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REVIEW ARTICLE

The demographic characteristics of populations living near oil and gas wells in the USA

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Abstract

This study documents the prevalence of historically marginalized populations (across age, income, education, race-ethnicity, and language) living near active oil and gas wells throughout the USA, at both local and aggregated scales. This is performed by way of areal apportionment using well location data and population characteristics from the American Community Survey. A clustering analysis of marginalized populations living near a high density of wells reveals four distinct regions of high prevalence: southern California, southwest Texas, Appalachia, and northwest New Mexico. At the nationwide scale, we find large absolute numbers of people living near wells, including marginalized groups: nearly 18 million people in total across the USA, many of which are Hispanic (3.3 million), Black (1.8 million), Asian (0.7 million), and Native American (0.5 million), live below the poverty line (3 million), older individuals (3 million), or young children (over 1 million). In certain states, this represents a large share of the total population – over 50% in the case of West Virginia and Oklahoma. Estimates are subsequently compared to county-level control groups to assess patterns of disproportionality. Wide variations are found across regions and metrics, underscoring the locally specific nature of these data. Our research contributes to the field of environmental justice by describing the populations living near oil and gas wells.

Keywords Oil and gas wells · Fossil fuel production · Demographics

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Introduction

New developments in crude oil and natural gas production technology have led to increasingly rapid deployment of wells across the USA. There are currently over one million known active wells (DrillingInfo, 2018). Concurrently, the scientific community is building a more holistic understanding of the environmental impacts resulting from this growth. Besides observed air, surface water and groundwater pollution, and explosion hazards and climate disruption due to methane leakage (Adgate et al., 2014; Osborn et al., 2011), increased attention is being paid to public health effects. McKenzie et al., (2017, 2018) for example documented increased cancer risk (in one case, over 8 times EPA's standard) for populations living in the proximity of oil and gas operations due to inhalation of non-methane hydrocarbons. This is one piece of a growing body of literature illustrating health risks across a range of impacts, including respiratory conditions (notably asthma), birth complications, and observations of increased hospitalization across a variety of medical fields, including cardiology, neurology, and oncology (Currie et al., 2017; Jemielita et al., 2015; Rasmussen et al., 2016; Stacy, 2017; Whitworth et al., 2018). These public health threats are associated with unconventional (i.e., shale/coalbed/tight) gas development in particular. Additional effects on these populations include losses in aesthetic and property values (Evensen & Stedman, 2018; McKenzie et al., 2016; Muehlenbachs et al., 2015) as well as increases in violent crime (Bartik et al., 2019).

Many studies exploring environmental justice issues demonstrate how adverse externalities are most likely to fall upon historically marginalized communities. Researchers have documented ubiquitous evidence of environmental inequities based upon race and other factors (Banzhaf, 2012; Banzhaf et al., 2019; Mohai et al., 2009; Taylor, 2014). These groups have been historically underserved and often at greater risk of exposure to environmental impacts.

To date, several prior analyses have explored community-level characteristics surrounding oil and gas wells. Most have used the same methods as herein and explored population and subgroup counts in specific production basins (Clough & Bell, 2016; Meng, 2015; Ogneva-Himmelberger & Huang, 2015; Pellow, 2016; Slonecker & Milheim, 2015), while few have explored national-level counts (Czolowski et al., 2017; Earthworks, 2018; Long et al., 2016). However, no prior studies have assessed, on a national scale, trends in narrower population groups, looking specifically at marginalized communities. In addition, few other studies disclose census margins of error with population estimates. This article addresses these research gaps.

Kroepsch et al. (2019) identified a range of critical questions for developing a research agenda on environmental justice in this context, and this study informs one of them: who lives near wells? This is a first, but critical step, in better understanding distributional inequity in this context. We hope this study will assist researchers, policymakers, and advocates to uncovering the mechanisms that resulted in systemic inequity and addressing persistent environmental injustice (Ma, 2020).

Methods

Input datasets

Demographic data was obtained using the U.S. Census Bureau's American Community Survey (henceforth, ACS; U.S. Census Bureau, 2021) 5-year estimates for 2012–2016. Census tracts provide the starting point for the analyses herein and represent the best balance between depth of demographic insight, accuracy of estimates, minimizing margin of error, and geographical resolution. While census block or block groups would have been more desirable in reducing the systematic uncertainty inherent to the areal apportionment calculations, margins of error were unfortunately too large for most demographic metrics at these scales.

