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Petro-riskscapes and environmental distress in West Texas: Community perceptions of environmental degradation, threats, and loss

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ABSTRACT

Unconventional oil and gas development (UOGD) expanded rapidly in the United States between 2004 and 2019 with resultant industrial change to landscapes and new environmental exposures. By 2019, West Texas' Permian Basin accounted for 35% of domestic oil production. We conducted an online survey of 566 Texans in 2019 to examine the implications of UOGD using three measures from the Environmental Distress Scale (EDS): perceived threat of environmental issues, felt impact of environmental change, and loss of solace when valued environments are transformed ("solastalgia"). We found increased levels of environmental distress among respondents living in counties in the Permian Basin who reported a 2.75% increase in perceived threat of environmental issues (95% CI = −1.14, 6.65) and a 4.21% increase in solastalgia (95% CI = 0.03, 8.40). In our subgroup analysis of women, we found higher EDS subscale scores among respondents in Permian Basin counties for perceived threat of environmental issues (4.08%, 95% CI = −0.12, 8.37) and solastalgia (7.09%, 95% CI = 2.44, 11.88). In analysis restricted to Permian Basin counties, we found exposure to at least one earthquake of magnitude ≥ 3 was associated with increases in perceived threat of environmental issues (4.69%, 95% CI = 0.15, 9.23), and that county-level exposure to oil and gas injection wells was associated with increases in felt impact (4.38%, 95% CI = −1.77, 10.54) and solastalgia (4.06%, 95% CI = 3.02, 11.14). Our results indicate increased environmental distress in response to UOGD-related environmental degradation among Texans and highlight the importance of considering susceptible sub-groups.

1. Introduction

The United States (U.S.) has seen a resurgence in oil and gas production, mainly driven by technological improvements such as horizontal drilling and high-volume hydraulic fracturing (commonly known as "fracking") that allow for production of natural gas from shale and other unconventional formations. The unconventional oil and gas development (UOGD) process additionally involves extensive land-clearing and development of multi-well pads, as well as injection of millions of gallons of highly pressurized water and chemical additives into formations [1,2]. Application of these technologies for UOGD propelled the U.S. to lead global production of crude oil and natural gas by 2009 [3,4]. According to the Congressional Research Service, annual oil production has increased each year since 2009, reaching 12,000 barrels per day in the lower 48 states in 2019 [5]. The percentage of oil and gas wells using unconventional techniques such as horizontal drilling grew from 15% in 2004 to greater than 60% by 2018 [6], with much of the increase in crude oil production coming from shale and related tight oil formations in Texas and North Dakota. By 2014, an estimated 1.5–4 million individuals lived within one mile of a UOG well [7].

1.1. Local and national benefits of UOGD

Beyond greater access to oil and natural gas, proponents of UOGD

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emphasize its central role in the "clean energy future" of the U.S [8]. Additional cited benefits include enhanced energy security and availability of domestic fuels, lower natural gas prices, and environmental benefits related to reduced coal extraction and coal-fired power plant electricity production [8,9]. Research-to-date also notes that negative environmental impacts of expanded UOGD may be counterbalanced by relatively more positive economic ones. Economic gains related to UOGD may include increased housing values, construction of new infrastructure, and direct and indirect employment growth [10], although evidence remains mixed and generally suggests that many of the jobs created by UOGD are filled by non-local residents [11,12]. Residents may benefit from drilling if properties are unified with mineral rights [13]. Oil and gas leases negotiated between industry and landowners also provide an opportunity for landowners to form coalitions and collectively negotiate for specific lease conditions that could potentially mitigate negative environmental impacts (e.g., protections for surface water and groundwater) [14]. Further, an optimal zone may exist on the periphery of UOGD, where economic benefits are realized, social stressors minimized, and place characteristics remain unchanged [15]. However, perceptions of benefits likely vary by region. For example, among residents of the heavily developed Marcellus shale in Pennsylvania, 48% believed only a few will see benefits [16].

1.2. Local consequences of UOGD

The adverse consequences of UOGD have also been extensively studied. Although natural gas has been touted as a clean fuel source, concern mounts about emissions of methane, a potent greenhouse gas, from UOGD activities and abandoned wells [17,18]. At a local scale, activities related to UOGD result in substantial disturbance to communities and environments. Disposal of waste from high-volume hydraulic fracturing may entail reinjection of large volumes of wastewater and resultant earthquakes due to disruption of underlying formations [19,20]. Additional sources of environmental disturbance related to UOGD include odor, noise, and air pollution from diesel equipment and trucks, fugitive emissions, secondary ozone formation, as well as contamination of surface water and groundwater from spills and well casing failures [1,21]. UOGD has been linked with reduced quality of life from survey respondents living in nearby communities [22–24] due to psychosocial stress related to traffic, safety, and unwelcome social and environmental change [22,25–27].

The literature to date further identifies a wide range of potential health threats of intensive extraction of oil and natural gas. These include anxiety and depression [28,29], migraine headache and fatigue [30], asthma exacerbations [31,32], cardiovascular disease [33], and adverse birth outcomes [1,34–40]. Most epidemiologic studies of oil and gas have used distance-weighted exposure metrics relative to wells and have not considered other sources of environmental disturbance such as injection-induced earthquakes [41,42]. In Oklahoma, felt manmade earthquakes ($\geq$ magnitude 3) secondary to wastewater injection were associated with increased Google search episodes for anxiety [42] and increased motor vehicle crashes [41].

1.3. The Permian Basin

While studies of the psychosocial and health-related impacts of intensive oil and natural gas extraction have primarily focused on communities in Colorado, Pennsylvania, and along the Gulf Coast [33,43–47], relatively few have taken place in Texas, which produced 41% of U.S. crude oil and 25% of natural gas in 2019, making it the top-producing state in both categories [48]. And, although the Permian Basin is the largest petroleum-producing basin in the U.S., no studies to date have focused specifically on local attitudes toward UOGD among individuals living there.

The Permian Basin is a shale basin approximately 400 km wide and 480 km long and includes the prolific Delaware and Midland sub-basins [49]. Recent advances in hydraulic fracturing have expanded production within the Permian into unconventional, tight oil shales. As of March 2020, the Permian Basin produced an average of 4.8 million barrels of oil (~35% of total U.S. production) and 495,544 thousand cubic meters of gas per day [50,51].

1.4. Risk perception and UOGD

Despite growth, in 2019 the UOGD industry employed less than three percent of workers in Texas [52]. As Freudenburg suggests, this job specialization leads to a small segment of the population controlling resources, like oil and gas, on which the rest of the population relies [53]. Industry also holds the power to protect public safety and health and the failure to do so – termed recreancy – leads to mistrust from individuals, which can increase risk perception [54]. In Colorado and the Marcellus shale, trust in the natural gas industry was the most important factor predicting reduced risk perception of UOGD [16,55]. Specific factors, such as earthquakes caused by wastewater injection, although still relatively rare in West Texas [56], may serve as signal events that increase perceptions of risk and reduce trust that the oil and gas industry is effectively managing risks [57,58]. Risk perception is a complicated social and psychological process [54,58] that can affect psychological response to environmental exposures [59–61]. For example, in Australia, Lai and colleagues found that individuals who initially felt coal seam gas development would have adverse effects on health, family, self-efficacy, and material resources also reported more negative emotions. Primary appraisal explained 41% of variance in negative emotions in their sample [59].

