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Discriminatory outcomes of industrial air permitting in Louisiana, United States

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ABSTRACT

Overwhelming evidence indicates that communities of Color in the United States are disproportionately harmed by pollution. Yet, state environmental regulators, who permit industrial polluters under the U.S. Clean Air Act, do not universally recognize these disparities. In Louisiana, regulators have denied the existence of pollution disparities and have suggested that infrastructure explains why heavy industry is concentrated in certain neighborhoods. We used a multi-part approach to determine if there is a racial disparity in Louisiana's industrial emissions and, if so, whether infrastructure or state permitting drives this disparity. First, we evaluated race (% people of Color) among census tracts with industrial facilities relative to reported emissions of criteria pollutants from 2019-2021 using a quartile analysis and a linear model that accounted for spatial clustering of facilities. Second, we tested whether census tracts with infrastructure variables have higher-than-average populations of Color using one sample T-tests. Infrastructure variables included petrochemical pipelines, railways, ports, lower Mississippi River access, and a high proportion of the workforce in manufacturing. We found that over half (378 of 671) of Louisiana's industrial facilities were spatially clustered along a 184-mile, winding stretch of the lower Mississippi River known as "Cancer Alley." Overall, communities of Color had 7-fold to 21-fold higher emissions, depending on the pollutant, than predominantly White communities. Among industry subsectors, Chemical Manufacturing was the largest single contributor to emissions in communities of Color. Census tracts with industrial infrastructure were, on average, racially similar to Louisiana overall (absolute difference, <7% people of Color). Collectively, our findings reveal a stark racial disparity in industrial emissions that is driven by state permitting, particularly of chemical manufacturers, rather than by infrastructure or labor supply. Immediate action is needed to address the discriminatory outcomes of industrial permitting in Louisiana, and future research should focus on the role of state permitting in environmental injustice more broadly.

1. Introduction

Decades of research have firmly established that racial minorities and low-income populations in the United States are disproportionately harmed by pollution (Evans and Kantrowitz, 2002; Liu et al., 2021; e.g., United Church of Christ Commission for Racial Justice, 1987). This nationwide disparity has persisted over time (Kravitz-Wirtz et al., 2016; Colmer et al., 2020), and is part of a larger global pattern of environmental inequalities (reviewed in Hajat et al., 2015; Hamann et al., 2018; Rigolon et al., 2018). Yet, relatively few studies examine the underlying drivers of pollution disparities, particularly from a regulatory perspective. In the United States, the primary authority for environmental regulation is the U.S. Environmental Protection Agency (EPA). Like all U.S. federal agencies, EPA is mandated to "make achieving environmental justice part of its mission" (*Executive Order 12898*, 1994). Under EPA's definition, environmental justice requires that "no group of people, including a racial, ethnic or a socioeconomic group, should bear a disproportionate share of the negative environmental consequences from industrial, municipal and commercial operations or the execution of federal, state, local and tribal programs and policies" (U.S. EPA, 2022a). This definition relies on disproportionate outcomes, rather than discriminatory intent. Accordingly, EPA regulations prohibit practices that "have a discriminatory effect," even if those practices are "neutral on their face" (U.S. EPA, 2017).

The EPA delegates many of its authorities to state environmental agencies, including the permitting and compliance of industrial operations under the U.S. Clean Air Act (42 U.S. Code § 7411). This delegation means that some U.S. residents are afforded more stringent protections

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than other residents, as a result of different practices and regulations among states. For example, Massachusetts (310 CMR 7 app C) and New Hampshire (N.H. Code Admin. R. Env-A 101.115) have a more protective, 50 ton-per-year threshold for classification as a "major source" of volatile organic compounds (VOCs) under the Clean Air Act, while Louisiana (La. Admin. Code, tit. 33, § III-509) and Mississippi (11 Miss. Code. R. § 2-6.1) use the default, federally-mandated 100 ton-per-year threshold (40 C.F.R. § 52.21). A less protective threshold translates to higher emissions, because the Clean Air Act requires major sources to employ pollution control technologies (40 C.F.R. § 52.21). Notably, the more protective states in this example are overwhelmingly White (80 – 93%), while the less protective states have large proportions (38 – 41%) of Black, Hispanic, and other historically-marginalized groups (U.S. Census Bureau, 2022a). Clearly, U.S. state regulatory agencies play a central role in environmental justice, with the potential to create, perpetuate, exacerbate, reduce, or eliminate disparities in pollution exposure.

The relevance of pollution research to state environmental regulation is determined, in part, by the geographic scale and type of pollution sources evaluated. Most studies of pollution disparities in the U.S. are either nationwide (e.g., Tessum et al., 2021; Liu et al., 2021; Ash and Boyce, 2018) or highly localized (e.g., Nagra et al., 2021), with less research focused on individual states (but see, e.g., Lee and Park, 2020). This research gap means that state regulators can acknowledge the existence of nationwide pollution disparities while also claiming that systemic disparities do not occur in their state, akin to the principle of ecological fallacy in epidemiology (Selvin, 1958). Additionally, many pollution studies in the U.S. focus on ambient concentrations of pollutants from all sources (e.g., Liu et al., 2021; Colmer et al., 2020), as opposed to regulated sources (but see, e.g., Tessum et al., 2021; Ash and Boyce, 2018). This broader focus leaves open the possibility that non-regulated sources (e.g. agricultural burning or urbanization) are driving pollution disparities. Such opportunities for disconnect between research and regulation may partially explain why racial disparities in pollution exposure have persisted for decades in the U.S., despite overall improvements in air quality (Colmer et al., 2020; Liu et al., 2021). In the absence of state-specific evidence of pollution disparities from regulated sources, federal protections aimed at promoting environmental justice may have diminished impact, particularly in states with less protective environmental regulations.

Louisiana is a heavily industrialized state that is internationally recognized for longstanding allegations of environmental racism and regulatory capture (Achiume et al., 2021; Berry, 2003; Davies, 2018; Keehan, 2018; Maraniss and Weisskopf, 1988). There is ample evidence that Louisiana is overburdened with pollution: more tons of toxic air pollution are released annually from its industrial facilities compared to any other U.S. state (U.S. EPA, 2022b); the estimated risks of cancer and respiratory disease from point sources of toxic air pollution are more than triple the U.S. average (U.S. EPA, 2022c); and toxc air pollution contributes to the state's exceptionally high overall cancer rate (Terrell and Julien, 2022). There do not appear to be any peer-reviewed studies of racial disparities in Louisiana's industrial emissions, though there are a few related studies. Perera and Lam found that industrial facilities in a few southeast Louisiana parishes are clustered in low-income/minority communities (Perera and Lam, 2013), but the authors did not quantify emissions or include other heavily industrialized parts of the state (e.g. Lake Charles). James et al. found that low-income/Black communities in southeast Louisiana were overburdened with toxic air pollution from all sources combined using 2005 data (James et al., 2012), which leaves open the possibility that the disparity was driven by non-regulated sources (e.g. urbanization) and/or was eliminated by subsequent air quality improvements (U.S. EPA, 2022d). Finally, Terrell and James reported that Black communities across Louisiana are disproportionately impacted by fine particulate matter (PM2.5) from all sources combined (Terrell and James, 2020), which could be driven by urbanization. The authors also reported a correlation between race and estimated health hazards from point sources of toxic air pollution (Terrell and James, 2020); however, this analysis did not include criteria pollutants, which are abundant and subject to a unique set of Clean Air Act regulations. Criteria pollutants include coarse particulate matter (PM10), fine particulate matter (PM2.5), nitrogen oxides (NO2), sulfur dioxide (SO2), and volatile organic compounds (VOCs). Determining whether a racial disparity exists for industrial emissions of criteria pollutants in Louisiana has immediate relevance to an ongoing civil rights investigation by the EPA (U.S. EPA, 2022e) and to regulatory decision-making by the Louisiana Department of Environmental Quality (LDEQ), which issues hundreds of permits each year for new or expanding industry (Louisiana Legislative Auditor, 2021). The LDEQ has suggested, without evidence, that spatial patterns of industrial emissions in Louisiana are driven by access to supporting infrastructure (e.g. pipelines), rather than racial bias (LDEQ, 2022a).