Locations of over one million identifiable active oil and gas wells in 2015, both conventional and unconventional, were taken from the DrillingInfo database (2018). This database has near comprehensive national coverage and is a compilation of public datasets from state agencies. Exact locations of wells are given by latitude/longitude coordinates in the database. Data from 2015 were used, despite some states possessing more recent production data, because it provided the most comprehensive single-year database nationwide. Indiana and Illinois are not included due to the low quality of source data for these states, where characteristics such as production, specific location, well type, and status are rarely specified. Thus, marginalized groups in these two states are unfortunately not able to be represented in this analysis. It is estimated that the database covers ~ 95% of the nation's wells and ~ 94% of its population (DrillingInfo, 2018).

Demographic estimation

We recombined ACS variables to create a shortlist of 13 demographic metrics to investigate covering race-ethnicity, educational attainment, language, age, unemployment, and income (see Online Resource 1 for additional details). These metrics were selected for this study due to their utility in the literature of environmental justice (Federal Interagency Working Group on Environmental Justice, 2016; Flanagan et al., 2018; U.S. Environmental Protection Agency, 2017). Our focus was on exploring links to race-ethnicity in addition to key socioeconomic metrics, such as poverty, unemployment, age, language, and education.

We extracted population counts of each population group living within four different buffer distances of each well (radii of 1/10, 1/4, 1/2, and 1 mile). The latter two distances are employed in intercomparisons with other studies (see Online Resource 2), and are the most common metric in extant literature (1 mile in particular). The former two are used in recognition of the fact that currently documented health impacts typically occur in very close proximity to wells with 1/10 mile representing an important threshold (McKenzie et al., 2018). Buffer zones were then overlaid on each census tract, and the share of each tract intersecting a buffer is calculated via areal apportionment, the most commonly used approach for this type of demographic analysis (Chakraborty et al., 2011).

Once population estimates are extracted at the census tract level, additional metrics (counts as a percent of total population and margins of error) are calculated. These are then aggregated up to county, state, and national levels.

Population statistics for each group are produced, and the margin of error (MOE; using the Census Bureau standard 90% confidence level) is calculated according to:

$$MOE_{agg} = \pm\sqrt{\sum_{c} MOE_{c}^{2}}$$

where MOE_c is the MOE of the cth component estimate. This step is reproduced for aggregation to the state and national levels. Water bodies were omitted using the 2015 Census Areal Hydrography National Geodatabase (U.S. Census Bureau, 2015).

To explore the prevalence of regions where marginalized groups live near wells, and metrics overlap, we perform a clustering analysis and develop an index. First, statistically high values for a subset of each population were identified by binning distributions into five categories according to the Jenks natural breaks classification method (i.e., minimizing variance within bins while maximizing variance between them). Online Resource 3 depicts the geographic distributions for the highest bin of each population. Then, to create a multivariate index, a score of 1 was assigned to each well-variable pair that fell into the highest bin. These were summed, such that for any given well, a score may range from 0 to 11 depending on the amount of demographic metrics exhibiting high values. The resulting index can be interpreted as a localized, overlapping measure of marginalized communities.

This index is smoothed using a kernel density function according to:

$$f(x) = \frac{1}{n}\sum_{i=1}^{n} K\left(\frac{x - x(i)}{h}\right)$$

where x is a datapoint (well), n is 1,040,537 (wells), K is a quartic kernel estimator, and h is 0.5 decimal degrees. This specific bandwidth parameter (h) was chosen as it represented the best tradeoff between highlighting local clusters and ensuring they were clearly visible in the full extent of the map. This smoothing process is performed only for Fig. 1C to enable an intuitive interpretation of results at a national scale and account for the role of well density in cumulating and exacerbating potential health impacts. Only wells with scores of 1 or above are depicted.

Comparative statistics

Population estimates were also compared with respective control groups. Within counties, this is performed by contrasting our estimate of the share of populations living near wells to that of corresponding county-wide estimates for the same group, as given by:

$$e_{i,b,j} = \left(1 - \left(\frac{p_{i,b}}{t_{i,b}} \div \frac{p_{i,j}}{t_{i,j}}\right)\right) \times 100$$

where p is the population estimate for demographic variable i, in buffer zone b or county j. Denominators t represent total population estimates for respective variable/region pairs. The resulting metric, e, is perhaps best understood as a county/variable pair's percent deviation from the expected value of its control group. To determine whether these deviations are statistically significant, we then follow the Census Bureau guidelines and apply the z-score formula below:

$$z_{i,b,j} = \frac{\left|Est_{i,b} - Est_{i,j}\right|}{\sqrt{MoE_{i,b}{}^2 + MoE_{i,j}{}^2}}$$

Here, *Est* refers to population estimates (as a share of total, or $\frac{p}{t}$ as defined above) and *MoE* denotes associated census margins of error. This yields a z-score for each county/variable pair that describes the extent to which estimates are statistically different from their control group counterparts at a 90% confidence level. Limitations of our methodology are discussed in the supplementary information.