In the U.S., support for UOGD generally falls along political party lines, due in part to a low percentage of the public understanding UOGD [62], though familiarity has increased over time [63]. Polling in 2020 finds that 63% of Democrats versus 26% of Republicans support a fracking ban [64]. Regardless of political affiliation, in experimental conditions, arguments about economic benefits of UOGD bolster support, but arguments regarding environmental losses completely cancel these gains [65]. Place-based factors such as rurality and proximity also affect support of UOGD, with political ideology playing a greater role among those living farther from UOGD [63,66–68].

1.5. Environmental distress and UOGD

The extant literature suggests that various environmental disturbances related to intensive oil and gas extraction may produce substantial distress among nearby residents. Studying local attitudes towards the changing landscape among residents of West Texas can improve understanding of how UOGD may affect mental health. Here, we use the term landscape to refer not only to the biophysical attributes of an area, but also to embedded social, cultural, and interpersonal meanings [69,70]. Prior work suggests that residents care most about how UOGD may degrade place attributes they value: aesthetic beauty, rural character, and peace and quiet [71].

For the present study, we examined whether levels of environmental distress are associated with UOGD, as measured first by residence in the Permian Basin; second, by density of oil, gas, and injection wells at the county level; and third, by the frequency of felt earthquakes. We assessed respondents' levels of environmental distress using validated measures derived from the Environmental Distress Scale (EDS). Development of the EDS was informed by environmental stress and risk theory combined with qualitative fieldwork in the Upper Hunter Valley in Australia [72]. It aims to measure the bio-psychosocial cost of development and can be applied to a wide range of environmental disruptions, including resource extraction [73], volcanic eruptions [74], and climate change [75]. We consider three specific subscales most relevant to UOGD in West Texas: (1) perceived threat and health impacts of specific environmental issues; (2) the felt impact of environmental change regarding physical symptoms, emotional and psychological symptoms, social and community dysfunction, and economic loss; and (3) solastalgia, the distress felt by individuals when their home environment no longer provides solace, strength, and support due to environmental degradation [76].

The majority of prior work on perceived threats and health impacts, felt impact, including mental health, and solastalgia related to UOGD has relied on qualitative interviews [28,77]. We apply the EDS to operationalize these concepts quantitatively. Solastalgia falls under what Albrecht terms "psychoterratic" states, which relate to the relationship between the biophysical environment and mental health [78]. These also include ecologic grief and eco-anxiety. We focus on solastalgia as it alone captures a place-based lived experience [77] and has been invoked in several studies of UOGD as a possible reason for adverse mental health impacts [28], but has not been formally evaluated.

1.6. Study objective

The objective of the present study was to characterize the impact of UOGD on levels of environmental distress measured via the EDS among individuals living in West Texas. We hypothesized – given research-to-date regarding the consequences of UOGD for physical and mental health – that county-level exposure to UOGD would be associated with increased environmental distress as measured by the EDS. Our preliminary findings will provide a benchmark for further study of environmental distress and mental health impacts of UOGD in Texas as the extent and scale of UOGD shifts over the next decade.

2. Methods

In March and April of 2019, we conducted an online, cross-sectional survey of Texas residents. Potential respondents were identified from a pre-existing panel developed by a third-party survey firm (Qualtrics, Provo, UT). Panel members were initially recruited by the survey firm through member referrals, email lists, gaming sites, customer loyalty portals, social media, and website intercept recruitment. The survey firm invited panel members to participate in the present study through email. The survey firm oversampled respondents from pre-specified counties in West Texas where UOGD is most intensive such that these individuals comprised half of the study sample. The remainder of respondents lived in counties outside of West Texas. Eligible respondents were at least 18 years old, resided in the state of Texas, and were either English or Spanish speaking.

2.1. Exposure to county-level UOGD

We considered three separate measures of county-level exposure to UOGD. First, we identified residents living in the Permian Basin (vs. elsewhere in Texas) based on their reported county of residence. Second, we used data from the Railroad Commission of Texas to identify the number of producing oil and gas and injection wells as of February 2019 in each respondent's county of residence [79]. These data did not differentiate between conventional and unconventional wells and thus both well types were included. We created an exposure measure in which we compared respondents living in counties with at least 2,689 total producing oil and gas or injection wells to those living in counties with less than 2,689 wells. This cut-point corresponded to the median number of total wells per county among survey respondents. Although our metric includes a mixture of conventional and unconventional wells, we assume that the majority of exposure is due to UOGD given the recent growth in UOGD in West Texas. For our final measure, we used data from the United States Geological Survey (USGS) to identify the number of earthquakes of magnitude three or greater ($\geq M\,3$) located within 100 km of the boundary of each Texas County in the one-year period prior to the survey period (between March 2018 and March 2019). As earthquakes occur relatively infrequently in most Texas counties, we compared respondents in counties exposed to at least one $\geq M\,3$ earthquake to respondents living in counties exposed to smaller or no earthquakes.

2.2. Environmental distress

The primary outcome of interest was environmental distress, as measured using three metrics derived from the EDS developed by Higginbotham and colleagues [73]. We measured the perceived threat of specific environmental issues; the felt impact of environmental change regarding physical symptoms, emotional and psychological symptoms, social and community dysfunction, and economic loss; and solastalgia, which captures the distress felt by individuals when their home environment no longer provides solace, strength, or support due to environmental degradation [76].

We first asked respondents to characterize their perceived threat of 18 separate environmental issues – including visual air pollution, dust, and pollution from waste disposal sites and management – to themselves or their families using a five-point-Likert scale (no threat, low threat, moderate threat, strong threat, extreme threat). For our measure of the felt impact of environmental change, respondents were asked whether they agreed or disagreed with 22 separate statements regarding the possible impacts of environmental change in their area – e.g., "I am worried about risks to human health from nearby environmental pollution" – based on a five-point Likert scale (strongly agree, agree, neither agree nor disagree, disagree, strongly disagree). Finally, for our measure of solastalgia, respondents were asked whether they agreed or disagreed with eight statements relating to change in their local environment – e.g., "I am worried that aspects of this place that I value are being lost" – using the same Likert scale as for felt impact. The questions that compromised each EDS subscale are included in the Online Appendix (Tables A1–A3).

For each subscale (perceived threat, felt impact, and solastalgia), we converted each Likert scale into numeric scores whereby the response that reflected the greatest degree of environmental distress was equal to five and the response that reflected the lowest degree of environmental distress was equal to one (i.e., strongly agree = 5 and strongly disagree = 1) with missing responses coded as zero. We then calculated a separate score for each subscale based on the numeric sum of responses to individual subscale items. Increases in all EDS subscale scores corresponded to a greater degree of environmental distress. In all analyses, we considered perceived threat, felt impact, and solastalgia as separate outcomes.