The goal of our study was to determine whether communities of Color in Louisiana bear a disproportionate share of industrial emissions of criteria pollutants, and whether this potential disparity can be attributed to LDEQ permitting or to racial demographics among areas with industrial infrastructure. We addressed these questions through a three-part analysis of publicly-available state and federal data (Table 1). Additionally, we examined the relative contributions of different industry subsectors to emissions for top and bottom race quartiles and for Louisiana overall. Our study has direct relevance to industrialized communities in Louisiana and provides a framework for future research to elucidate the role of state regulation in perpetuating environmental injustice more broadly.

2. Materials and Methods

2.1. Data Sources

We obtained a list of LDEQ-regulated facilities with corresponding 2019-2021 emissions data from the LDEQ Annual Certified Emissions Dataset (accessed Jul 10, 2022) (LDEQ, 2022b). This inventory includes all pollution sources in Louisiana that are required to report annual emissions to LDEQ, such as power generating plants, landfills, petrochemical plants, and other types of industrial manufacturing facilities (e.g., lumber mills and steel plants). It does not include pollution sources that are exempt from LDEQ permitting (e.g., vehicles or agricultural burning) or emissions reporting (e.g. dry cleaners or other small sources). A small number of facilities contained multiple entries for a given year; in those cases, we obtained the correct values from Emissions Certification Statements via the LDEQ Electronic Database Management System (EDMS). We obtained the most recently-reported (2021) North American Industry Classification System (NAICS) code for each facility from LDEQ's emissions inventory (accessed Dec 1, 2022) (LDEQ, 2022b).

We accessed demographic data from the U.S. Census Bureau's 2015-2019 American Community Survey via Social Explorer, a tool that calculates percentage data where applicable (Social Explorer, 2022). Specifically, we obtained census tract-level data for race (Population of Color, which we calculated as 100% minus the percentage of residents identifying as White), occupation (percentage of workforce currently employed in manufacturing), and land area. We obtained the 2019 U.S. Rails National Shapefile and the 2010 Census Tract Boundaries Shapefile from the U.S. Census Bureau (U.S. Census Bureau, 2022b, 2022c). We identified ports in Louisiana with access to the Gulf of Mexico (i.e. excluding the inland ports of Natchez, Vicksburg, and Monroe) from the Ports of the United States dataset from the U.S. Geological Survey (U.S. Geological Survey, 2022). We accessed the most recent (2020) shapefiles for pipelines carrying crude oil, natural gas, or petroleum products from the U.S. Energy Information Administration (U.S. Energy Information Administration, 2022).

Table 1
Study Design to Evaluate Potential Racial Disparity in Air Pollution Burden.

Analysis[1]	Expected Associations by Scenario		
	No Disparity	Disparity Due to Infrastructure	Disparity Due to LDEQ Permitting
Linear model of emissions versus race	None	Emissions associated with race	Emissions associated with race
Emissions by race quartile (% people of Color)	None	Emissions highest in Q4	Emissions highest in Q4
T-tests of race in tracts with infrastructure	None	% people of Color above state mean	None

[1] Emissions analyses included only tracts with LDEQ-reporting facilities (i.e. excluding zero values).

2.2. Geocoding Industrial Facilities

Because the LDEQ emissions inventory does not include spatial data (i.e. GPS coordinates or addresses), we used a multi-step approach for geocoding facilities based on their Agency Interest (AI) number, a unique identifier assigned by LDEQ. First, we identified all facilities that were operational in 2020 from the emissions dataset (accessed July 11, 2022). We then used the radius search tool in LDEQ's Emissions Reporting and Inventory Center (ERIC) to obtain GPS coordinates for facilities within 25 miles of each major city in Louisiana (LDEQ, 2022c). This piecemealed approach was necessary because the ERIC tool does not return results for large geographic areas. Because the tool returns multiple coordinates per facility (one set for each emissions source), we used the GPS coordinates for the source with the highest VOC emissions at each facility. After combining the information from each city search, we had geocoded 423 of the 739 facilities represented in the 2020 emissions inventory (accessed July 11, 2022). We geocoded another 248 facilities manually in Google Earth Pro, after obtaining the physical address of the facility from LDEQ's EDMS using the AI lookup feature and confirming the presence of the facility based on satellite imagery (LDEQ, 2022d).

2.3. Mapping and Spatial Grouping Industrial Facilities and Infrastructure

We used QGIS (Version 3.6.3) for all mapping and spatial analysis, unless otherwise noted. We assigned census tracts to all geocoded facilities using a spatial join. We classified census tracts as containing railways or pipelines if they intersected with those respective map layers. We classified census tracts as being near a port if their centroid was located within 100 km of a coastal port (i.e. excluding the inland ports of Monroe, Natchez, and Vicksburg). We manually selected census tracts that bordered the Mississippi River below the Highway 90 Bridge in Baton Rouge (river mile 233.9) and classified these tracts as having Mississippi River access. We selected this cut off point because the bridge has relatively low clearance that restricts transportation via large marine vessels (U.S. Coast Guard, 2013), and satellite imagery reveals an obvious lack of industrial development upriver of the Hwy 190 Bridge.

We identified clusters of industrial facilities using density-based cluster analysis (DBSCAN) in QGIS (Version 3.6.3), with a minimum cluster size of 10 facilities and a maximum distance of 0.1 degree between facilities using the NAD83 projection. Given the highly irregular shape of many census tracts, we manually identified the tracts corresponding to each cluster of facilities. In doing so, we aimed to identify the minimum number of tracts needed to encompass all corresponding facilities without creating any "holes" (i.e. non-cluster tracts surrounded by cluster tracts).

2.4. Analyses of Race versus Industrial Emissions

We conducted all statistical analysis in R Statistical Software (R Core Team, 2020), unless otherwise noted.

For each pollutant (PM10, PM2.5, NOx, SO2, CO, and VOCs), we calculated normalized emissions per census tract as the sum of all emissions reported for 2019-2021 (tons), divided by three years, and divided by the land area (mi^2) of the census tract ($tons/yr/mi^2$). We used Imperial units (i.e. tons and miles) for consistency with LDEQ permitting and emissions inventory systems.

We used a separate linear regression model for each pollutant to determine whether normalized emissions ($tons/yr/mi^2$) were associated with population of Color (%) among industrialized census tracts (i.e. excluding tracts with zero emissions). Prior to this analysis, we transformed percentage data (arcsine transformation) and emissions data (natural log transformation) to improve normality, then scaled and centered these data. Exploratory analysis revealed significant spatial autocorrelation ($P < 0.0001$) in a linear regression of normalized VOC emissions with percent population of Color, as tested by a simulation with 10,000 replicates and measured by Moran's I (Hartig, 2021). To reduce spatial autocorrelation, we added facility cluster as a fixed effect to each pollutant model, as well as an interaction term between facility cluster and percent population of Color. This results in linear regressions with no statistically significant spatial autocorrelation ($P = 0.18$ for PM10, $P \geq 0.46$ for all other pollutants), which therefore may have appropriate standard errors for coefficient estimates.

To better understand the associations detected in the linear models, we analyzed emissions by race quartile using raw (i.e. untransformed) data. Specifically, we calculated median (non-zero) emissions ($tons/yr/mi^2$) for industrialized census tracts ($N = 276$) grouped by % people of Color.

Group thresholds corresponded to quartile breaks for % people of Color among all Louisiana census tracts ($N = 1{,}126$). To quantify emissions disparities, we calculated the ratio of emissions between census tract groups with the highest versus lowest percent people of Color (i.e., Q4/Q1).

To explore the geographic nature of emissions disparities, we mapped the locations of census tracts with industrial facilities ($n = 248$) in the highest and lowest emissions quartiles ($N = 62$ tracts per quartile), relative to the racial composition (% Color) of those census tracts, We excluded tracts that were unpopulated or had zero emissions reported for all pollutants.