Results

Population-specific clustering

Oil and gas resources are extracted across a wide swath of the USA – the combined land area within one mile of all wells covers approximately 270,000 mi^2, or ~ 7.6% of the country. Figure 1A and B illustrate the degree to which this infrastructure is not only widespread but also concentrated in the same large production basins.

We begin with a local, census tract level analysis of each population group in isolation. This allows us to explore the prevalence of clusters or regions across the country where certain marginalized groups may be living near wells in relatively high numbers, as a share of total population. An array of maps highlighting the predominant clusters by group are provided in Online Resource 3. For Blacks, these stretch across several southern states (LA, MS, AL, AR) and several urban settings (Los Angeles, Cleveland, Akron, Youngstown). Alaskan Native and Native American clusters can be observed in Alaska (Prudhoe Bay, Utqiagvik, Anchorage) and pueblos in northwestern New Mexico. For Asian communities, these are largely concentrated in California, in urban settings of the San Joaquin Delta and greater Los Angeles area, as are Hawaiians and Pacific Islanders. Clusters of Hispanic populations stretch across large expanses of California and Texas.

In terms of socioeconomic metrics, clusters of populations with lower levels of educational attainment are predominantly located in California (Central Valley, Los Angeles), Texas (mainly near the U.S.-Mexico border), Louisiana (Lafayette, New Orleans), southwest West Virginia, and eastern Kentucky. These regions are

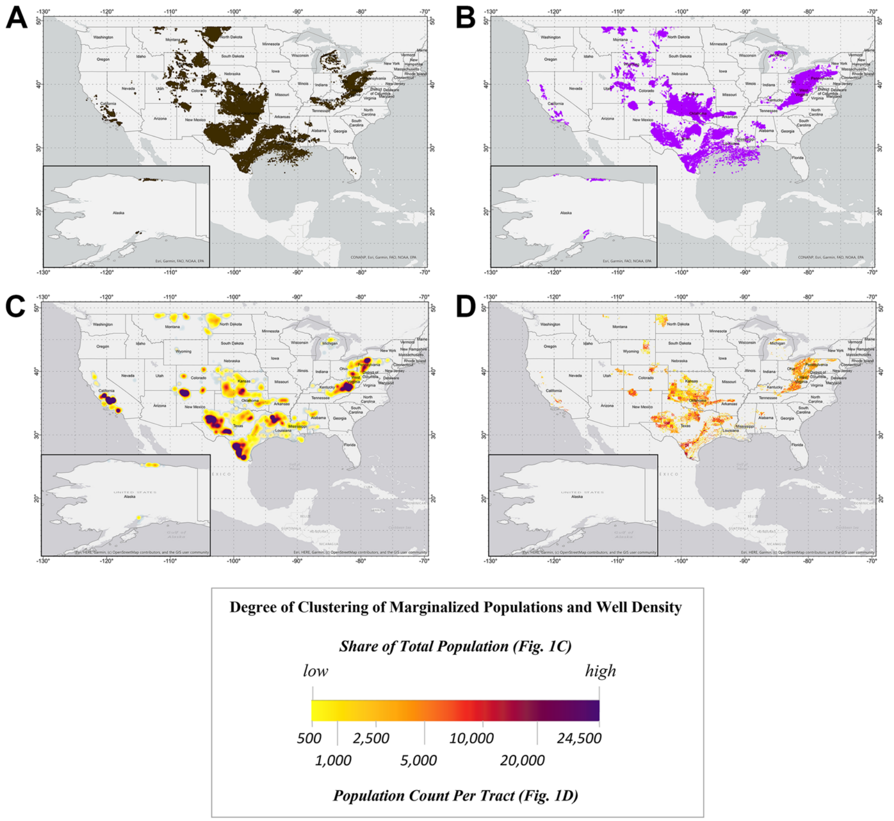

Fig. 1 Disposition of oil and gas wells and marginalized population clusters across the USA. **A** depicts active oil wells in black ($n = 473{,}469$), and **B** active gas wells in purple ($n = 377{,}738$) for the year 2015. **C** and **D** illustrate clustering of multiple marginalized population groups overlapping with areas of high well density. **C** denotes an index score calculated using an equally weighted aggregate statistic, representing how many marginalized populations overlap as a share of total population living near wells. **D** depicts these data terms of absolute population count per census tract, rather than relative shares as in **C**. All well types are factored into this analysis ($n = 1{,}040{,}537$); Hawaii is omitted in this figure given its lack of wells