2.3. Covariates

We captured several sociodemographic characteristics for survey respondents. These included gender (male, female); categorical age (18–24, 25–34, 35–44, 45–54, 55–64, and 65+), years lived in Texas (less than one year, one to five years, five to 10 years, more than 10 years), educational attainment (less than high school, high school or equivalent, associate degree, some college, and college degree or more), and employment status (employed full-time, employed part-time, not employed). We additionally captured covariates that characterize the physical and mental health of survey respondents. We asked respondents to characterize their health as excellent, very good, good, fair, or poor. We used the Patient Health Questionnaire-2 (PHQ-2) and the Generalized Anxiety Disorder (GAD-2) to assess symptoms of depression and anxiety, respectively, among respondents [80,81]. Depression and anxiety symptoms comprise distinct, although frequently comorbid, aspects of psychological distress; the PHQ and GAD scales are widely used to capture such distress in population health surveys. Using these scales, we calculated the number of respondents who satisfy criteria for potential caseness for anxiety (GAD-2 score ≥ 3) and the number of respondents who satisfy criteria for potential caseness for depression (PHQ-2 score ≥ 3) [82,83]. We additionally classified each county as urban or rural based on 2013 Urban Influence Codes (UIC) [84].

2.4. Statistical analysis

We first summarized the distribution of sociodemographic characteristics and health characteristics for the study population overall and based on whether respondents lived in the Permian Basin. We additionally summarized the proportion of respondents who characterized their perceived threat of environmental issues as an "extreme threat" or "strong threat" and the proportion who stated they "strongly agreed" or "agreed" with statements related to the felt impact of environmental change and solastalgia, respectively.

2.4.1. Primary analyses

For our primary analysis, we used multivariate linear regression to examine the association between each of our three of the binary county-level exposures (any earthquakes $\geq M$ 3 versus no M 3 quakes; $\geq$ 2,689 oil, gas, or injection wells versus $<$ 2,689; living in the Permian Basin versus elsewhere) and each of the three EDS outcome measures (perceived threat, felt impact, and solastalgia). We then transformed subscale scores into percentages such that beta coefficients corresponded to the average percent increase or decrease in each subscale score associated with the exposure of interest. The assumptions for this analytic approach are well-established, and include that the relationship between each environmental exposure and the EDS scores is linear; that the variance of residuals is the same for all values of the independent variable; and that observations are independent of each other [85].

We first examined associations of interest in the study population overall. Next, we conducted subgroup analyses among men and women, as past research indicates that women may perceive greater environmental distress in response to ecological perturbances [55,62,67,86]. For all of our analyses we adjusted for *a priori* specified individual-level characteristics (age, gender, and employment status) that could plausibly affect whether a respondent lives in West Texas (and therefore the extent of their UOGD exposure) as well as their level of environmental distress, thereby confounding the associations of interest. Past research suggests that both physical and mental health are impacted by exposure to intensive extraction of oil and natural gas, [28] therefore we did not adjust for self-rated health, PHQ-2, or GAD-2 scores as these variables are more likely to mediate, rather than confound, the associations of interest.

2.4.2. Secondary analyses

Past literature indicates potentially different relationships between UOGD and environmental distress among urban- and rural-dwelling participants. Therefore, as a secondary analysis, we repeated our primary analysis of county-level oil and gas exposure and dimensions of environmental distress separately for respondents in urban and rural counties. Next, in order to further examine the impact of UOGD among respondents living in West Texas, we restricted our analytic sample to respondents living in the Permian Basin. In this subset of the study population, we used multivariate linear regression to examine the association between the remaining two county-level exposures (oil, gas, or injection wells; exposure to $\geq M$ 3 earthquakes) and each of the three outcome measures of environmental distress (perceived threat, felt impact, and solastalgia). As with our primary analysis, we adjusted for age category, gender, and employment status.

2.4.3. Sensitivity analyses

We conducted the following sensitivity analyses. First, we repeated our primary analyses using alternative, categorical specifications of the $\geq M$ 3 earthquake exposure variable (zero earthquakes, one earthquake, more than one earthquake) and the oil, gas, or injection well exposure variable (tertiles defined as $<$ 740; 740 – 5,589; $>$ 5,589 wells). Second, we repeated our analyses with linear terms specified for earthquakes and wells. We rescaled these variables such that beta coefficients reflected the percent change in environmental distress subscale scores for every four additional earthquakes and 1,000 additional oil, gas, or injection wells, respectively. Finally, as the earthquake metric reflects the frequency of $\geq M$ 3 quakes in the 12-month period prior to survey completion, we repeated our primary analyses excluding respondents who had resided in Texas for less than one year.

Statistical analyses were performed with R version 3.2.3 (R Foundation for Statistical Computing, Vienna, Austria). We report 95% confidence intervals but do not strictly interpret results using null hypothesis significance testing. Rather, we attempt to determine if regression results are compatible with an association between exposure and outcome [87]. This study was approved by the Institutional Review Boards at the University of California, Berkeley (Protocol 2019-01-11693) and Columbia University (Protocol Y01M00).

3. Results

3.1. Study overview

In total, 1,163 respondents consented to complete the online survey. We excluded 54 (4.6%) respondents who were under the age of 18 years at the time they completed the survey. We excluded 173 (14.9%) respondents who resided outside of Texas at the time they completed the survey, which likely reflects some combination of individuals who had moved to a permanent address outside of Texas; individuals whose permanent residence was within the state of Texas but resided elsewhere at the time they completed the survey; and individuals with whom the link to complete the survey was shared, but who were not recruited directly by the survey firm. We further excluded 369 (31.2%) individuals who did not reach the end of the survey and one duplicated response, yielding a final study population of 566 individuals.

3.2. Sample characteristics

Respondents represented 115 of 254 Texas Counties, of which 27 were located in the Permian Basin. Of the respondents in the Permian Basin, the greatest percentage of respondents were from Midland County (N = 77, 13.6%), Andrews County (N = 29, 5.1%), and Ector County (N = 28, 4.9%). Of non-Permian respondents, the greatest percentage of respondents were from Harris County (N = 41, 7.2%), Dallas County (N = 24, 4.2%), and Tarrant County (N = 23, 4.1%) (Table A1 in the Online Supplement). The majority of respondents were female (N = 398, 75.5%), between the ages of 18 and 34 (N = 334, 59.0%) and had resided in Texas for more than 10 years (N = 232, 45.0%). Approximately three-quarters of respondents were employed either full-time (N = 198, 35.0%) or part-time (N = 112, 19.8%). In total, 13.0% (N = 56) of respondents characterized their health as fair, and 4.9% (N = 20) of respondents characterized their health as poor. More than two-thirds of the study population satisfied the criteria for potential caseness for anxiety based on the GAD-2 score (N = 392, 69.3%), and nearly all respondents satisfied the criteria for potential caseness for depression based on PHQ-2 scores (N = 405, 72%) (Table 1).