2.5. Analyses of Emissions by Industrial Subsector

We evaluated the contribution of different industry subsectors to overall emissions, based on NAICS codes. We also examined subsector contributions to emissions among census tracts that were predominantly people of Color (>65%) or predominantly White (≤16.9% people of Color). We chose these racial percentages because they correspond to the quartile breaks (Q4 and Q1, respectively) when considering population of Color among all census tracts in Louisiana ($N = 1{,}126$).

2.6. Analyses of Industrial Infrastructure

To inform our study design, we evaluated collinearities among infrastructure variables and other potential predictors of industrialization using Pearson's correlation. These were binary variables coded to 0 or 1 and included access to pipelines, railways, the lower Mississippi River, a coastal port within 100 miles, an abundance of manufacturing labor (i.e. ≥10% of the workforce in manufacturing), and a majority population of Color among census tracts. We also included log-transformed land area of tracts in the correlation matrix, because we expected that binary variables were more likely to occur in larger tracts. This exploratory analysis revealed collinearities among a subset of predictor variables (Table A.1), which resulted in unreliable performance of zero-inflated negative binomial models of these variables versus facility counts. We therefore adopted a more straightforward approach of reporting odds ratios for each predictor variable, without making any causal inference. For each predictor, we calculated the odds (OR) of census tracts having industrial activity (i.e. at least one industrial facility) using Equation 1,

$$OR = (A/B)/(C/D) \tag{1}$$

where A = the number of tracts with the predictor variable and at least one industrial facility, B = the number of tracts with the predictor variable and without industrial facilities, C = the number of tracts without the predictor variable and with at least one industrial facility, and D = the number of tracts without the predictor variable and without industrial facilities. We calculated the corresponding 95% confidence intervals using Equation 2.

$$CI = e^{\left(log(OR) \pm 1.96 * \sqrt{(1/a + 1/b + 1/c + 1/d)}\right)} \tag{2}$$

For each infrastructure variable, we used One-Sample t-Tests to compare proportions of residents of Color among tracts with the variable against the state mean.

3. Results

3.1. Spatial Clustering of Geocoded Industrial Facilities

We successfully geocoded 671 of the 797 industrial facilities that reported emissions to the LDEQ in 2019, 2020, and/or 2021. The remaining 126 facilities could not be geocoded because a specific physical address was not listed in LDEQ's electronic database (EDMS). In most cases, these were relatively small emissions sources associated with oil and gas extraction that had general location information provided in lieu of an address (e.g. "15 miles southwest of Venice, LA"). Collectively, these non-geocoded sources represented < 5% of reported emissions for each criteria pollutant (Table A.2).

We found that 22% of Louisiana census tracts contained at least one geocoded industrial facility ($N = 248$ of 1,148 census tracts; Fig. 1). For simplicity, we subsequently refer to these as "industrialized census tracts." The density-based analysis identified eight distinct clusters of industrial facilities (from east to west): Lower, Middle, and Upper Industrial Corridor, Denham Springs, Lafayette, Vermillion Bay, Sterlington, and Lake Charles (Fig. 2). Collectively, these eight clusters represented nearly two-thirds of all geocoded facilities (422/671) and encompassed 347 census tracts, including some non-industrialized tracts that were surrounded by industrialized tracts (see Materials and Methods). Clusters varied in size, with the smallest (Sterlington) containing 10 facilities and representing three census tracts, and the largest (Upper Industrial Corridor) containing 255 facilities and representing 123 census tracts (Fig. 2). The Industrial Corridor, which is typically considered a continuous area, was broken into three clusters; a 16-km stretch of agricultural and residential land in eastern St. James Parish separated the Upper and Middle Industrial Corridor, while a 9-km stretch of commercial and residential development in Jefferson Parish separated the Middle and Lower Industrial Corridor (Fig. 2). Collectively, the Industrial Corridor clusters represented 378 facilities and 276 census tracts (including some tracts surrounded by, but not containing, industrial facilities – see Materials and Methods). Industrial Corridor facilities spanned 184.1 river miles, from the Louisiana Generating LLC - Big Cajun II Power Plant in Point Coupee Parish to the Chevron Oronite Co LLC - Oak Point Plant in Plaquemines Parish.

3.2. Race versus Industrial Emissions

Among all Louisiana census tracts, proportions of residents of Color averaged 42.4%, with a median of 34.5%. Of the 671 geocoded facilities, 651 reported non-zero emissions for at least one pollutant to LDEQ in 2019-2021, representing 246 census tracts. We excluded one of these tracts from the analysis because it was unpopulated, according to census data. A few facilities reported zero emissions for a subset of pollutants, resulting in slightly different sample sizes among pollutants ($N = 219$ to 244 census tracts; Table 2). Across all pollutants, race was a significant predictor of the magnitude of emissions from industrial facilities that reported non-zero emissions (summarized in Table 2; see Tables A.3-A.8 for results of individual pollutant models). There was no evidence of spatial autocorrelation in any model ($P = 0.18$ for PM10; $P \geq 0.46$ for all other pollutants). Median emissions were 7.4 to 21.0 times higher, depending on the pollutant, among industrialized tracts with high proportions of residents of Color compared to industrialized tracts with high proportions of White residents (Q4 versus Q1 race, respectively; Table 3). For most pollutants ($PM_{2.5}$, SO_2, CO, and VOCs), median emissions of industrialized tracts increased consistently with increasing percentages of residents of Color (Table 3). Similar results were obtained when using mean (versus median) emissions (Table A.9) and when tracts with zero emissions were included (Table A.10). Mapping revealed that industrialized census tracts with very low emissions (Q1) were disproportionately White, while industrialized census tracts with very high emissions (Q4) were disproportionately of Color (Figs. 3-5 and B.1-B.3).

Table 2
Summary of Individual Linear Regression Models of Emissions versus Race*.

Modeled Pollutant	Census Tracts (N)**	Population of Color (%)		
		Estimate	T	P
PM_{10}	241	0.41	4.40	< 0.0001
$PM_{2.5}$	230	0.34	4.20	< 0.0001
NO_x	235	0.30	3.52	0.0005
SO_2	219	0.28	3.37	0.0009
CO	233	0.32	3.76	0.0002
VOC	244	0.40	5.16	< 0.0001

* All models included Facility Cluster and an interaction term with Race to account for spatial correlation (see Methods). Multiple $R^2 = 0.23$-0.35, Adjusted $R^2 = 0.17$-0.30; $F \geq 3.78$, $P < 0.0001$. Full results of each model are presented in Tables A.3-A.8.

** Corresponds to number of census tracts with non-zero reported emissions.

3.3. Emissions among Industry Subsectors

Chemical manufacturing facilities (NAICS Code 325) were responsible for more emissions of every pollutant than any other industry subsector, representing between 26.9% and 38.2% of industry-wide emissions of PM10, PM2.5, NOx, SO2, CO, and VOCs (Table A.11). Other major contributing industries for all (or most) pollutants were Petroleum and Coal Products Manufacturing (Code 324; 16.6% to 32.0%), Utilities (Code 221; 12.7% to 25.7%), and Paper Manufacturing (Code 322; 2.2% to 20.4%). Smaller, but significant, proportions of certain pollutants came from other subsectors, such as PM10 from Mining (Code 212; 12.1%) and VOCs from Pipeline Transportation (Code 486; 10.3%; Table A.11).

Chemical Manufacturing was the most common subsector represented among communities predominantly of Color (Q4, >65.0% people of Color), while Pipeline Transportation was the most common subsector represented among predominantly White communities (Q1, ≤16.9% people of Color; Table 4). In both groups, Chemical Manufacturing, Utilities, and Petroleum/Coal Products Manufacturing represented large proportions of emissions for most pollutants (Fig. 6; Tables A.12 and A.13). A notable difference was that Chemical Manufacturing was responsible for larger percentage of emissions in communities of Color (>65.0% people of Color) compared to mostly White communities (≤16.9% people of Color), while Utilities contributed a larger percentage of emissions in the latter versus former (Fig. 6; Tables A.12 and A.13).