mirrored in the findings both for communities with high unemployment and those under the poverty line, with the addition of several regions (San Joaquin Delta, CA; Farmington, NM; north-central MT, areas across LA/MS/Appalachia). Limited English-speaking communities are concentrated in northern Alaska, California (Central Valley, Los Angeles), Texas (South Texas and the Rio Grande Valley, Houston and Dallas metro areas), and Garden City (KS).

Regarding age groups, communities with relatively higher numbers of children under 5 years old are found in California's Central Valley, throughout Texas (particularly across the Eagle Ford, Permian, and Anadarko Basins), and in the North (north-central MT, western ND in the Bakken Formation). These regions are comprised of children composing up to 13% of the total population living near wells – over double the national average. Communities with high levels of older individuals (over 64 years old) are observed across the nation, yet are concentrated in the following states: MT, ND, TX, KS, OK, NE, CO, MI, WV, TN, OH, and PA. A subset of these (CO, NE, MI) intersect very little with other demographic metrics.

Additional income metrics (in particular the GINI coefficient) reveal many communities facing relatively high income inequality in southern states (TX, LA, MS, OK), in Appalachian states (WV, OH, PA), and in Montana. Median Family Income metrics further highlight clustering in both poor and affluent neighborhoods, with the latter typically surrounding major cities where fossil fuel extraction is prevalent.

Marginalized population overlap index

We then created a national index to highlight regions where clusters across multiple marginalized population groups and areas of high well density coincide. Figure 1C illustrates areas with a high degree of intersectionality for all wells across the country. Approximately 41 distinct (non-contiguous) clusters can be observed. The highest ones are found in CA's Central Valley, notably near Bakersfield and Coalinga (in the San Joaquin Basin). Moving east, a large cluster can be observed in the area surrounding Farmington, NM – a region containing several Native American tribes, with the Navajo Nation, Southern Ute, and Jicarilla Apache Nation having the greatest overlap. In the Permian Basin, two clusters emerge (one northwest of Odessa, TX, and the other west of Sonora, TX). Nearby, we observe three distinct clusters on the TX-Mexico border, near the environs of Laredo, TX (Eagle Ford Shale). Three significant clusters remain: one located northwest of Shreveport, LA (Haynesville-Bossier Shale), and two in Appalachia: south of Charleston, WV, and near Allegheny National Forest, PA. Figure 1D adapts the approach used in panel 1C to use absolute population counts, rather than relative shares. Clusters remain largely the same with the exception of some regions diminishing (e.g., California and Wyoming). This underlines the fact that these clusters represent areas where marginalized groups are found both in disproportion and in high numbers.

Summary statistics by distance from well

A local lens is most useful to identify larger disparities and truly explore questions of environmental justice. The analyses presented above were completed to provide a deeper and more focused assessment of such trends. Though it conveys a limited perspective, aggregation at the national and state levels is helpful for obtaining a broad snapshot of trends.

Table 1 summarizes national statistics for each population within one mile of a well. For each group, two comparative statistics are provided: national totals and control counties. The latter represents a control group reflecting demographic trends specific to oil and gas producing regions: population estimates for counties within which wells are located. There is a varying degree to which the county-level population estimates are significantly statistically different from controls (5–57%; 90% CI),

Table 1 National summary statistics of population counts within one mile of a well. Percentage rows denote population counts as a share of the total population within the same one-mile buffer. The control counties column denotes population counts for population groups within the counties where wells are located. Column 3 shows differences between estimates of population shares within a one-mile buffer, and their respective county controls. Column 4 provides summaries of the overall share of counties that exhibited significantly different estimates from their control groups, while column 5 provides p-values from this analysis (see Online Resource 5 for county/variable level detail)

