larger as the envelopes become more extreme; Table 2 summarizes correlations for envelopes ranging from the top 25<sup>th</sup> percentile of pipeline density to the top 97.5<sup>th</sup> percentile of pipeline density.

## **Discussion**

### ***Significance of Findings***

The correlation between pipeline density and social vulnerability is a previously undocumented characteristic of the US natural gas gathering and transmission pipeline network. Relationships between  $\rho_{NG}$  and SVI suggest that nationally, negative impacts associated with natural gas pipelines, including air and water pollution, public health and safety concerns, and other burdens, fall disproportionately on communities with already limited capacities to deal with challenges created by these impacts.

Relationships between pipeline density and social vulnerability neither imply that vulnerable communities were targeted by pipeline developers nor that vulnerable communities sprang up near pipelines. The relationships do, however, confirm that gathering and transmission pipeline densities are not randomly distributed with respect to county-level social vulnerability in the US. in general, counties with more socially vulnerable populations experience higher densities of gathering and transmission pipelines than counties with less socially vulnerable populations.

Because the pipeline network was constructed over the course of several decades by many different companies operating under various regulatory and policy conditions (US Energy

Information Administration, 2020), one possible explanation is that the observed inequitable distribution of pipeline density is an emergent property of an inherently complex system of governance. Governance systems for energy, natural resources, and the environment exhibit structural complexity (e.g., Craig, 2012; Jacquet et al., 2018; Newig et al., 2010), and complex systems are often characterized by emergent behaviors or properties that cannot be traced to any specific system component (Manson, 2001). Perhaps the observed disparity in the distribution of gathering and transmission pipelines is an example of such emergent behavior. If so, complex systems theory may prove useful for understanding how governance systems and other structures interact to produce racial and socioeconomic disparities in the distribution of pollution and other burdens associated with fossil fuel infrastructure.

Suggesting that the association between pipeline density and social vulnerability is an emergent property of a complex system does not imply that no one bears responsibility for the inequitable distribution of environmental and public health burdens. On the contrary, multiple parties – local and state officials, federal regulators, corporations – share responsibility through decisions that often prioritize economic interests over the equitable distribution of burdens (Foreman, 2011; Steel & Whyte, 2012; Sze et al., 2009). At minimum, our results re-emphasize a major theme in EJ research: overt discrimination and malicious intent are not prerequisites for discriminatory outcomes (e.g., Bullard, 1993; Pulido, 2000; Ranganathan, 2016; Vasudevan & Smith, 2020).

Regardless of responsibility or intent, the disproportionately high density of natural gas pipelines in areas of high social vulnerability warrants further attention. Although the concentration of infrastructure in areas of high social vulnerability is consistent with patterns observed at upstream and downstream ends of the oil and gas supply chain (Colborn et al., 2014; Davies,

2019), midstream pipelines and related infrastructure have unique burdens. We discuss some of these burdens in the following section. We focus specifically on Indigenous communities and others located in rural parts of the US given that many new oil and gas pipelines are routed through rural landscapes (Strube et al., 2021).

### *Implications*

Decision-makers responsible for permitting midstream pipelines have justified rural routes by implying that societal risk is connected to population size density, asserting, in some cases, that societal risks are greater in urban areas than to rural areas. For example, federal regulators eliminated an early route for the Dakota Access Pipeline partly because of its proximity to the city of Bismarck, ND and its urban water supply. Regulators instead chose a rural route adjoining the present-day Standing Rock Sioux reservation (Whyte, 2017).

Although population density may predict the severity of certain impacts (e.g., a gas pipeline explosion may harm more people in an urban area than an equivalent explosion in a rural area), we contend that rural pipeline impacts, in general, are not simply diffuse or less intense versions of urban impacts. Instead, recent research suggests that gathering and transmission pipelines pose fundamentally distinct cultural, economic, and other challenges for rural areas (Caretta & McHenry, 2020; Donnelly, 2018; Emanuel & Wilkins, 2020; Whyte, 2017). The recent wave of oil and gas pipeline development in the US and elsewhere highlights the need for more nuanced thinking about the implications of expanding pipeline infrastructure into rural areas. We highlight some of these below.