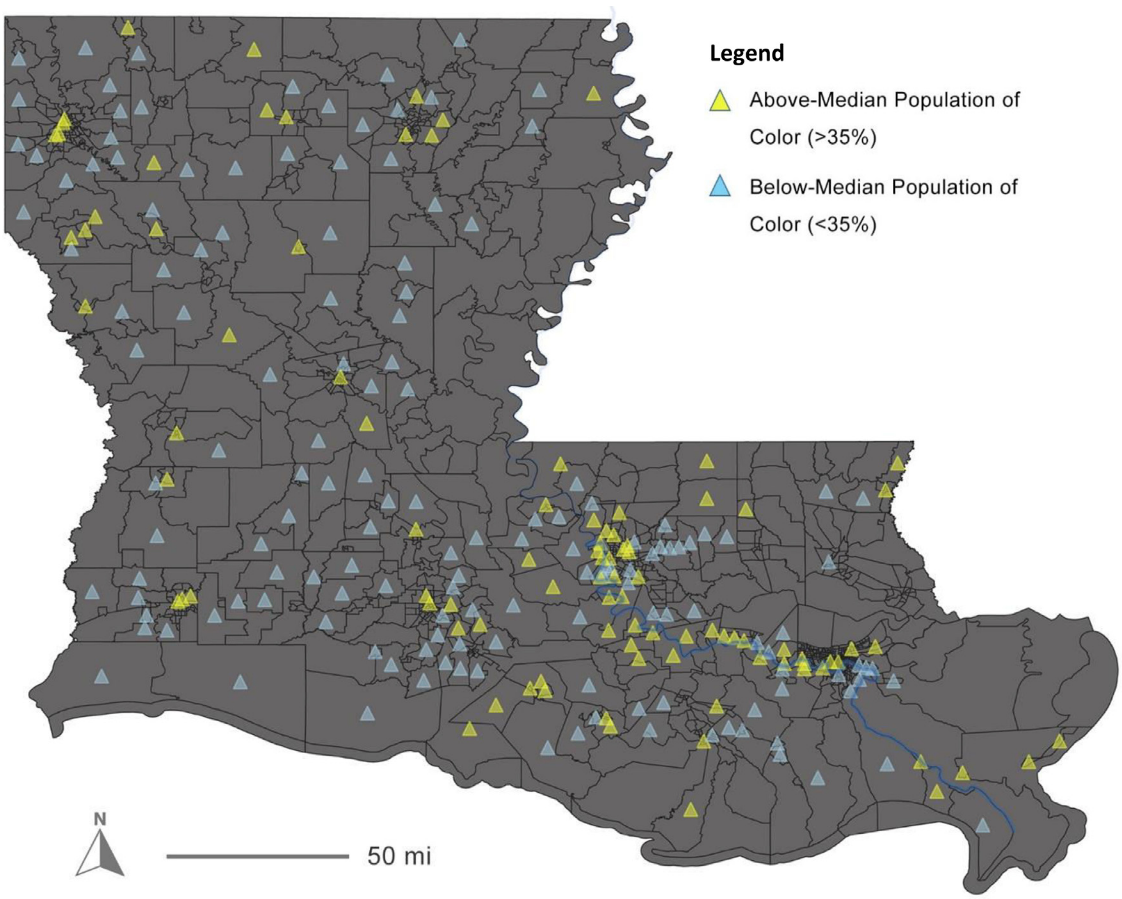

Fig. 1. Centroids of census tracts (N = 245) that contain at least one industrial facility, relative to the racial composition of those census tracts. Black lines represent tract boundaries. The dark blue line represents the lower Mississippi River (shown for consistency with other figures). Centroids are omitted for three census tracts that contain at least one industrial facility because they do not have a residential population.

Table 3
Median Emissions* versus Race among Census Tracts with Industrial Activity.

Census Tract Group** (% Population of Color)	PM_{10}	$PM_{2.5}$	NO_x	SO_2	CO	VOC
Mostly People of Color (65.5 – 100%)	1.37	1.97	5.41	0.21	5.73	6.83
Disproportionately People of Color (34.6 – 65.4%)	1.56	1.00	6.16	0.12	3.54	1.45
Disproportionately White (17.0 – 34.5%)	0.13	0.11	1.29	0.04	0.89	0.88
Mostly White (0 – 16.9%)	0.13	0.10	0.73	0.01	0.64	0.53
Disparity Factor†	10.5	19.7	7.4	21.0	9.0	12.9

* Normalized reported emissions (tons/year/mi^2) for LDEQ-regulated facilities in 2019-2021.
** Group thresholds correspond to quartile breaks for % population of Color among all census tracts in Louisiana (see Methods); sample sizes vary by pollutant and range from 36 to 77 census tracts per group (see Table A.9).
† Calculated as the emissions ratio for tracts with mostly people of Color versus mostly White tracts.

3.4. Racial Demographics around Industrial Infrastructure

Odds ratios indicated that tracts were more likely to be industrialized if they intersected with a railway or petrochemical pipeline, bordered the lower Mississippi River, or had relatively high proportions (≥10%) of the workforce employed in manufacturing (Table 5; Figs. 2 & B.4). Mean percentages of residents of Color among tracts with industrial infrastructure were similar to, or lower than, the statewide mean (42.4%; Table 4), except for railways, which had 46.2% residents of Color (Table 6). As described in our Methods, collinearities among potential predictors of facility presence/absence prevented us from reliably analyzing these variables in a single model (Table A.1).

4. Discussion

Our study provides conclusive evidence that communities of Color are disproportionately burdened with industrial air pollution in Louisiana and that state environmental regulation is the driving force of this disparity. We found that the Louisiana Department of Environmental Quality (LDEQ) has permitted a pattern of industrialization wherein reported emissions of common industrial pollutants are 7 to 21-fold higher among industrialized communities of Color compared to industrialized White communities (Table 3). This disparity can be primarily attributed to the Chemical Manufacturing Industry, which represents more LDEQ-reporting facilities and more emissions in predominantly Black communities - and in Louisiana overall - than any other industry sub-