Population group	Population living within one mile of a well	Difference in share of population in one mile proximity, versus county controls (%)	Aggregate share of counties with estimates significantly different from control groups (%)	Mean p-value (normal dist., 90% CI)	Control counties	National total
Black	1,836,200	−1.9	41	0.069	12,773,100	44,654,400
[%]	10.00%				11.90%	13.90%
Asian	697,500	−3.3	24	0.244	7,668,400	16,614,600
[%]	3.80%				7.10%	5.20%
Hawaiian/Pacific Islander	34,600	−0.1	5	0.377	361,700	560,000
[%]	0.20%				0.30%	0.20%
Hispanic	3,318,000	−6	34	0.17	25,776,600	58,691,300
[%]	18.00%				24.00%	18.20%
Native American	457,000	0.5	16	0.298	2,172,600	5,430,300
[%]	2.50%				2.00%	1.70%
White	15,129,100	7.1	41	0.054	80,570,800	244,659,400
[%]	82.20%				75.10%	76.00%
Below poverty line	2,872,400	−0.4	23	0.297	17,230,500	48,509,300
[%]	15.60%				16.00%	15.10%
Under 5 years old	1,184,400	−0.1	17	0.346	6,981,800	20,050,500
[%]	6.40%				6.50%	6.20%
Over 64 years old	2,692,000	0.9	26	0.296	14,682,500	46,794,900
[%]	14.60%				13.70%	14.50%
Less than HS degree	1,814,600	4.7	19	0.315	10,870,100	28,445,400
[%]	14.80%				10.10%	13.30%

Table 1 (continued)

Population group	**Population living within one mile of a well**	**Difference in share of population in one mile proximity, versus county controls (%)**	**Aggregate share of counties with estimates significantly different from control groups (%)**	**Mean *p*-value (normal dist., 90% CI)**	**Control counties**	**National total**
Limited English spoken	143,300	−0.2	7	0.378	1,119,400	6,136,700
[%]	0.80%				1.00%	1.90%
Unemployed	604,700	−0.4	10	0.368	3,979,800	12,032,700
[%]	3.30%				3.70%	3.70%
Total population	18,405,100				107,301,000	322,087,500
[%]	5.70%				100.00%	100.00%

depending on the metric (see Table 1). For many counties, population numbers were simply too low and/or metrics had margins of error too large to yield strong statistical power in the relationships explored. Significance measures for each county/variable pair are provided in Online Resource 4, and summary statistics for the half, quarter, and tenth mile buffer distances are found in Online Resource 5.

These results underscore the degree to which the US population and oil and gas production are intertwined. Over 18 million people live within one mile of wells. Many of these consist of marginalized groups (Hispanic: 3.3 m; Black: 1.8 m; Asian: 0.7 m; Native American: 0.5 m; below the poverty line: 2.9 m; over 64 years old: 2.7 m; under 5 years old: 1.2 m). From a relative standpoint, at a national aggregated scale, most population groups are found to be less prevalent near wells than their county-level controls. The exceptions to this are Native Americans, Whites, people over 64 years old, and people with less than a high school degree. For these populations, we find a respective 25.0%, 9.5%, 6.6%, and 46.6% higher prevalence living within one mile of wells than controls.

State-level tables were also derived to depict population counts by demographic group within one mile of wells. Online Resource 6 provides data for the 29 states where oil and gas production is prevalent. The five states with the greatest number of people living near wells are Texas (5.0 m), Ohio (3.0 m), California (2.2 m), Oklahoma (1.9 m), and Pennsylvania (1.9 m). On a percentage of total state population basis, these are: West Virginia (50.9%), Oklahoma (50.1%), Ohio (25.9%), Texas (18.7%), and Pennsylvania (15.0%). These measures highlight the fact that many people across the country are bearing the externalities of oil and gas development – particularly in West Virginia and Oklahoma where a majority of people live near active wells.

With respect to summary results, a subset for one mile and ½ mile (state and national levels) can be compared to other estimates in the literature; see Online Resource 2 for a comprehensive assessment. In cases where metrics and methodological approaches overlap, our findings are extremely similar.

The comparative analyses outlined in this section were performed as an additional means of investigating disproportionality through county, state, and national scales. Percentage differences from respective control groups for each county/variable pair can be found in Online Resource 4. These data illustrate the wide distribution that can be seen across counties, in terms of disproportionality for any given population, and emphasize the locally specific nature of these findings.

Discussion

In this study, we shine a light on the colocation of historically marginalized groups and wells. While the negative impacts of production are real and widespread, a nuanced approach is needed in moving beyond this framework and exposing cases of environmental injustice. A key factor to acknowledge is that oil and gas development may be desired and spurred on by local communities, in seeking royalties and potential employment. This stands to reason as Bartik et al. (2019) have noted large positive welfare implications on frontline communities. This economic benefit is likely to be more tangibly perceived than the indirect negative externalities, particularly with respect to health impacts that are still being uncovered. It should be noted that, more generally, the permitting process for oil and gas development differs on Native American lands, where most of these populations live.