Several oil and gas transmission pipelines proposed or built in recent years have unique implications for Indigenous communities in rural areas due to impacts – actual and potential – on their contemporary and ancestral territories. Although Indigenous peoples in the US overwhelmingly reside in urban areas (Weaver, 2012), Indigenous knowledge systems, cultures,

339 and identities are inextricably tied to certain landscapes, waterways, and other spaces that are  
340 predominantly rural in nature (e.g., Emanuel, 2019; Whyte, 2017). The Dakota Access,  
341 Keystone XL, Trans Mountain Expansion, Enbridge Line 3 pipelines, and the now-cancelled  
342 Atlantic Coast and Northern Gateway Pipelines all traverse or proposed to traverse territories of  
343 Indigenous peoples in the US and Canada (Emanuel, 2017; Estes, 2019; Hunsberger & Awâsis,  
344 2019; Jonasson et al., 2019; McCreary & Milligan, 2014; Whyte, 2017). Some Tribes and First  
345 Nations oppose these projects not only because of concerns over pollution or risks to human  
346 health, but also because of the pipelines' potential to cause irreparable cultural harm by  
347 damaging or destroying present-day or ancestral territories with religious, historical, or cultural  
348 significance (e.g., Chen, 2020; Emanuel & Wilkins, 2020; Estes, 2019; Vypovska et al., 2018).  
349  
350 Despite the high stakes for Indigenous peoples, few culturally-oriented pipeline assessments  
351 exist. Those that do are commissioned mainly by affected Tribes or First Nations in response to  
352 regulatory processes that fail to address concerns they deem important (e.g., Honor the Earth,  
353 2020; Tsleil-Waututh Nation, 2015). These assessments describe how pipeline construction and  
354 operation may disrupt, for example, the ability of Indigenous peoples to maintain place-based  
355 food traditions or cultural practices. They also highlight ways in which regulatory proceedings  
356 renew or exacerbate longstanding ethical and legal issues surrounding the participation of  
357 Indigenous peoples in decision-making about their own lands and communities (Emanuel &  
358 Wilkins, 2020; Honor the Earth, 2020; Tsleil-Waututh Nation, 2015; Whyte, 2017).  
359 Occasionally, these assessments lead to agreements to provide redress for impacts to Indigenous  
360 communities, or they serve to outline co-management strategies (e.g., Vypovska et al., 2018).  
361 Often, however, they serve to document various ways in which planning and permitting exclude  
362 Indigenous perspectives, weaken sovereignty, or otherwise undermine Indigenous self-  
363 determination (Emanuel & Wilkins, 2020; Estes, 2019; Whyte, 2017). In the US, issues raised  
364 by Indigenous peoples in culturally-oriented pipeline assessments and other venues are often  
365 perceived as less important than the priorities of project proponents (e.g., Brown, 2017).



366

367 Pipeline construction and operation have implications for rural landscapes more generally,  
368 including implications associated with easements on privately-owned lands. Easements are  
369 property rights obtained through landowner negotiation or eminent domain, a legal process that  
370 requires landowners to relinquish certain property rights to pipeline builders and operators. The  
371 societal implications of pipeline easements, however, extend far beyond delineated and  
372 compensated boundaries. Easements for gathering and transmission pipelines place practical  
373 restrictions on adjacent land uses, affect nearby property values, and increase the risks of fire or  
374 catastrophic explosions in areas further away from easement boundaries (e.g., Caretta &  
375 McHenry, 2020; Hansen et al., 2006; Holdsworth et al., 2021). Landowners bear these risks and  
376 are still obligated to pay taxes on properties crossed by easements (Caretta & McHenry, 2020).

377

378 Rural communities often do not have the same capacity as urban areas to respond to emergencies  
379 and disasters and are often limited in their response capabilities (Brennan & Flint, 2007; Furbee  
380 et al., 2006). These limitations extend to explosions, leaks, or other incidents related to  
381 midstream pipeline infrastructure. Some natural gas transmission pipelines proposed in recent  
382 years exceed 1 m in diameter and have internal gas pressures approaching 1 MPa, elevating  
383 general concerns about safety and emergency response capabilities (Finley-Brook et al., 2018).  
384 Safety and other concerns about pipelines may erode the sense of belonging felt by rural  
385 residents, leading some people to move away (Caretta & McHenry, 2020). Moreover, changes  
386 associated with midstream infrastructure potentially create rifts between neighbors who disagree  
387 about the relative benefits and burdens of hosting pipelines in their communities (Caretta &  
388 McHenry, 2020). Overall, research from rural Appalachia confirms that easements, safety  
389 concerns, and other factors facilitate drastic alteration of communities, transforming rural

