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

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

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

Plain Language Summary

Recent years have seen a wave of oil and gas development in the United States (US) and elsewhere. Research on human health and other societal impacts of oil and gas focuses mainly on upstream activities, including hydraulic fracturing, and on downstream activities, including refining and electricity production. Gathering and transmission pipelines, which connect upstream and downstream parts of the supply chain, also have negative impacts but receive less attention than other areas. No prior research has determined whether negative impacts of gathering and transmission pipelines fall equitably across society. We analyzed 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 low. These results have implications for environmental justice, which is concerned, in part, with how environmental burdens are distributed throughout society. We highlight some of the burdens faced by Indigenous peoples and others who are impacted by ongoing pipeline development. Our work reiterates a need for researchers and decision-makers to look closely at these impacts, especially in light of environmental justice policy, to understand the broader societal costs of oil and gas infrastructure.

Introduction

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

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

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

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

We processed social vulnerability and pipeline datasets using ArcGIS (Redlands, CA). First, we overlaid the pipeline shapefile on an equal-area projected map of US counties. We then used the "Intersect" function to divide the pipeline shapefile into segments within individual counties. Next, we computed pipeline segment lengths (km) by applying the "Calculate Geometry" function to the resulting attribute table. After computing segment lengths, we used the "Spatial Join" function to combine the pipeline and county layers into a data table, modifying the function's merge rules to compute the sum of pipeline segment lengths for each county.

Counties that contained no pipeline segments (881 of 3,142, or 28% of US counties) are visible on the map in Figure 1 but excluded from further analysis. Similarly, pipeline segments located in open water (e.g., the Gulf of Mexico) are visible in Figure 1 but excluded from further analysis. We computed the density of natural gas gathering and transmission pipelines, ρ_{NG}, as pipeline km per 100 km^2 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^2), SVI, ρ_{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 ρ_{NG} within their respective bins. For exceedance thresholds, we used the 75^{th}, 90^{th}, 95^{th}, and 97.5^{th} 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, ρ_{NG}, is 6.1 km of pipeline / 100 km^2 of land area for the 2,261 counties. Half of the counties have ρ_{NG} of at least 3.7 km / 100 km^2. The distribution of ρ_{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, ρ_{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 ρ_{NG} value of 7.5 km / 100 km^2, which is significantly greater than the mean ρ_{NG} value of 4.5 km / 100 km^2 for counties in the lowest quartile of social vulnerability ($p<0.001$). The median ρ_{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 ρ_{NG} , median ρ_{NG} , or the shape of the SVI cumulative distribution.

For pipeline-containing counties in the top quartile of social vulnerability, the distribution of ρ_{NG} is shifted to the right of the ρ_{NG} distribution for counties in the bottom quartile of social vulnerability (Figure 2). Because of the positive skew in ρ_{NG}, the difference in ρ_{NG} between the two groups grows larger at higher quantiles of ρ_{NG}. For example, the difference in ρ_{NG} is less than 1 km / 100 km^2 for counties that have relatively low densities of pipelines within their vulnerability quartiles, but the difference grows to more than 20 km / 100 km^2 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^2 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^2 to 40 km / 100 km^2 (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 ρ_{NG} experienced by counties at the high-density end of each group's distribution.

For all pipeline-containing counties in the US, ρ_{NG} and SVI are correlated (Pearson's $r = 0.14$, $p< 0.001$). The relationship between ρ_{NG} and SVI is driven mainly by counties that have relatively high ρ_{NG} for their SVI (Figure 3). For example, counties in the top 25% envelope of ρ_{NG} (defined as counties in the top 25th percentile of density for a given range of SVI) have a correlation between ρ_{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 25th percentile of pipeline density to the top 97.5th 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 ρ_{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, and identities are inextricably tied to certain landscapes, waterways, and other spaces that are predominantly rural in nature (e.g., Emanuel, 2019; Whyte, 2017). The Dakota Access, Keystone XL, Trans Mountain Expansion, Enbridge Line 3 pipelines, and the now-cancelled Atlantic Coast and Northern Gateway Pipelines all traverse or proposed to traverse territories of Indigenous peoples in the US and Canada (Emanuel, 2017; Estes, 2019; Hunsberger & Awâsis, 2019; Jonasson et al., 2019; McCreary & Milligan, 2014; Whyte, 2017). Some Tribes and First Nations oppose these projects not only because of concerns over pollution or risks to human health, but also because of the pipelines' potential to cause irreparable cultural harm by damaging or destroying present-day or ancestral territories with religious, historical, or cultural significance (e.g., Chen, 2020; Emanuel & Wilkins, 2020; Estes, 2019; Vypovska et al., 2018).