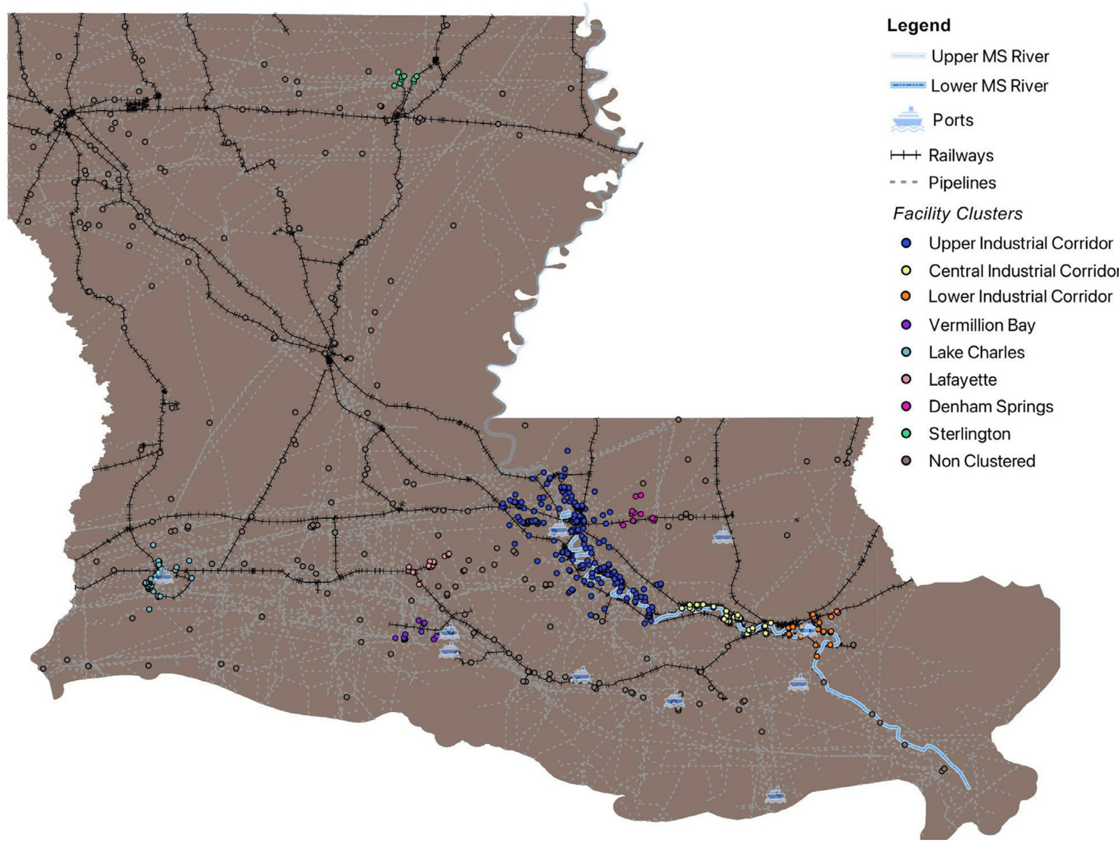

Fig. 2. Locations of industrial facilities (N = 671) and industrial infrastructure in Louisiana. Facilities are color-coded to illustrate results of the densitybased cluster analysis.

Table 4
Industrial Sectors Represented among Census Tracts Grouped by Race*.

Industry Subsector and Description		Number of Facilities in Census Tract Group	
		Mostly People of Color**	Mostly White†
114	Fishing, Hunting and Trapping	0	1
211	Oil and Gas Extraction	4	23
212	Mining (except Oil and Gas)	0	1
213	Support Activities for Mining	1	1
221	Utilities	6	16
311	Food Manufacturing	5	2
321	Wood Product Manufacturing	2	9
322	Paper Manufacturing	3	1
324	Petroleum and Coal Products Manufacturing	7	7
325	Chemical Manufacturing	32	26
326	Plastics and Rubber Products Manufacturing	0	1
327	Nonmetallic Mineral Product Manufacturing	3	0
331	Primary Metal Manufacturing	2	1
332	Fabricated Metal Product Manufacturing	4	5
333	Machinery Manufacturing	1	1
336	Transportation Equipment Manufacturing	2	5
424	Merchant Wholesalers, Nondurable Goods	9	4
483	Water Transportation	0	1
486	Pipeline Transportation	11	53
488	Support Activities for Transportation	3	1
493	Warehousing and Storage	3	0
531	Real Estate	1	0
562	Waste Management and Remediation Services	9	5
Total		108	164

* Industry subsectors designated by the North American Industry Classification System (NAICS). Census tracts are grouped by race, using quartile breaks (Q4, Q1) for the entire state and excluding tracts without industry (see Methods).

** Census tracts (n = 42) with >65.0% people of Color.

† Census tracts (n = 77) with ≤16.9% people of Color.

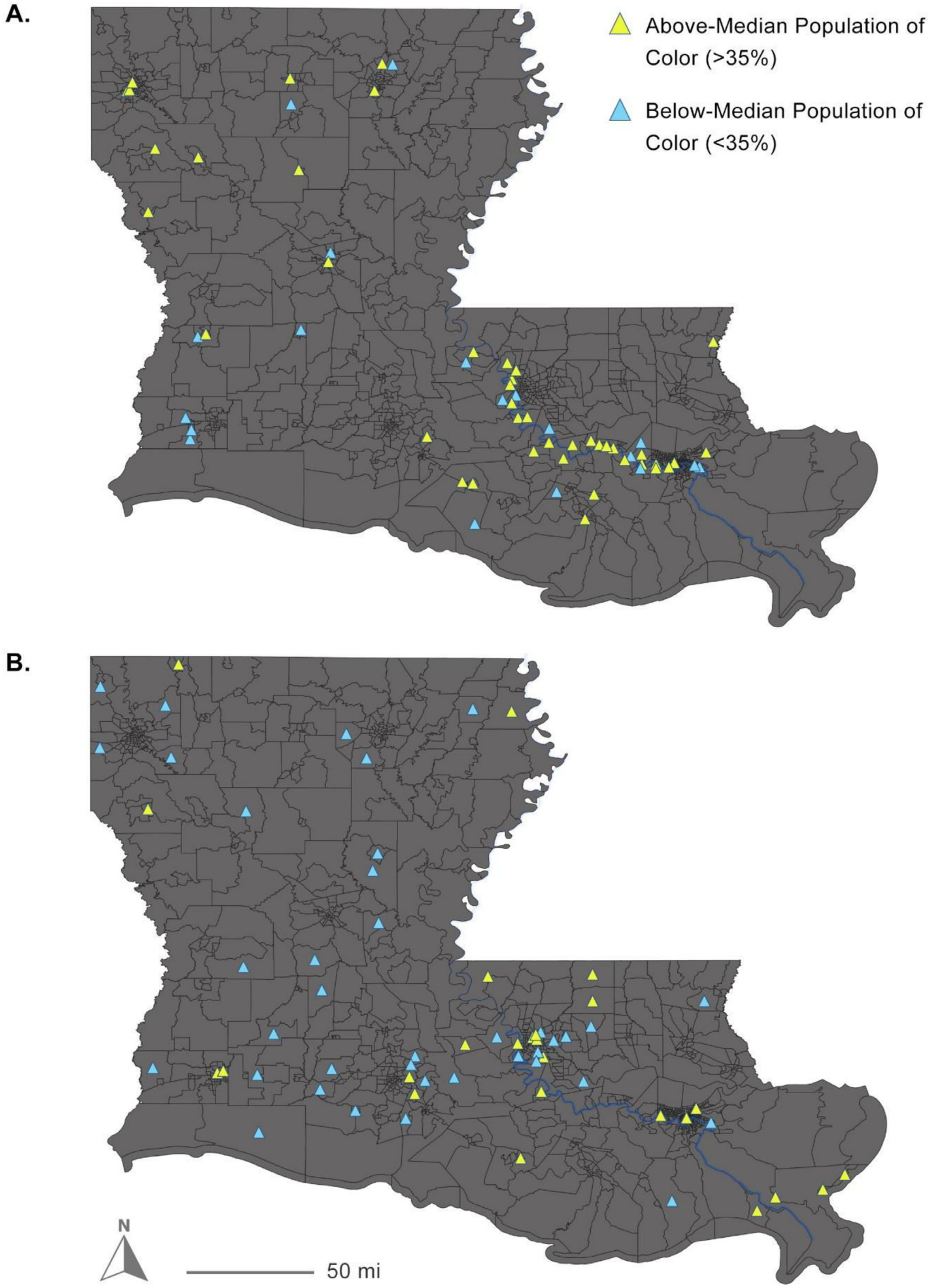

Fig. 3. Centroids of industrialized census tracts with the highest (A) and lowest (B) industrial emissions of fine particulate matter ($PM_{2.5}$), relative to the racial composition of the tract. Panels correspond to the top and bottom pollution quartile, respectively (N = 61 census tracts per quartile).

sector (Fig. 6, Tables A.11 – A.13). Petroleum and Coal Products Manufacturing also contributed to substantial emissions of most pollutants in communities of Color. Our analysis did not support LDEQ's speculation that Louisiana's racial disparity in pollution burden might be driven by differential access to industrial infrastructure (Table 6, Figs. 2 & B.1). Collectively, these findings indicate a need for systemic changes in U.S. state permitting to achieve compliance with national environmental justice policies.