landscapes into sprawling, industrial settings within a few years (Caretta & McHenry, 2020; Donnelly, 2018). Implications of these changes for rural public health and other societal concerns are still coming into focus, but one emerging theme is that oil and gas infrastructure often exacerbates existing social vulnerability (Blinn et al., 2020; Hemmerling et al., 2021). Together, these examples call into question the idea that midstream pipelines have negligible societal impacts in rural areas simply because populations are less dense than in urban areas.

### ***Recommendations***

In the US, federal EJ policy requires inclusion of socioeconomic analyses in pipeline regulatory reviews to help identify and address adverse environmental and other impacts that could fall disproportionately on vulnerable populations as a result of permitted activities (e.g., Emanuel & Wilkins, 2020). For natural gas pipelines, federal regulators are also charged with determining whether projects are in the public interest (Kalen & Hsu, 2020). This work motivates us to combine these two policy priorities into a new question: Is it in the public interest to preserve or exacerbate existing patterns that disproportionately burden vulnerable populations with negative impacts from natural gas pipelines? This question guides our recommendations to decision-makers and others.

Federal policy guidance includes recommendations for conducting EJ analyses, which are sections of environmental review documents that allow regulators to identify disparities in environmental impacts by race or income status (US Council on Environmental Quality, 1997). Regulators and proponents rely on these analyses to draw conclusions and make decisions about pipelines and other infrastructure projects (Emanuel, 2017). Federal courts in the US have granted agencies wide latitude to choose or develop their own EJ analyses (*Sierra Club v. Federal Energy Regulatory Commission*, 2017), and although decades of research have improved the ability to identify disparities using demographic data, federal EJ analyses are

frequently criticized as methodologically unsound, procedurally rote, or ineffective at preventing or minimizing negative impacts disproportionately imposed on socially vulnerable populations (e.g., Bullard, 2018; Davies, 2019; Emanuel & Wilkins, 2020). In some pipeline cases, federal EJ analyses involve only cursory demographic screenings, which can mask racial disparities or other social inequities in pipeline routing (Emanuel, 2017; Estes, 2019). Alone, such screenings are unlikely to capture the complexity of concerns about impacts and potential disparities faced by vulnerable populations, and federal policy guidance cautions against this use (e.g., US EPA, 2014). Decision-makers must re-envision the roles of demographic tools and analyses as they work toward more holistic assessments of the societal burdens of pipelines and related infrastructure. Culturally-oriented assessments and community-based research have the potential to complement demographic analyses, and we reiterate many prior calls to better incorporate these types of approaches into environmental reviews (e.g., Arquette et al., 2002; Blue et al., 2020; Halseth, 2016; Stevenson, 1996; Wilson et al., 2019).

Regulators and corporations must commit to early, good-faith efforts to incorporate community perspectives into decision-making. At present, however, power asymmetries between corporations and regulators on one hand and socially vulnerable communities on the other sometimes prevent timely and meaningful efforts to incorporate these perspectives into decision-making about pipelines (e.g., Emanuel & Wilkins, 2020). Structural changes to the regulatory system may be required to overcome this particular barrier. Natural gas regulators in the US have recently signaled that they intend to review policies on identifying and addressing impacts of pipeline authorizations on low wealth and racially marginalized communities (US Federal Energy Regulatory Commission, 2021). Periodic reviews such as this one could help regulators adopt structural changes to improve the effectiveness of their EJ policies, including accountability mechanisms to ensure that impacted communities are engaged meaningfully in environmental decision-making processes.

Scientists, for their part, can partner with communities to describe and quantify impacts related to environmental degradation, health and safety, and other issues. This work may include quantifying the value of property or assets lost through eminent domain for the construction of pipelines and related infrastructure, or identifying the extent to which midstream infrastructure increases societal tensions or desires to relocate from rural communities. Scientists also have the ability to provide technical critiques of regulatory claims about EJ and to hold regulators to rigorous standards for the design and implementation of EJ analyses. For example, regulators who draw conclusions based on demographic analyses should understand the sensitivities and limits of detection for these analyses.