3.3. Sample characteristics by level of UOGD exposure

Respondents living in counties in the Permian Basin were more likely to be male (35.3% vs. 23.7%), more likely to be under the age of 55 (98.4% vs. 82.6%), and more likely to have at least a college degree (34.6% vs. 23.4%), but less likely to have resided in Texas for more than 10 years (36.6% vs. 45.6%). Respondents living in counties in the Permian Basin were also approximately twice as likely to be employed full-time as compared with respondents residing elsewhere in Texas (66.1% vs. 38.3%) and were more likely to characterize their health as excellent (33.9% vs. 24.5%). We observed a similar percentage of respondents who met the criteria for potential caseness for anxiety based on GAD-2 scores and for depression based on PHQ-2 scores in the Permian vs. elsewhere. EDS subscale scores were higher among respondents living in counties in the Permian Basin, particularly for the

Table 1
Demographic characteristics, health status, and Environmental Distress.[1]

	Overall (N = 566)	Permian Basin (N = 292)	Elsewhere (N = 274)
Gender – N (%)			
Female	398 (75.5)	189 (64.7)	209 (76.3)
Male	168 (24.5)	103 (35.3)	65 (23.7)
Age – N (%)			
18 – 24	156 (26.8)	83 (28.4)	73 (26.6)
25 – 34	178 (27.9)	103 (35.3)	74 (27.4)
35 – 44	114 (18.5)	64 (21.9)	50 (18.3)
45 – 54	53 (9.5)	27 (9.3)	26 (9.5)
55 – 64	45 (11.8)	11 (3.8)	34 (12.4)
65 +	20 (5.5)	4 (1.4)	16 (5.8)
Years Lived in Texas – N (%)			
Less than one year	63 (10.0)	36 (12.3)	27 (9.9)
One to five years	165 (26.4)	94 (32.2)	71 (25.9)
Five to 10 years	104 (18.6)	53 (18.2)	51 (18.6)
More than ten years	232 (45.0)	107 (36.6)	125 (45.6)
Missing	2 (0.4)	2 (0.7)	0 (0.0)
Education – N (%)			
Less than high school	27 (5.1)	13 (4.5)	14 (5.1)
High school or equivalent (i.	114 (30.6)	58 (19.9)	86 (31.4)
e., GED)	85 (13.1)	50 (17.1)	35 (12.8)
Associate degree	130 (24.2)	63 (21.6)	67 (24.5)
Some college, no degree	165 (24.2)	101 (34.6)	64 (23.4)
College or more			
Employment – N (%)			
Employed full-time	198 (35.0)	193 (66.1)	105 (38.3)
Employed part-time	112 (19.8)	50 (17.1)	62 (22.6)
Not employed	149 (26.3)	44 (15.1)	104 (38.3)
Missing	7 (0.8)	5 (1.7)	2 (0.7)
Health Status – N (%)			
Excellent	166 (25.1)	99 (33.9)	67 (24.5)
Very good	186 (31.0)	102 (34.9)	84 (30.7)
Good	138 (26.0)	66 (22.6)	72 (26.3)
Fair	56 (13.0)	19 (6.5)	37 (13.5)
Poor	20 (4.9)	6 (2.1)	14 (5.1)
Anxiety – N (%) [2]	392 (69.3)	203 (69.5)	189 (69.0)
Depression – N (%) [3]	405 (71.7)	203 (69.5)	202 (73.7)
Environmental Distress –			
Median (IQR) [4]	60.0 (50.0 –	61.0 (50.0 –	59.1 (49.1 –
Perceived Threat	69.1)	71.1)	65.2)
Felt Impact	48.3 (32.9 –	50.0 (38.8 –	43.5 (29.4 –
Solastalgia	61.2)	62.4)	60.0)
	60.8 (48.9 –	64.4 (53.3 –	60.0 (42.8 –
	77.8)	80.0)	77.8)

[1] We used weights to calculated percentages to account for over-sampling of respondents in the Permian Basin.
[2] We used the Generalized Anxiety Disorder-2 (GAD-2) to assess symptoms of anxiety. We identified individuals who satisfied the threshold for potential caseness for anxiety with GAD-2 score ≥ 3 where the maximum possible score is 8.
[3] We used the Patient Health Questionnaire-2 (PHQ-2) to assess symptoms of depression. We identified individuals who satisfied the threshold for potential caseness for depression with PHQ-2 score ≥ 2 where the maximum possible score is 8.
[4] Environmental distress subscale scores are summarized as percentages.

felt impact and solastalgia subscales. We note some spatial overlap of the three exposures of interest – Permian Basin; oil, gas, and injection wells; and ≥ *M* 3 earthquakes – across Texas counties (Fig. 1).

3.4. Responses to the environmental distress scale

We summarized responses to specific survey items included in the subscales for perceived threat, felt impact, and solastalgia. Perceived threat was greatest for disturbances such as foul-smelling air from industrial activity (N = 168, 27.7%); heavy vehicle movements (N = 188, 32.0%); and noise, pollution, and vibration from frequent trains, trucks, and manufacturing (N = 163, 28.2%) (Table A2 in the Online Appendix). With respect to felt impact, respondents tended to agree most strongly with statements regarding the implication of destruction of the natural environment for the future. These statements included: "I am disturbed that decisions about development activity here do not give higher priority to long-term land use for future generations" (N = 243, 39.9%) and "I am concerned that future generations will not be able to enjoy the natural environment" (N = 305, 52.4%) (Table A3 in the Online Appendix). Among questions regarding solastalgia, nearly half of respondents either agreed or strongly agreed that they were worried that aspects of the place that they valued – such as clean air and water or beautiful scenery – were being lost (N = 280, 47.1%) (Table A4 in the Online Appendix).

Overall, we noted patterns of responses wherein respondents from counties in the Permian Basin were consistently more likely to characterize their perceived threat of environmental issues as "extreme" or "strong" threats. Respondents in the Permian were also more likely to "agree" or "strongly agree" with various statements regarding felt impacts of environmental change in their area and solastalgia (Table A2–A4 in the Online Appendix). Less than 10% of responses were either missing or omitted (i.e., respondent selected "does not apply" as their response) for specific subscale items across all three EDS subscales.

3.5. Primary regression analysis results

For our primary analysis, we examined the association between our three county-level environmental exposures (any earthquakes ≥ *M* 3 versus none; ≥ 2,689 oil, gas, and injection wells versus < 2,689; living in the Permian Basin versus elsewhere) and each of the three EDS measures (perceived threat, felt impact, and solastalgia) in the study population overall and then separately for men and women. In the study population overall, we found limited evidence for an association between exposure to ≥*M 3* earthquakes or living in a county with ≥ 2,689 oil, gas, or injection wells and EDS subscale scores. EDS subscale scores were consistently higher – reflecting increased levels of environmental distress – among respondents living in counties that overlapped with the Permian Basin. This was particularly the case for perceived threat, where we observed a 2.75% increase (95% CI = −1.14, 6.65), and solastalgia, where we saw a 4.21% increase (95% CI = 0.03, 8.40). In our subgroup analysis of women, we also found that EDS subscale scores were higher among respondents in counties that overlapped the Permian

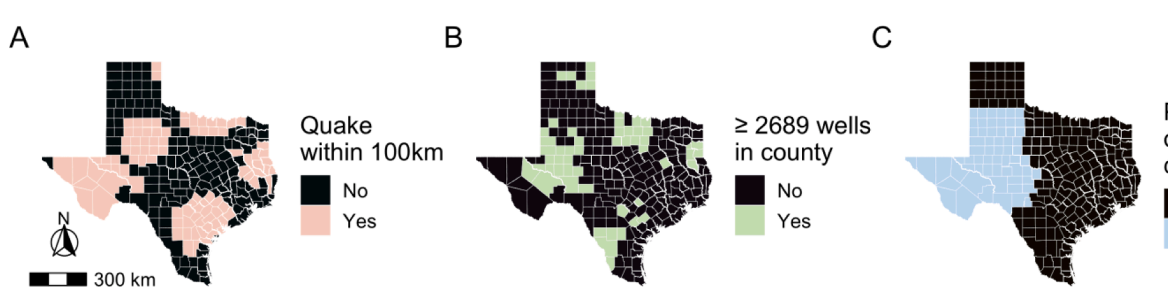


Fig. 1. County-level oil and natural gas exposures. From left to right, we depict whether (A) at least one earthquake of magnitude ≥ *M* 3 occurred between March 2018–March 2019; (B) counties in which there are at least 2,689 producing oil and gas and injection wells; and (C) counties within the Permian Basin.