Despite the high stakes for Indigenous peoples, few culturally-oriented pipeline assessments exist. Those that do are commissioned mainly by affected Tribes or First Nations in response to regulatory processes that fail to address concerns they deem important (e.g., Honor the Earth, 2020; Tsleil-Waututh Nation, 2015). These assessments describe how pipeline construction and operation may disrupt, for example, the ability of Indigenous peoples to maintain place-based food traditions or cultural practices. They also highlight ways in which regulatory proceedings renew or exacerbate longstanding ethical and legal issues surrounding the participation of Indigenous peoples in decision-making about their own lands and communities (Emanuel & Wilkins, 2020; Honor the Earth, 2020; Tsleil-Waututh Nation, 2015; Whyte, 2017). Occasionally, these assessments lead to agreements to provide redress for impacts to Indigenous communities, or they serve to outline co-management strategies (e.g., Vypovska et al., 2018). Often, however, they serve to document various ways in which planning and permitting exclude Indigenous perspectives, weaken sovereignty, or otherwise undermine Indigenous self-determination (Emanuel & Wilkins, 2020; Estes, 2019; Whyte, 2017). In the US, issues raised by Indigenous peoples in culturally-oriented pipeline assessments and other venues are often perceived as less important than the priorities of project proponents (e.g., Brown, 2017).