Scientists and decision-makers should pay closer attention to the cumulative impacts of co-located pipelines, compressors, and other types of mid-stream infrastructure. Regulatory analyses focus on the implications of newly-proposed infrastructure and – with few exceptions – disregard impacts associated with the gradual accumulation of infrastructure in a community. Yet people nearby do not experience newly-proposed facilities in isolation; they are exposed to the cumulative effects of all nearby infrastructure on air quality, noise, explosion risks, and more. Calls to consider cumulative impacts – and to reconsider how cumulative impacts are evaluated in decision-making – are not new (Parkes et al., 2016), and thorough reviews of cumulative impacts should consider how past decisions affect conditions in the present (Halseth et al., 2016). With that in mind, it is important to remember that much oil and gas infrastructure in the US predates not only EJ policies but also anti-discrimination laws, including the US Civil Rights Act. The siting of such infrastructure may reflect overt and institutionalized racism that shaped infrastructure planning and decision-making during most of US history (Bullard, 2002). It is therefore possible that existing pipeline routes may reflect historical practices that deliberately sought to concentrate polluting infrastructure in marginalized communities. With this in mind, decision-makers who review cumulative impacts of proposed pipelines should acknowledge that

new infrastructure concentrated along existing easements or corridors could reinforce historic practices of oppression. The relationships between social vulnerability and pipeline density revealed in this study reiterate an urgent need for researchers and decision-makers to pay close attention to the cumulative environmental, public health, and other burdens experienced by vulnerable populations – especially as the buildout of midstream pipelines continues in the US and elsewhere.

## **Conclusions**

We analyzed multiple, publicly-available datasets and found that the existing network of natural gas pipelines in the US is concentrated more heavily in counties where people experience high levels of social vulnerability than in counties where social vulnerability is lower. The study, however, does more than simply document another way in which vulnerable populations are disproportionately impacted by hazardous or polluting infrastructure. It reiterates a need to identify and address disparate societal impacts of infrastructure at the level of an entire system, whether the system is part of the oil and gas supply chain or some other sector.

Assuming natural gas gathering and transmission pipelines continue to be built, decision-makers and the general public should keep in mind that the network is already distributed inequitably with respect to social vulnerability, and that future projects can either maintain the inequitable status quo or shift the distribution in ways that will potentially exacerbate or ameliorate current disparities. A more complete view of the oil and gas supply chain can inform decision-makers and the general public about the larger societal costs of US energy dominance, including the extent to which vulnerable rural communities subsidize this policy through inequitable exposure to environmental, health, and other risks.

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## Acknowledgments

The authors received no external funding to support this work. Primary datasets can be accessed using links provided in the Methods section. Derived datasets (e.g., pipeline density by county) can be accessed at <https://doi.org/XX.XXX/zenodo.XXXXXXX>.