Our findings are consistent with the longstanding perspectives of residents and advocates who contend that industrial operations dispropor-

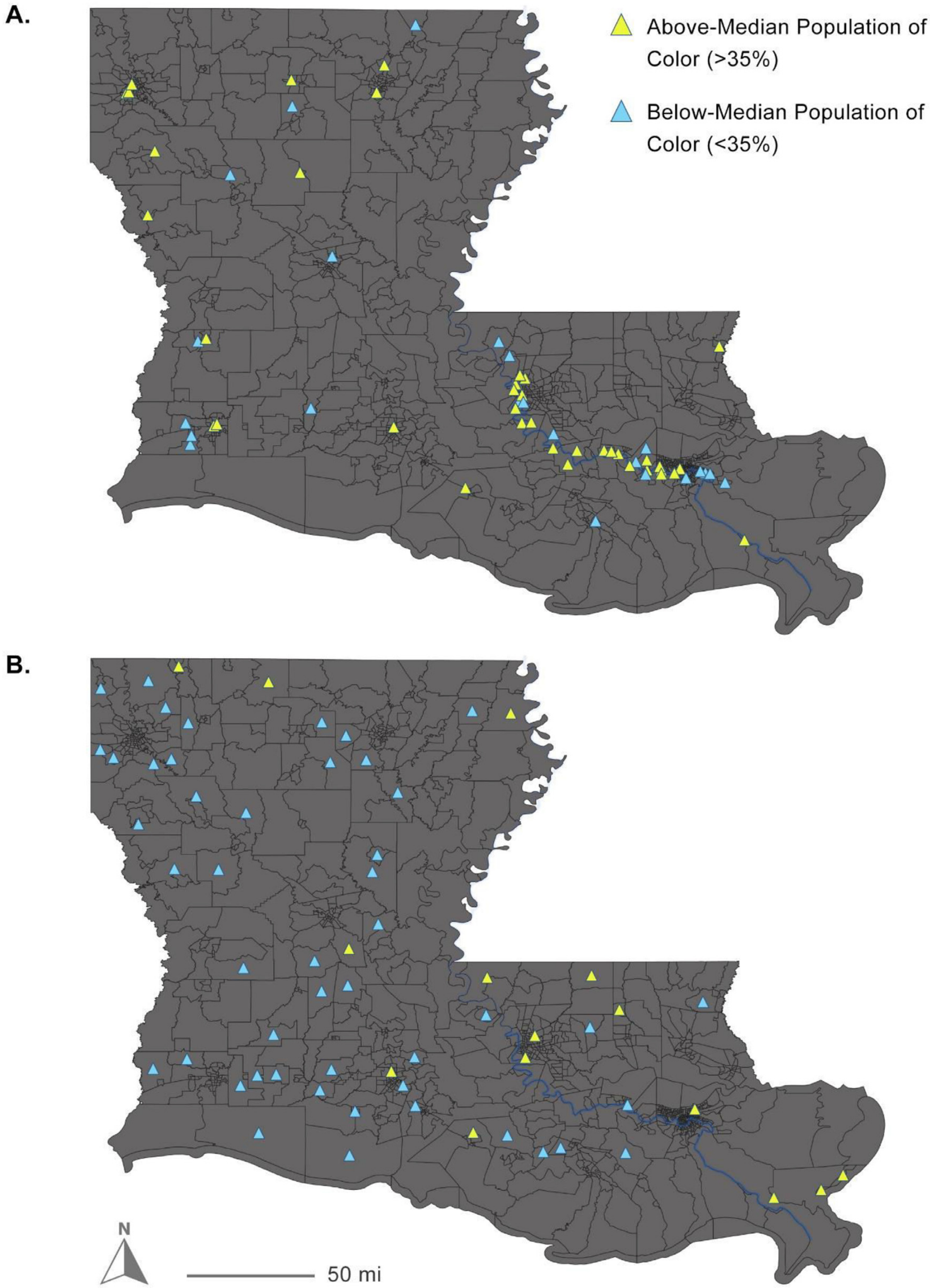

Fig. 4. Centroids of industrialized census tracts with the highest (A) and lowest (B) industrial emissions of nitrogen oxides (NO_x), relative to the racial composition of the tract. Panels correspond to the top and bottom pollution quartile, respectively (N = 61 census tracts per quartile).

tionately harm communities of Color in Louisiana (e.g., Achiume et al., 2021; Kruzman, 2022). While southwest Louisiana appears to be an exception, we recognize that the 2014 expansion of Sasol's chemical complex in Mossville displaced many Black residents, altering the area's demographics (University Network for Human Rights, 2021).) We found that the *magnitude* or *type* of industrial operations drives Louisiana's pollution disparity, as opposed to the presence of industry *per se*, given that every census tract in our analysis had at least one industrial facility. This disparity applied to all criteria pollutants, the health effects of which are relatively well studied. Exposure to particulate pollution

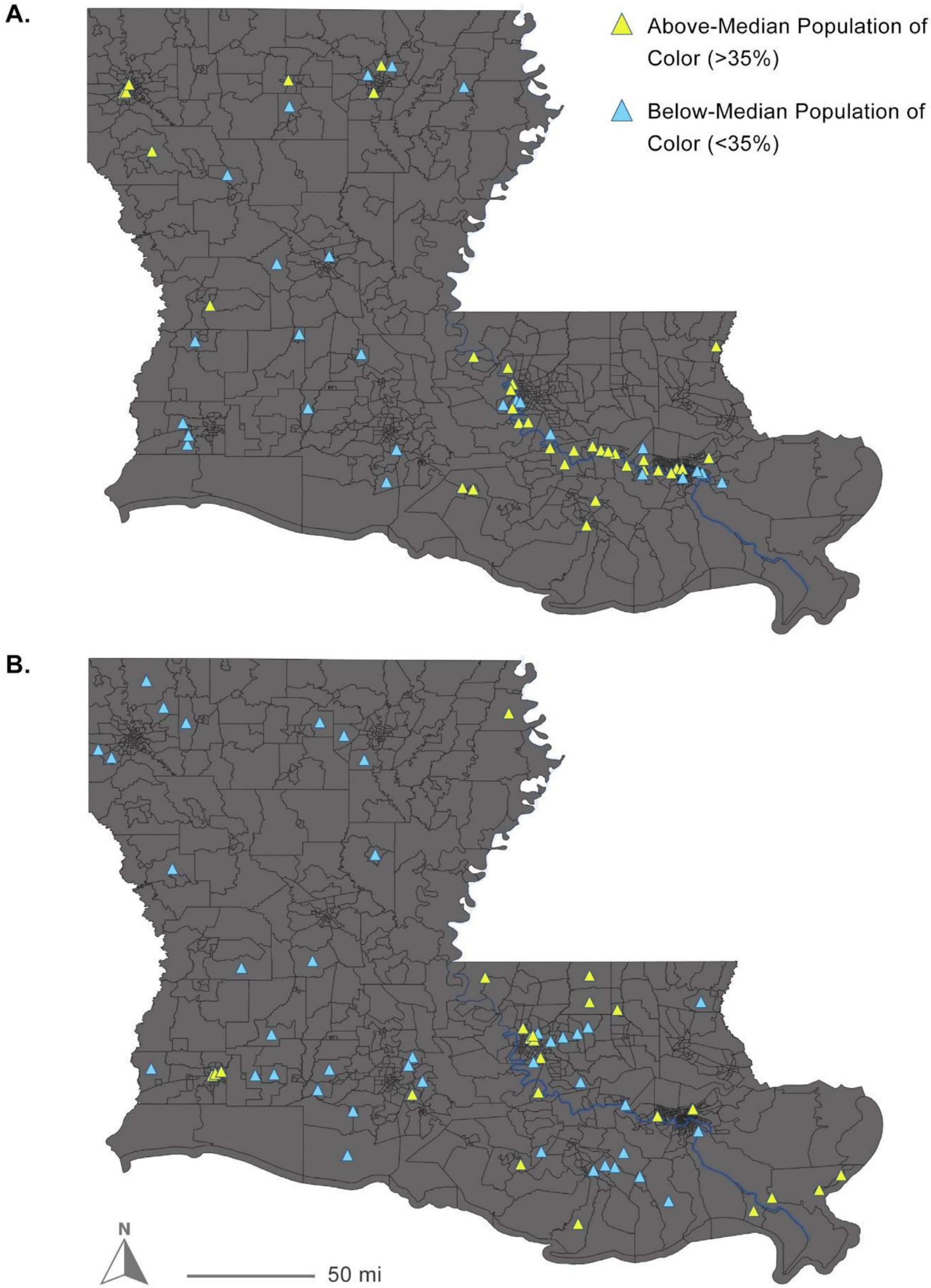

Fig. 5. Centroids of industrialized census tracts with the highest (A) and lowest (B) industrial emissions of volatile organic compounds (VOCs), relative to the racial composition of the tract. Panels correspond to the top and bottom pollution quartile, respectively (N = 61 census tracts per quartile).