Production also relies on labor inputs, meaning that fossil fuel extraction industries and inhabited areas frequently overlap. The analysis presented herein is not causal, but correlative; we provide a characterization of the extent to which the colocation phenomenon is prevalent. Developing this knowledge is particularly important in light of the fact that there is evidence of health impacts for populations living in close proximity to wells (Gold & McGinty, 2013; Macey et al., 2014; Rabinowitz et al., 2015; Steinzor et al., 2013). Additionally, there have been numerous examples of recent incidents involving gas leaks from wellheads, such as in Belmont County, Ohio, in February 2018. Vulnerable communities are often at a disadvantage when it comes to mitigating environmental exposures and overcoming impacts, so it is critical to understand where they might be most readily exposed to the negative externalities of production. In turn, understanding where and how oil and gas development intersect with diverse communities should aid in formulating the appropriate industry practices and public policies to reduce impacts to proximate populations.

There are four notable regions in the country where intersectionality across marginalized groups points to a need for deeper region-specific research, particularly surrounding health impacts. The first such region is southern California, particularly in greater Los Angeles and the Central Valley. The former reveals a prevalence of Hispanic, Asian, Black, and Hawaiian/Pacific Islander populations living in proximity to oil and gas wells, while the latter registers more along metrics such as language, poverty, and unemployment, among Hispanic communities. This is in large part explained by the fact that wells in the Los Angeles urban setting tend to be located within ethnically diverse central neighborhoods, while the Central Valley is home to a large agricultural workforce facing its own set of socioeconomic challenges.

The second notable region, concentrated in southwest Texas, includes the Permian Basin and the Eagle Ford Shale. These regions mirror similar characteristics as California's Central Valley. A third major region of note, Appalachia, differs somewhat from the others in terms of demographics. Here, these are predominantly elderly White populations and groups with low income and high unemployment. Finally, a fourth region to highlight appears in northwest New Mexico, largely composed of Native American populations and communities with high unemployment, poverty, and children under the age of five. These areas should form a primary focus for science and policy given the degree to which this colocation and cumulation can dramatically worsen inequities and health disparities (Morello-Frosch et al., 2011).

Another important policy aspect for exploration in subsequent research is the relationship between employment and populations living near wells. Our results highlight widespread clusters of high unemployment near wells 4–12 times the national average (Online Resource 3). While this question has been explored nationally in the context of shale wells (Maniloff & Mastromonaco, 2017), the approach presented in this study, supplemented by time-series analysis and causal inference methods (e.g., using difference-in-differences or instrumental variables), is well suited to exploring this question for a broader range of well types using the frequent (i.e., annual) time step proffered by the ACS.

Our study differs in several key ways to the most similar prior analyses (Czolowski et al., 2017; Earthworks, 2018; Gold & McGinty, 2013). One chief aspect is that our study uncovers national statistics for 12 new population groups, and the intersectionality of these. It is the first national study to include census margins of error alongside estimates, and uses more recent data for both wells and populations: all prior national studies rely on the 2010 Census and demographic trends have likely changed significantly since then, particularly in fossil fuel extraction zones. Finally, Alaska is also included in our scope of analysis, exposing areas of potential interest (particularly near Prudhoe Bay).

We envision multiple ways in which these findings can be useful to a variety of audiences. First, for policymakers having a responsibility to ensure the safety and welfare of people living near oil and gas operations, these data can aid in crafting policy tailored to protecting vulnerable populations on the front lines. Second, these communities themselves and representative organizations will have the means to contextualize and quantify affected groups, in advocacy efforts aimed at addressing environmental injustice. Third, researchers can more accurately scope areas of interest for studies aimed at furthering our understanding of impacts from wells on proximate populations. Fourth, industry can use these data to customize and enhance their stakeholder outreach efforts and operational considerations by better understanding the makeup of the populations with which operators interact.

Our findings illustrate the sheer extent to which aggregate numbers of people live in close proximity to wells, both in terms of marginalized populations and specific geographies where fossil fuel production is prevalent. The data highlights key areas of layered social vulnerability, and by way of these quantification efforts, reinforces the need to further understand how frontline communities are impacted by oil and gas development.

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Declarations

Conflict of interest The authors declare no competing interests.

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