## Tables

**Table 1:** Pipeline Density Characteristics of US Counties

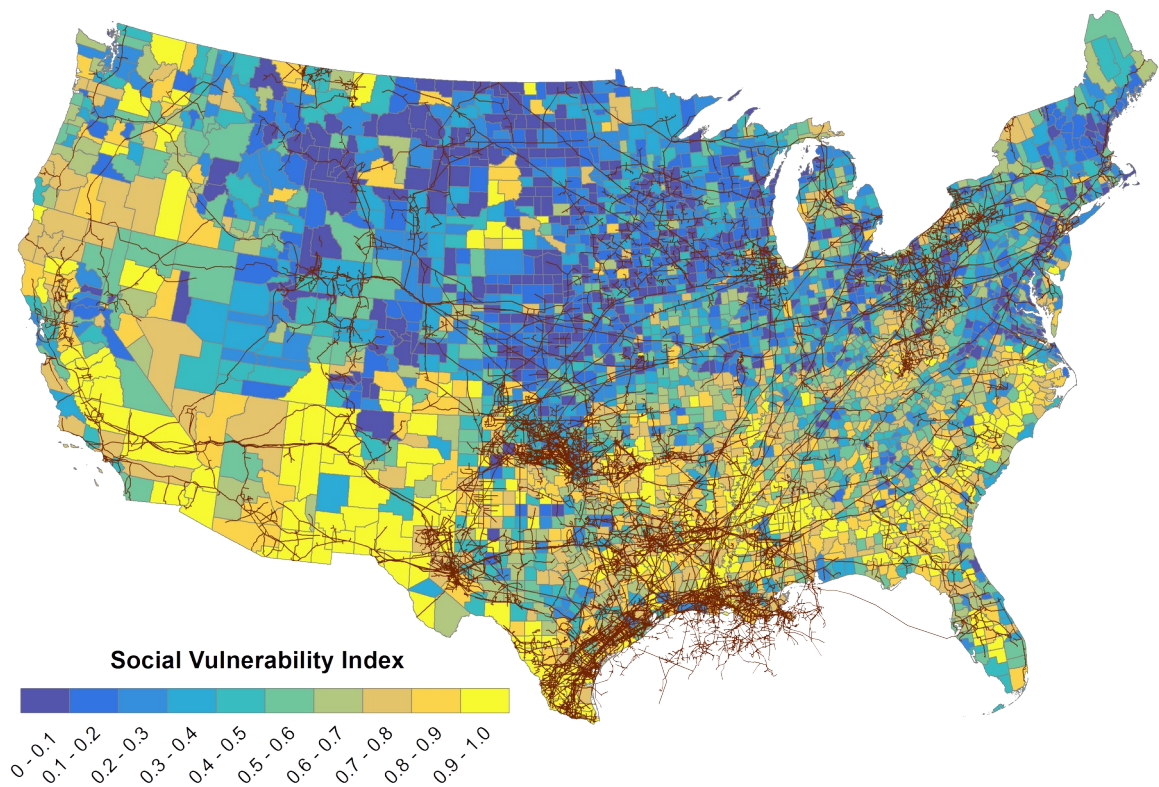
Category	Mean	Median	95% CI
County SVI > 0.75	7.5	4.1	0.2 - 38.2
County SVI < 0.25	4.5	3.2	0.2 - 15.4
All Counties	6.1	3.7	0.2 - 29.4

**Table 2:** Correlations between  $\rho_{NG}$  and SVI for groups shown in Figure 3

Percentile Group	r	p	N
>97.5	0.65	<0.001	58
90-95	0.59	<0.001	113
75-90	0.47	<0.001	225
<75	0.33	<0.001	562