(PM10 and/or PM2.5) can cause lung cancer, respiratory disease, cardiovascular disease, and cognitive impairment (reviewed in Yang et al., 2019; Dockery et al., 1989; Hamanaka and Mutlu, 2018). Exposure to gaseous pollutants (NOx, SO2, CO, and VOCs) can cause respiratory and cardiovascular disease (reviewed in Bernstein et al., 2004). Many VOCs are toxic and disrupt other bodily systems; for example, benzene causes blood disorders, various cancers, and reproductive problems (Wilbur et al., 2008). Although less studied, pollutant mixtures can be more harmful than their individual parts (e.g., Huang et al., 2012; Last, 1991). Industrial permits typically allow facilities to emit dozens of different

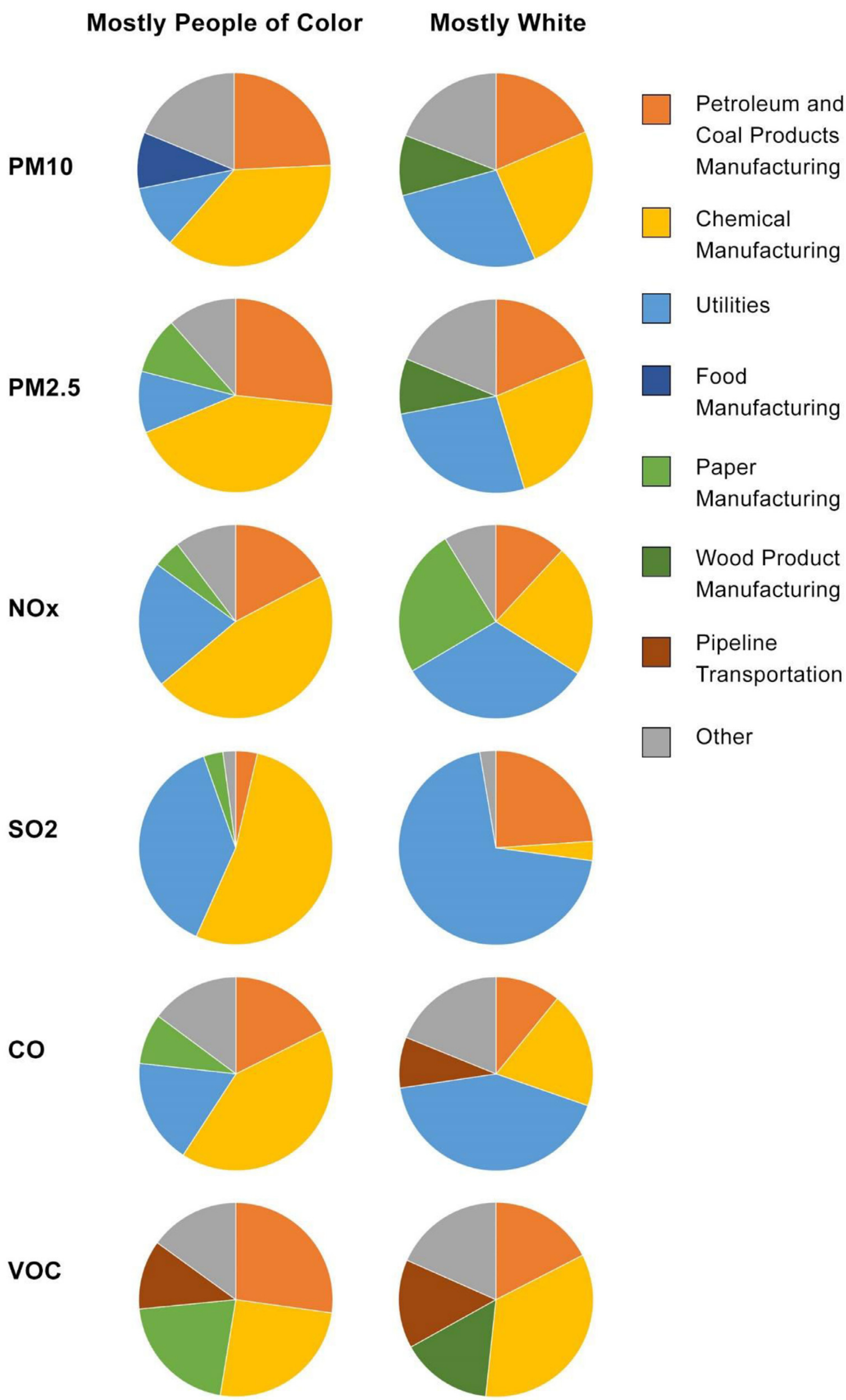

Fig. 6. Proportion of emissions by industry subsector among census tracts grouped by race. Groupings
correspond to >65.0% or ≤16.9% people of Color (top and bottom statewide race quartiles), respectively. See Tables A.11 and A.12 for percentage values and sample sizes.

pollutants (e.g., LDEQ, 2020), the combined health effects of which are poorly understood. There are currently no state or federal regulations that limit the *total* risk from air pollution, and we are unaware of any such local regulations in Louisiana. For the past two decades, scientific advisors to the U.S. EPA have been recommending a more holistic, multipollutant approach to regulating air quality (National Research Council, 2004; Page, 2005; Air Quality Management Subcommittee, 2007). Our study reveals that this approach would also benefit environmental justice in Louisiana, where communities of Color are overburdened with all major types of industrial pollutants.

Table 5
Odds of Census Tracts Containing at Least One Industrial Facility Relative to Infrastructure Variables*.

Infrastructure	Tracts with Industry		Tracts w/o Industry		Odds Ratio (95% CI)
	+ Infrastructure (N)	- Infrastructure (N)	+ Infrastructure (N)	- Infrastructure (N)	
Pipeline Access	224	23	472	407	8.40 (5.36-13.16)
Rail Access	191	56	395	484	4.18 (3.02-5.79)
≥10% Workforce in Manufact.	108	139	150	729	3.78 (2.78-5.13)
Lower MS River Access	43	204	52	827	3.35 (2.18-5.16)
Coastal Port within 100 km	174	73	659	220	NS (0.58-1.09)

* Among census tracts with all data available (N = 1,126). NS = not significantly different from 1.0.

Table 6
Racial Demographics of Tracts with Industrial Infrastructure versus Louisiana Overall*.

Infrastructure	Tracts (N)	Mean Population of Color (%)	Versus LA overall (42.4%)	
			T	P
Pipeline Access	696	38.8	-3.47	0.0005
Rail Access	586	46.2	3.15	0.002
≥10% Workforce in Manufacturing	258	35.5	-4.28	<0.0001
Lower MS River Access	95	45.4	1.11	0.27
Coastal Port within 100 km	833	41.7	-0.64	0.52

* Among census tracts with all race data available (N = 1,126).