Table 2
Multivariate analysis for percent difference in EDS scores associated with county-level exposures overall and by gender in Texas.[1,2,3]

	All Respondents (N = 566) β (95% CI)	Women (N = 398) β (95% CI)	Men (N = 168) β (95% CI)
Earthquakes			
Perceived Threat	−1.83 (−6.53, 2.87)	−1.76 (−6.97, 3.45)	−1.00 (−11.23, 9.23)
Felt Impact	0.76 (−3.50, 5.03)	1.37 (−3.01, 5.75)	0.31 (−10.50, 11.12)
Solastalgia	0.08 (−5.15, 5.30)	1.31 (−4.43, 7.05)	−1.41 (−13.09, 10.28)
≥ 2,689 Wells			
Perceived Threat	− 0.70 (−5.88, 4.49)	−0.05 (−5.56, 5.45)	− 4.22 (−16.29, 7.85)
Felt Impact	−0.69 (−5.35, 3.97)	−0.20 (−5.34, 4.93)	− 1.28 (−12.95, 10.40)
Solastalgia	2.12 (−3.62, 7.86)	4.77 (−1.88, 11.41)	− 6.39 (−16.86, 4.07)
Permian Basin			
Perceived Threat	2.75 (−1.14, 6.65)	4.08 (−0.21, 8.37)	−1.88 (−10.93, 7.17)
Felt Impact	0.94 (−2.72, 4.59)	2.06 (−1.96, 6.08)	−3.44 (−10.78, 3.90)
Solastalgia	4.21 (0.03, 8.40)	7.09 (2.44, 11.88)	−3.77 (−11.79, 4.25)

[1] We used linear regression to examine the difference in environmental distress subscale scores in respondents with and without county-level oil and natural gas exposure. All models were adjusted for categorical age (18 – 24, 25 – 34, 35 – 44, 45 – 54, 55 – 64, and 65 + years), and employment status (employed full-time, employed part-time, not employed). Overall model was additionally adjusted for gender (male, female).

[2] We created county-level indicator variables for environmental exposures including earthquakes (at least one earthquake $\geq M$ 3 versus none), oil, gas, or injection wells (≥ 2,689 wells versus < 2,689 wells), and whether county of residence overlapped with the Permian formation.

[3] Environmental distress subscale scores were standardized such that β coefficients correspond to the percent change in subscale score.

Basin for perceived threat (4.08% increase, 95% CI = −0.21, 8.37) and solastalgia (7.09% increase, 95% CI = 2.44, 11.88). Among men, all three county-level exposures appeared associated with decreased EDS subscale scores – reflecting decreased levels of environmental distress – although these findings were considerably less precise than our findings among women due to the smaller number of male respondents included in our analysis (Table 2).

3.6. Secondary regression analysis results

In our analysis of urban and rural counties, we noted several associations, almost all of which had wide confidence intervals due to the relatively small sample sizes within subgroups. Among urban residents, we found limited evidence for differences in EDS subscale scores among urban residents based on county-level earthquake exposure. Urban residents living in counties with ≥ 2,689 oil, gas, or injection wells had slightly decreased EDS subscale scores as compared to those living in counties with < 2,689 oil, gas, or injection wells but again estimates were imprecise. Among rural residents, earthquake exposure was associated with decreased EDS scores. Living in a rural county with ≥ 2,689 oil, gas, or injection wells appeared to be associated with modestly increased average subscale scores for perceived threat (2.50% increase, 95% CI = −7.14, 12.13) and felt impact (0.93% increase, 95% CI = −5.78, 7.63) as compared with respondents in counties with < 2,689 oil, gas, or injection wells. Notably, living in a rural county with ≥ 2,689 oil, gas, or injection wells was associated with a 9.58% increase in reported solastalgia (95% CI 0.22, 18.94). Among respondents in rural counties, average solastalgia scores were increased by 5.41% among those living in counties in Permian Basin as compared with respondents living in counties elsewhere (95% CI = −2.11, 12.94) (Table 3).

As an additional secondary analysis, we restricted the analysis to respondents living in counties in the Permian Basin. In this subset of survey respondents (N = 292), we found that exposure to at least one $\geq M$ 3 earthquake was associated with an increase in average perceived threat score by 4.69% (95% CI = 0.15, 9.23), although we found limited evidence for any association between exposure to $\geq M$ 3 earthquakes and either felt impact or solastalgia. Conversely, respondents in counties with ≥ 2,689 oil, gas, or injection wells had increased average scores for felt impact (2.11% increase, 95% CI = −3.70, 7.92) and solastalgia (3.83% increase, 95% CI = −2.84, 10.50), with limited evidence for an association between exposure to oil, gas, or injection wells and perceived threat scores (Fig. 2, Table A5 in the Online Appendix).

Table 3
Multivariate analysis for difference in EDS scores associated with county-level exposures for urban and rural residents.[1,2,3]

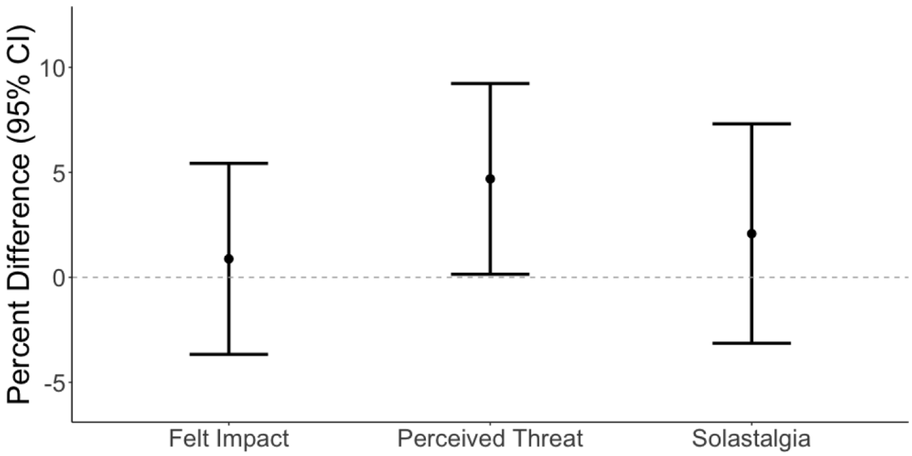
	All Respondents (N = 566) β (95% CI)	Urban (N = 340) [4] β (95% CI)	Rural (N = 226) [4] β (95% CI)
Earthquakes			
Perceived Threat	−1.83 (−6.53, 2.87)	−1.87 (−7.28, 3.54)	−5.29 (−14.38, 3.80)
Felt Impact	0.76 (−3.50, 5.03)	1.48 (−3.48, 6.43)	−3.21 (−11.43, 5.02)
Solastalgia	0.08 (−5.15, 5.30)	1.46 (−4.57, 7.50)	−6.27 (−16.14, 3.60)
≥ 2,689 Wells			
Perceived Threat	−0.70 (− 5.88, 4.49)	−1.65 (−7.81, 4.51)	2.50 (−7.14, 12.13)
Felt Impact	−0.69 (− 5.35, 3.97)	−1.37 (−6.93, 4.19)	0.93 (−5.78, 7.63)
Solastalgia	2.12 (− 3.62, 7.86)	−0.39 (−7.05, 6.27)	9.58 (0.22, 18.94)
Permian Basin			
Perceived Threat	2.75 (−1.14, 6.65)	1.72 (−3.28, 6.73)	−6.18, 9.77)
Felt Impact	0.94 (−2.72, 4.59)	−0.63 (−5.48, 4.22)	0.60 (3.10, 6.67)
Solastalgia	4.21 (0.03, 8.40)	0.49 (−5.13, 6.10)	5.41 (−2.11, 12.94)