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

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

Figures

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

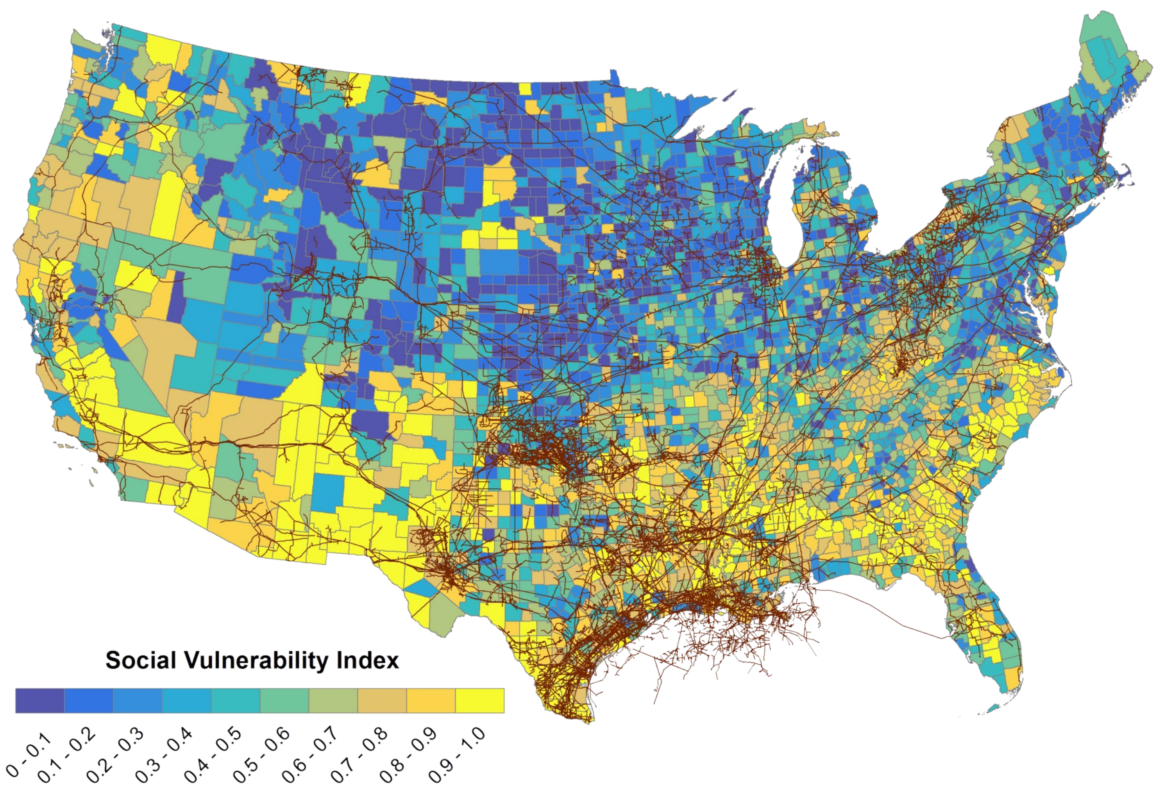

Figure 2: Cumulative frequency distributions of natural gas gathering and transmission pipeline density for counties in the lowest quartile of social vulnerability (blue), counties in the highest quartile of social vulnerability (red), and all counties (dashed). Distributions of densities for the highest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

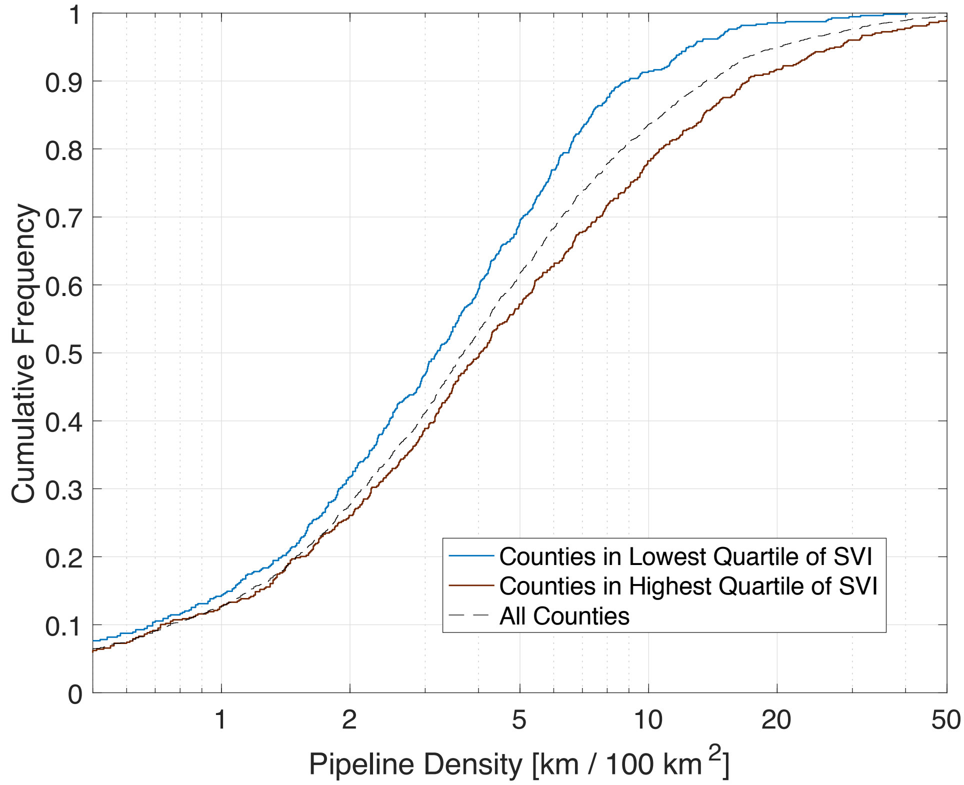

Figure 3: Pipeline density versus social vulnerability for US counties. Colors indicate envelopes for pipeline density percentiles based on bins of SVI (e.g., gray points indicate counties in the lower 75th percentile of density for their SVI bins, blue points indicate counties in the 75th to 90th percentile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