As the primary permitting authority, the LDEQ plays a central role in determining the distribution of negative impacts from Louisiana's industrial operations. In response to allegations of discriminatory decision-making, LDEQ recently cited "numerous factors unrelated to the demographics of the surrounding communities" to explain the spatial pattern of industrialization (LDEQ, 2022a). These factors include historical land prices, pipelines, railways, highways, and an abundance of minerals, petrochemicals, water, and labor (LDEQ, 2022a). We challenge LDEQ's claim that historical land prices or industrial infrastructure are unrelated to demographics, given that racist practices have shaped current patterns of residential segregation (reviewed in Charles, 2003), including with respect to industrial operations and zoning (Ard and Smiley, 2022; Morello-Frosch and Jesdale, 2006; Morello-Frosch and Lopez, 2006; Whittemore, 2017). Regardless, neither infrastructure nor labor explained the emissions disparity identified in our study. Four of the five infrastructure variables we examined were strongly associated with industrialization (Table 5), but only one of these variables (i.e. railways) was also associated with higher proportions of residents of Color, and this association was modest (Table 6). As further evidence that Louisiana's emissions disparity is unrelated to infrastructure, our linear model found an effect of race on emissions after controlling for spatial clustering of industrial facilities, which tends to occur around infrastructure (Tables 2 & A.3-A.8; Fig. 2).

Our study provides a framework for evaluating the role of state industrial permitting in pollution disparities. This framework could be easily adopted for other industrialized states where local pollution disparities have been identified but the relative contributions of regulated and non-regulated emissions sources are not fully understood, including New Jersey (Dressel et al., 2022) and Texas (Tiefenbacher and Iii, 1999). Future studies could use a similar approach to examine the efficacy of new state laws and regulations aimed at reducing or eliminating pollution disparities. For example, New Jersey passed a landmark environmental justice bill in 2020 (SB232), requiring that the state Department of Environmental Protection identify disproportionately polluted communities and take active steps to reduce these disparities through changes to the agency's industrial permitting program (Singleton et al., 2021). The most direct approach to determining the success of these and other emerging environmental justice policies would be to evaluate temporal changes in the magnitude of industrial emissions reported in state inventories. However, temporal studies that rely on state emissions inventories must account for changes in reporting requirements over time, and researchers should be aware that these requirements can vary dramatically among states. For example, Texas requires annual reporting for any facility that emits 100 tons per year (tpy) or more of a criteria pollutant (30 Tex. Admin. Code § 101.10), while Mississippi requires that only very large emitters (≥250 tpy) report annually, with facilities emitting 100-249 tpy of a criteria pollutant reporting their emissions once every 3 years (MDEQ, 2022).

A limitation of our study is that it relies on reported emissions by census tract as a proxy for the local, negative impacts associated with heavy industry. These impacts can include health problems from pollutant exposures (reviewed in Brisbois et al., 2019), depressed home values (Chay and Greenstone, 2005; Hanna, 2007), increased poverty (reviewed in Gamu et al., 2015), and loss of community resources (e.g. school closings; U.S. EPA, 2022e). We use reported emissions because it is a straightforward metric that is associated with each of these harms, and it is directly attributable to a specific regulatory action (i.e. industrial air permitting). Further, these emissions values are readily available for all criteria pollutants in Louisiana, whereas corresponding ambient concentrations and estimates of associated health risks are not currently available. Estimating these refined metrics for industrial emissions of criteria pollutants is a significant undertaking that is beyond the scope of this study, but which is a priority for future research.

While our study reveals a stark racial disparity in reported emissions, more research is needed to quantify corresponding differences in exposure and economic harm. Exposure disparities could differ significantly from emissions disparities if certain racial groups are more likely to spend time outdoors, live closer to (or more downwind of) industrial facilities in their census tract, live in dilapidated (i.e. less air tight) homes, or be exposed to emissions from adjacent census tracts (Baxter et al., 2013). Based on our direct knowledge of Louisiana's industrialized communities, we expect these factors to contribute to an exposure disparity that is similar to – or potentially more extreme than – the emissions disparity identified in our study. Regardless, quantifying pollutant exposures and economic harms from industrial operations in Louisiana is a major priority for future research. The latter is particularly challenging due to the lack of baseline economic data, since industrialization of most communities occurred many decades ago. Further, our firsthand experiences suggest that home sales are relatively infrequent in Louisiana's heavily industrialized areas, potentially limiting the utility of housing market data. Still, creative modeling approaches can overcome some of these challenges (e.g., Chay and Greenstone, 2005), and these research topics remain largely unexplored in Louisiana.

Another caveat of our study is that emissions reporting is subject to bias. State and federal emissions inventories in the U.S. are compiled from self-reported industry data, and companies may have incentives to underreport their emissions (Hausman and Stolper, 2021). A 2004 report by the Environmental Integrity Project and the Galveston-Houston Association for Smog Prevention estimated that actual emissions of toxic pollutants from industrial facilities are four to five times higher than the values reflected in EPA's national inventory (Environmental Integrity Project and the Galveston-Houston Association for Smog Prevention, 2004). More recently, peer-reviewed studies have identified underreporting of greenhouse gas emissions from cities (Gurney et al., 2021) and methane emissions from petrochemical extraction ("Assessment of methane emissions from the U.S. oil and gas supply chain," 2018), suggesting that emissions underreporting is a pervasive problem. In Louisiana, the LDEQ allowed industrial facilities to retroactively lower their reported emissions of ethylene oxide, after EPA determined that the pollutant was substantially more toxic than previously thought (U.S. EPA, 2022f). For example, in 2019, Sasol Chemicals USA (LLC) retroactively changed its 2014 ethylene oxide emissions to less than 6% of the original reported value, based on testing performed by Sasol (Sasol Chemicals USA (LLC), 2020). (This timing was significant from a regulatory perspective because a risk assessment using 2014 emissions data was used to inform EPA rulemaking in 2020 (U.S. EPA, 2020). Thus, state emissions inventories, including the one used in our study, are subject to reporting bias that may result in emissions disparities being underestimated.

Our findings add to a growing body of evidence that communities of Color are disproportionately harmed by pollution in Louisiana (James et al., 2012; Nagra et al., 2021; Perera and Lam, 2013; Terrell and James, 2020; Terrell and Julien, 2022), and we specifically identify industrial permitting as the driving force of this disparity. Yet, in permitting decisions and in response to allegations of discrimination, the LDEQ has concluded that pollution disparities are not meaningful if legally enforceable pollution limits are not violated, including the National Ambient Air Quality Standards (NAAQS; LDEQ, 2022a). There are two flaws in LDEQ's logic. First, LDEQ assumes that NAAQS are fully protective of human health and well-being, an assumption that is contradicted by evidence of synergistic harm from multipollutant mixtures and by periodic revisions to the NAAQS (U.S. EPA, 2022g). As other authors have noted, revisions of environmental standards (including the NAAQS) have generally resulted in more protective (i.e. lower) pollution limits, as new research has identified previously unknown mechanisms of toxicity (Hausman and Stolper, 2021). The second problem with relying on NAAQS to ensure environmental justice is that there are major spatial gaps in the NAAQS air monitoring network. For example, seven of the ten Louisiana parishes with the highest reported industrial emissions of PM2.5 do not have a NAAQS monitor for PM2.5 (LDEQ, 2022e). Current EPA practice incentivizes this lack of monitoring because, in the absence of information, EPA effectively assumes compliance with NAAQS (U.S. EPA, 2022h). As these observations illustrate and as other authors have noted, regulators tend to err on the side of false negatives with respect to identifying harm from pollution exposure (Gee and Krayer von Krauss, 2005).

5. Conclusions and Implications

Decades of research has demonstrated that environmental injustice is a pervasive and persistent problem in the U.S. and across the globe. While U.S. federal policies and regulations have attempted to address nationwide disparities in pollution exposure, there is no evidence that these efforts have been successful overall. Environmental justice in the U.S. has been undermined by a regulatory system that affords residents of certain states more stringent environmental protections and enables state environmental regulators, like in Louisiana, to concentrate industrial emissions in communities of Color. Our study identified, quantified, and characterized a racial disparity in pollution exposure that many residents have known about for decades. These findings highlight the need for systemic change in the implementation of the U.S. Clean Air Act, including more robust federal oversight to ensure that state permitting decisions avoid discriminatory outcomes, particularly with respect to chemical and petroleum manufacturing. As long as pollution disparities persist locally, environmental justice will remain an elusive goal in the United States.

Data availability

Data will be made available on request.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.envc.2022.100672.

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