[1] We used linear regression to examine the difference in environmental distress subscale scores in respondents with and without county-level oil and natural gas exposure. All models were adjusted for categorical age (18 – 24, 25 – 34, 35 – 44, 45 – 54, 55 – 64, and 65+ years), gender (male and female), and employment status (employed full-time, employed part-time, not employed).

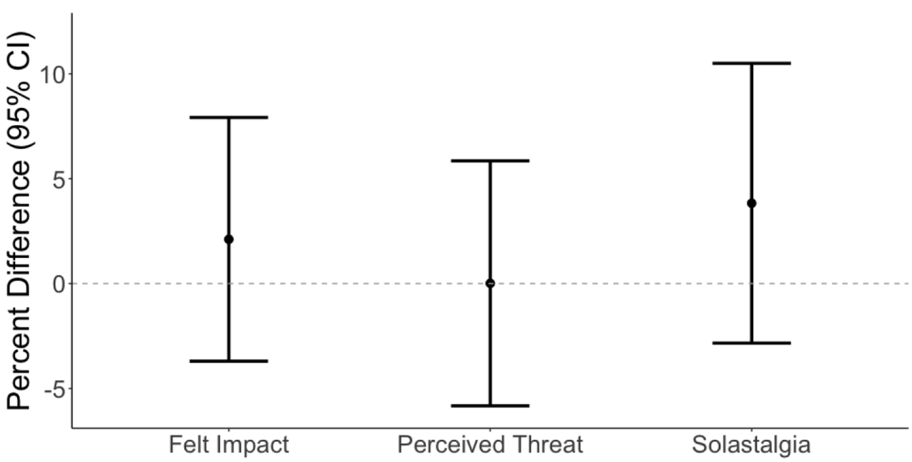
[2] We created three county-level indicator variables environmental exposures including earthquakes (at least one earthquake $\geq M$ 3 versus none), oil, gas, or injection wells (≥ 2,689 wells versus < 2,689 wells), and whether county of residence was in the Permian Basin.

[3] Environmental distress subscale scores were standardized such that β coefficients correspond to the percent change in subscale score.

[4] Respondents were classified as residing in urban or rural counties based on urban influence codes (UIC).



PANEL A: ≥ *M* 3 Earthquakes



PANEL B: Oil, Gas, or Injection Wells

Fig. 2. Multivariate analysis for difference in environmental distress subscale scores associated with county-level exposures among respondents in counties in the Permian Basin (N = 292). We used linear regression to examine the difference in environmental distress subscale scores in respondents with and without county-level oil and natural gas exposure. All models were adjusted for categorical age (18 – 24, 25 – 34, 35 – 44, 45 – 54, 55 – 64, and 65+ years), gender (male and female), and employment status (employed full-time, employed part-time, not employed). We created three county-level indicator variables environmental exposures for whether respondents lived in a county that experienced at least one earthquake ≥ *M* 3 between March 2018 – March 2019 (Panel A) and with at least 2,689 oil, gas, or injection wells (Panel B).

3.7. Sensitivity analyses

As a sensitivity analysis, we created alternative specifications of county-level exposures to earthquakes and oil, gas, or injection wells. Overall, we found a U-shape for earthquake exposure where, compared to people living in counties with no earthquakes, those in counties with one earthquake ≥ *M 3* showed a decrease in EDS subscale scores, but those in counties with more than one ≥ *M 3* earthquake had increased subscale scores. For our categorical analysis of oil, gas, or injection wells, we found consistent decreases in EDS subscale scores in the second and third tertiles of exposure versus the first. However, estimates from categorical analyses are notably imprecise for both the earthquake and wells exposure (Table A6 in the Online Appendix). In models with continuous exposure variables, we observed small increases in environmental distress subscale scores associated with additional ≥ *M* 3 earthquakes in the study population overall and among urban residents. We found no evidence of change in subscale scores associated with additional oil and gas and injection wells at the county level (Table A7 in the Online Appendix). Finally, we repeated our main analysis excluding 63 individuals who had resided in Texas for less than one year at the time they completed the survey. Estimates for the association between measures of UOGD and EDS scores were similar for the study population overall, and the pattern of findings among men and women was consistent with our primary analysis (Table A8 in the Online Appendix).

4. Discussion

In the Spring of 2019, we conducted a cross-sectional, online survey of 566 Texas residents to examine the relationship between county-level exposure to UOGD – as measured based on the occurrence of any ≥ *M* 3 earthquakes; the number of producing oil and gas and injection wells; and residence in a county in the Permian Basin – and environmental distress. Most studies of the community repercussions of UOGD have taken place in Colorado and Pennsylvania; to our knowledge no other studies to date have examined the implications of intensive oil and natural gas extraction for residents of West Texas. We know of no studies that have used the EDS to examine community perceptions of the implications of UOGD.

4.1. Higher EDS scores among those living in the Permian Basin

Given the newer and intensive nature of oil and gas extraction in West Texas, we specifically examined the subset of respondents who resided in counties in the Permian Basin. Among these respondents, we found more consistent evidence of increased environmental distress associated both earthquakes and county-level oil and gas injection wells as compared with respondents living elsewhere. Our findings further suggest important subgroup differences, as levels of environmental distress differed between men and women and between respondents living in urban versus rural counties, with more distress among women and rural dwellers. Past research consistently identifies increased levels of psychiatric distress, depression, and anxiety and decreased quality of life as consequences of local exposure to UOGD [22–29,42,88]. In a recent study by Mayer and colleagues conducted in three Colorado communities, individuals were asked to rate satisfaction with their health using response categories from "very dissatisfied" to "very satisfied" and those living in communities that host UOGD were more likely to be "dissatisfied" or "very dissatisfied" with their health [88].