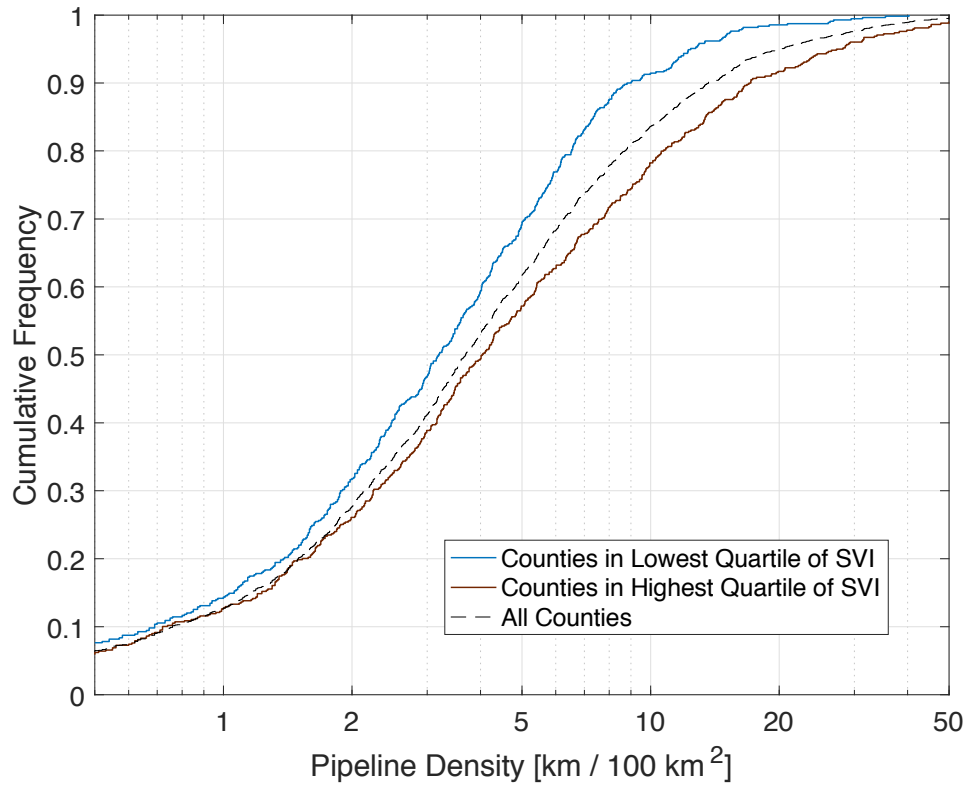
770 **Figures**

771 **Figure 1:** Natural gas gathering and transmission pipelines in the conterminous US, with social  
772 vulnerability index shown for each US county. One Alaska county is included in the statistical  
773 overview of the results but is not shown here.



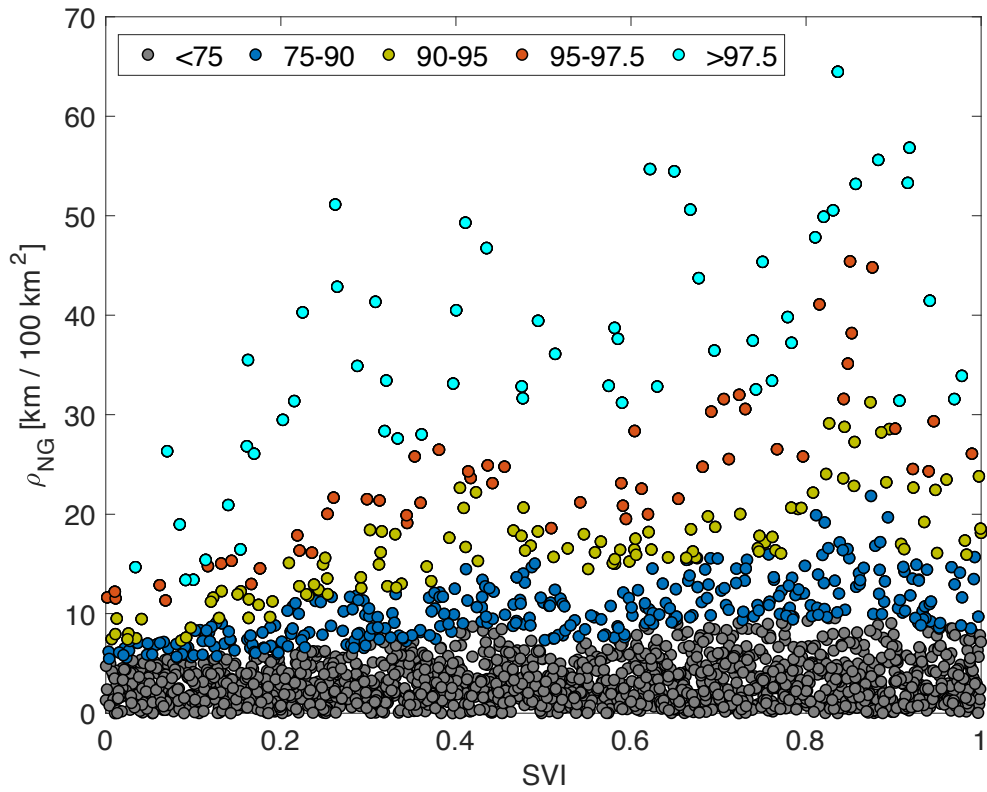
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776 **Figure 2:** Cumulative frequency distributions of natural gas gathering and transmission pipeline  
777 density for counties in the lowest quartile of social vulnerability (blue), counties in the highest  
778 quartile of social vulnerability (red), and all counties (dashed). Distributions of densities for the  
779 highest and lowest quartiles differ significantly from one another (KS statistic = 0.17,  $p < 0.001$ ).



780  
781

782 **Figure 3:** Pipeline density versus social vulnerability for US counties. Colors indicate envelopes  
 783 for pipeline density percentiles based on bins of SVI (e.g., gray points indicate counties in the  
 784 lower 75<sup>th</sup> percentile of density for their SVI bins, blue points indicate counties in the 75<sup>th</sup> to 90<sup>th</sup>  
 785 percentile of density for their SVI bins, etc.).



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