4.2. Greater environmental distress among female respondents

Our study population was predominantly female, with some key differences in educational attainment (more education) and levels of employment (more employment) among respondents living in Permian-adjacent counties versus elsewhere. Notably, scores from the PHQ-2 and GAD-2 suggested relatively high levels of symptoms of both depression and anxiety in this study population as compared with the general population [89]. In the study population overall, we found mixed evidence regarding the implications of UOGD for environmental distress. Among women, we found more consistent evidence that increased levels of UOGD exposure were associated with higher levels of environmental distress. This finding is consistent with past research, which indicates that women are more likely to experience environmental distress [55,62,67,86]. Increased environmental distress was particularly evident for women living in counties in the Permian Basin, whose average scores for perceived threat, felt impact, and solastalgia were consistently higher than those for women living elsewhere in the state of Texas.

Limited prior work has reported stronger feelings of solastalgia in women versus men, but future work should continue to consider such gender differences [77].

Among men, we found no consistent evidence of any of the three county-level UOGD exposures with increased levels of environmental distress. It is possible that more intensive county-level UOGD is associated with increased economic opportunity for men. According to labor force statistics for 2019, the majority (79.8%) of Americans employed in oil and gas extraction were men [90], and it is possible that individuals who benefit economically from UOGD are more accepting of or more likely to overlook subsequent degradation of their ambient environment. Further, men have previously reported higher perceived benefits [91] and lower perceived risks of UOGD compared to women [16]. However, we note that a relatively small number of men completed our survey, making estimates much more imprecise for men than for women. Nevertheless, the gender differences in environmental distress scores we found warrant further assessment in larger samples of individuals exposed to regional UOGD where employment in oil and gas extraction can be ascertained.

4.3. Urban-rural differences in EDS response

We found stronger relationships between county-level well density and residence in the Permian Basin and the EDS sub-scales among rural versus urban dwellers. Most notably, we found that living in a county with $\geq$ 2,689 oil, gas, or injection wells was associated with a 9% increase in reported solastalgia in our subgroup analysis of rural residents. Prior literature suggests urban/rural differences in the calculation of risks versus benefits from UOGD. Individuals in rural areas may depend more heavily on the land for their livelihood, meaning reliance on oil and gas revenues may increase their willingness to accept risks [71,92]. Rural dwellers, however, may also have a stronger attachment to place, identities and livelihoods tied up in environmental quality [93], possibly leading to more environmental distress – and in particular more pronounced feelings of solastalgia – due to UOGD. For example, rural versus city respondents reported more intense transportation problems related to congestion and motor vehicle crashes [94]. This "homesickness" while at home in a place changed by UOGD has been reported previously [26,28]. We note again that our subgroup analyses relied on relatively small numbers and are therefore inherently imprecise. Differences between residents in rural and urban counties suggested by our findings therefore warrant further consideration in a larger study population.

4.4. Application of the EDS in other contexts

While the present study was a cross-sectional survey of respondents in West Texas, the EDS can measure the evolution of participant responses to environmental change over time and across a wide range of environmental disruptions. For example, Cunsolo Willox and colleagues administered the EDS within an Inuit population to evaluate effects of climate change on environmental distress over time [95]. The study population reported decreased ice and snow quality, which in turn affected their ability to hunt and forage, reduced place attachment, and possibly increased consumption of processed foods and rates of diabetes. In addition, similar to reports from individuals living near UOGD sites in the U.S. and Australia [26,59,96], the Inuit reported feelings of helplessness and frustration associated with observed environmental change over time. In Indonesia, individuals exposed to volcanic eruptions scored higher on the three EDS subscales included in our study: solastalgia, perceived threat, and felt impact. In particular, differences in solastalgia emerged among individuals living in communities more severely affected, reporting loss of sense of quiet and threats to farming. The relationship between UOGD and farming is complicated. Farmers and ranchers use oil to run their operations [60] and mineral rights payments may help sustain the farm [71,92]. Farmers may agree to lease their farms for UOGD only if "the price was right" while simultaneously describing concerns about hazardous spills and cropland degradation [24]. Others perceive that UOGD is destroying their farmland and way of life but see no way to collectively organize and fight back [97].

4.5. Question-specific responses to the EDS in the present study

For the present study, the greatest perceived threats to the environment were disturbances such as foul-smelling air from industrial activity, heavy vehicle movements, and noise; pollution and vibration from frequent trains, trucks, and manufacturing. Many respondents in our sample agreed with statements about the possible impact of environmental change for future generations, including being upset with destruction of heritage buildings and landmarks due to industrial development, and disturbance that decisions about development activity did not give higher priority to long-term land use for future generations. Among questions regarding solastalgia, nearly half of respondents either agreed or strongly agreed that they were worried that aspects of the place that they valued – such as clean air and water or beautiful scenery – were being lost. In the Permian, oil and gas development are more disruptive to local environments, but also play a more central role in local economy. Among our respondents, respondents in the Permian were consistently more likely to perceive threat of various environmental issues as "extreme" or "strong" compared with those outside of the Permian. They were also more likely to "strongly agree" or "agree" with statements regarding the possible impacts of environmental change and solastalgia. These results suggest that place-based "psychoterratic" concepts, such as solastalgia [78], may be particularly salient to understand links between UOGD and mental health. For example, a recent cross-sectional study in the Marcellus shale found that those holding more favorable views about where they lived, i.e., higher place satisfaction, reported less negative environmental and more favorable economic beliefs about UOGD [98].

4.6. Environmental degradation due to UOGD

The extent of environmental degradation associated with UOGD has been detailed extensively in the literature. For example, UOGD can compromise the quality of the ambient environment through pollution of the air, water, and soil; through noise and light pollution; and via induced or manmade earthquakes [1]. In Texas, oil and gas production has resulted increasingly frequent spills over time. In 2009, one spill occurred for roughly every 235 producing wells, whereas by 2015, one spill occurred for roughly every 130 wells [99]. The majority of these spills resulted in a loss of crude oil, which can lead to environmental degradation [100,101]. UOGD also affects air quality. For example, Hildebrand and colleagues noted elevated levels of ambient benzene, toluene, and xylene in the Eagle Ford shale region of Texas, most likely related to equipment inefficiencies [102]. However, increased natural gas production and consequent reduced use of coal for electricity generation appears to improve air quality (particulate matter and ozone levels) in Texas [103].

Further, UOGD-related truck traffic can damage roads, increase traffic, and increase motor vehicle crashes. Seventy-three percent of surveyed city and county officials in the Eagle Ford Shale region of Texas reported increased motor vehicle crashes related to increased UOGD in the region [94]. The Texas Department of Transportation attributed a 27% increase in roadway fatalities to UOGD in the Permian Basin [104]. In a study conducted by McElroy and colleagues in Colorado, residents near UOGD have also made the explicit link between increased truck traffic and worse air quality due to increased truck exhaust [105].

Our finding that county-level exposure to UOGD is associated with environmental distress – particularly in the Permian Basin where oil and gas extraction is most intensive – is consistent with the evidence-to-date regarding substantial degradation to the ambient environment and declines in quality of place associated with UOGD. Moreover, there is substantial evidence that measures of environmental quality such as perceived restorativeness, biodiversity, and naturalness are associated with improved health and psychological well-being [106,107]. For example, in Australia, Lai and colleagues found that a negative perception of UOGD on resources was associated with negative psychological states [108]. The link between UOGD and environmental distress we observe in the present study may reflect underlying psychiatric distress related to environmental disruption and degradation more generally.

4.7. Change in the social environmental due to UOGD

Beyond the direct implications for the health of the ambient environment, UOGD can affect the social quality of place. Prior research documents increased crime [109] and sexually transmitted infection rates [110,111], likely due to an influx of workers. We note that there are likely positive social implications of UOGD. Indeed, the positive and negative effects of UOGD are mirrored by reactions from community members. Economic gains come mainly in the form of increased local tax revenue and employment [71,109,112]. For example, related to injection-induced earthquakes in Oklahoma, the majority of study participants described them as unsettling and possibly costly, but one participant described them as "toothless tigers" that have little effect on everyday life, and several indicated that while they understood the cause of the quakes, they did not want increased regulation that could stymie economic gains [92].

4.8. Multi-scalar approach to UOGD regulation

While we used place-based measures to capture local response to environmental change, state, national and global factors drive UOGD; in 2019, the U.S. became a net-energy exporter for the first time since 1952 [113]. High energy demand and supporting policies initiated at the national level can render local places like the Permian Basin energy sacrifice zones [114]. For example, the 2005 Energy Policy Act exempted UOGD from numerous federal environmental regulations, including the Clean Water Act [115]. Our study connects the larger forces driving UOGD to the perceived environmental threats, felt impact, and solastalgia experienced by individuals at the local level. Healy and colleagues have introduced the term *embodied energy injustices* to describe the upstream and downstream externalities associated with energy production [115]. As local communities bear the brunt of externalities related to extraction and processing, involving them in the decision-making process [16,97] through actions such a Memorandums of Understanding, may improve distributional and procedural justice [116], however, it can also reduce public trust in industry. In the U.S., regulatory authority of UOGD lies at the state level, but legislators can use studies such as ours to inform themselves about local effects of UOGD and create policies accordingly. While local communities debate individual well locations, operators can take advantage of directional drilling to consider development city-wide [117]. And because demand for fossil fuels and their repercussions (i.e., climate change) occurs on a global scale, we will require transboundary energy justice efforts to adequately regulate local UOGD.

4.9. Limitations

Although our study is the first we know of to examine the implications of UOGD in West Texas, we were limited by a relatively small sample size. This precluded us from conducting a range of stratified analyses of interest, including by employment and socioeconomic status. Interpretation of the subgroup analyses we did conduct is limited by a lack of statistical power, as evidenced by relatively wide confidence intervals in the analysis restricted to men and to residents in urban or rural counties only. Prior studies have predominantly relied on convenience samples or samples comprised of individuals already reporting their concern about UOGD [22,25,60,71,105,118,119]. By contrast, we used a third-party survey firm to randomly sample participants with oversampling of respondents in the Permian Basin to ensure adequate representation for our online survey.

Second, we included all producing oil, gas, and injection wells, not just unconventional wells. While this method fully characterized exposure to oil and gas development in Texas, it limited our ability to specifically evaluate associations between UOGD and environmental distress. However, unconventional wells make up the majority of new development, particularly in the Permian Basin. We also only measured county of residence and were therefore unable to more precisely characterize respondent's proximity to UOGD. We additionally lacked additional individual characteristics – such as occupation and industry and household composition – that could further contextualize our study findings. For example, individuals employed in oil and gas extraction may experience relatively less distress related to environmental degradation if their livelihood is predicated upon these activities. We observed that many respondents agreed or strongly agreed with statements regarding the destruction of the environment for future generations, which raises in the interesting possibility that individuals with children or grandchildren may be more sensitive to destruction of the ambient environment. Approximately 8.9% of responses were missing or omitted for specific subscale items. However, we find no evidence of systematic differences in the extent of missingness among respondents in Permian and non-Permian counties (8.8 vs 9.0% of responses, respectively). We therefore anticipate that the effect of missing responses would have been to attenuate the results presented here.

Symptoms of anxiety and depression as measured by the GAD-2 and PHQ-2, respectively, were notably higher in our study population than estimated for the general population. Whereas more than two-thirds of respondents for the present study scored high enough on both the GAD-2 and PHQ-2 to satisfy "caseness" for anxiety or depression, use of the PHQ-2 in primary care populations suggests a prevalence of depression closer to 12% [89]. The apparently high prevalence of psychiatric distress in our study population is important to consider in interpretation of our findings on environmental distress, although GAD-2 and PHQ-2 are both relatively crude measures of psychiatric symptoms.

Our analytic approach assumes that observations are independent of one another. This assumption could plausibly be violated if individuals living in close proximity to one another can influence each other's attitudes and perspectives towards local pollution and UOGD. However, given the relatively modest sample size and the distribution of respondents throughout the state of Texas, we feel it is unlikely that individuals' outcomes are dependent. Interpretation of our results as causal effects of UOGD on residents' levels of environmental distress would require an additional set of assumptions including exchangeability between exposed and non-exposed individuals [120]. Given our limited sample size and a limited set of adjustment variables – notably the absence of data on household income, race/ethnicity, or additional health-related variables – we feel our estimates are more appropriately interpreted as summary measures of the association between UOGD exposure and levels of environmental distress.

Another limitation of the present study is its cross-sectional nature. Whereas other studies have used the EDS to measure changes in levels of environmental distress over time, we did not assess temporal changes in UOGD exposures, but rather included measures of earthquakes from February 2018–February 2019, the count of producing oil and gas injection wells, and residence in the Permian Basin. Results may have differed if we assessed changes in UOGD factors related to environmental distress because individuals may habituate to exposures, like noise pollution [121]. Individuals particularly bothered by UOGD may choose to move to a new location, possibly leaving those less-opposed or -affected living closer to UOGD. Further, owning mineral rights may lower risk perception [16] and increase economic gains and exposure, although not in all cases. In Denton, Texas, >60% of mineral value was owned by individuals living outside the city [122]. We note however, that we have no concerns regarding the directionality of exposure and outcome in our cross-sectional survey as it is unlikely that respondents' levels of environmental distress would lead to changes in county-level UOGD activity. Finally, the EDS queries participants about past and current feelings and environmental changes. Recent work suggests that individuals make the link between UOGD and climate change, express concern about the technology impeding uptake of renewables, and worry about the environment left for future generations [123]. Future work should address this longer time-scale environmental distress.

5. Conclusion

We conducted a cross-sectional survey focused on the implications of intensive oil and gas extraction for environmental distress in West Texas. Our study is the first to focus on community attitudes towards UOGD in West Texas, where UOGD has recently accelerated. Results suggest meaningful differences in population subgroups with the strongest associations between county-level UOGD exposure and among respondents in the Permian Basin where UOGD is most intensive. These findings are consistent with past research, which notes feelings of distress and anxiety related to environmental degradation and underscores the importance of considering population subgroups that may be more susceptible to feelings of environmental distress in response to perceived environmental degradation. Collectively, our study and the literature on mental health and UOGD to date suggest that oil and gas development regulation promulgated at the federal, state, and local level should consider the mental health and wellbeing of local residents in cost-benefit analyses, in addition to their physical health. Our work motivates further examination of the implications of UOGD for environmental distress and the importance of individual-level characteristics such as gender, occupation, and county of residence. Such local, place-based studies should be factored into scholarship summarizing embodied energy injustices and when considering energy regulation on scales from local to global.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.erss.2020.101798.

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