HEI STATEMENT

Synopsis of Research Report 242

Long-Term Trends in Air Quality in Unconventional Oil and Gas Development Regions in the United States

BACKGROUND

Over the past two decades, unconventional oil and gas development (UOGD)* has led to a significant increase in oil and gas production across the United States.

Emissions associated with UOGD can affect local and regional air quality. UOGD processes emit a mix of pollutants that are relevant to health, including methane, nonmethane hydrocarbons (such as ethane, propane, and benzene), and nitrogen oxides (NO_x). These air pollutants may affect air quality directly (e.g., benzene is a hazardous air pollutant) or by reacting with other air pollutants to form, for example, fine particles and ozone in the lower atmosphere (e.g., nonmethane hydrocarbons and NO_x may react to form ozone). Assessing exposure to such pollutants is difficult because the amount of pollution in the air depends on several factors that often vary by local conditions, such as proximity, topography, or meteorological conditions.

Simultaneously, operations and regulation have evolved alongside UOGD expansion. Many changes in regulations and operations have been designed to address concerns over potential population-level air pollution exposures and associated health effects. Nonetheless, questions remain regarding the effect of air pollutants associated with UOGD on air quality, how exposures vary among populations, and whether evolving industry practice, regulation, and governance, and other local and regional factors have indeed led to the intended changes in emissions.

Studies have now begun using historical air quality monitoring data to assess trends in air quality (and potential population exposures and links to source emissions) in UOGD regions in the United States.

What This Study Adds

- This study evaluates long-term air quality trends across UOGD regions in the United States, primarily in Texas (1997–2023) and Colorado (2008–2024).
- The investigators compiled publicly available data on methane, nonmethane hydrocarbons, and NO_x concentrations from air quality monitoring stations in each state. They then evaluated long-term air quality trends associated with UOGD in both states using statistical techniques for analyzing time series data.
- Long-term trends in nonmethane hydrocarbon and NO_x concentrations increased and then stabilized over time in Texas, generally correlating with regional UOGD production volumes in the state.
- In contrast, long-term trends in nonmethane hydrocarbon and NO_x concentrations declined over time in Colorado, and methane growth was slower than the global background, while UOGD production continued to increase.
- These findings suggest that emissions levels near UOGD are likely declining in Colorado but not noticeably in Texas.
- This study demonstrated differences in long-term trends in air pollutant concentrations near UOGD in Texas and Colorado that likely reflect differences in a mix of local and regional factors in each state.

Drs. Gunnar W. Schade (Texas A&M University) and Detlev Helmig (Boulder AIR) and colleagues sought to evaluate long-term trends in air quality across two large UOGD regions with different regulatory frameworks (Texas and Colorado) and to assess whether emissions associated with UOGD might be changing over time. Their study was funded through HEI Energy's

This Statement, prepared by HEI Energy, summarizes a research project funded by HEI Energy and conducted by co-principal investigators Gunnar W. Schade (Texas A&M University) and Detlev Helmig (Boulder AIR) and their colleagues. Research Report 242 contains the detailed Investigators' Report and a Commentary on the study prepared by the HEI Energy Review Committee.

* A list of abbreviations and other terms appears at the end of Research Report 242.

Request for Qualifications (RFQ) E23-1: Trends in Air Quality and Community Exposures Associated with Oil and Gas Development.

APPROACH

The overarching objective of their study was to use air quality data collected in UOGD regions in Texas and Colorado (**Statement Figure**) to determine any identifiable trends in emissions of nonmethane hydrocarbons and NO_x (Aim 1). The investigators also used satellite-derived data to assess trends in formaldehyde vertical column densities, which can be used as a marker for nonmethane hydrocarbons, near UOGD in Texas and New Mexico (Aim 2).

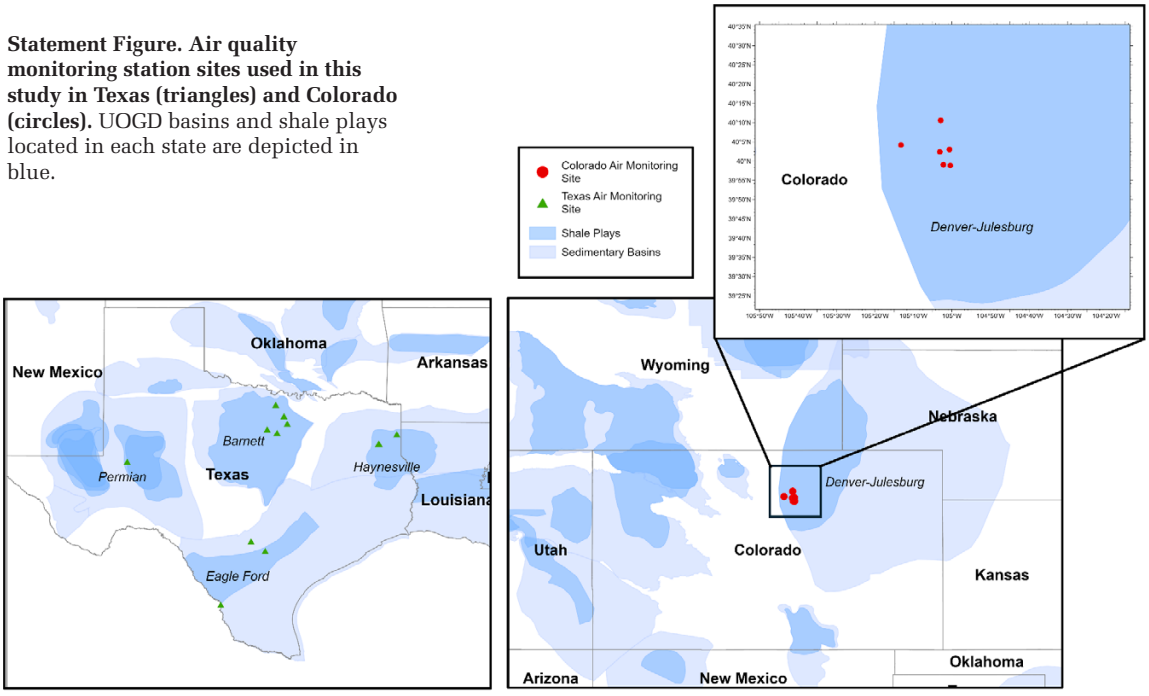
For Aim 1, the investigators gathered data on ethane, propane, benzene, and NO_x, known emissions from UOGD activities, from air quality monitoring stations located near the Barnett Shale, Eagle Ford Shale, Haynesville Shale, and the eastern Permian Basin in Texas. Helmig and colleagues collected data on the same pollutants, as well as methane, from air quality monitoring stations near the Denver–Julesburg Basin in Colorado. The data spanned the 1997–2023 period for Texas and 2008–2024 for Colorado. The differences in study times were the result of data availability. For Texas data, investigators also assessed correlations of UOGD production volumes with long-term trends in air pollutant concentrations in each study basin.

The investigators then used statistical methods for analyzing time series data (referred to as trend analysis) to evaluate trends in air pollutant concentrations over time. They used separate statistical techniques for the Texas (fitting natural cubic spline curves) versus Colorado (NOAA's FFT curve-fitting tool) analysis. To assess whether the use of two different statistical techniques notably affected the long-term air quality trends found in both states, the investigators qualitatively compared the long-term trends found for ethane from data for one site in Texas and one site in Colorado.

For Aim 2, the investigators obtained satellite-derived data on atmospheric formaldehyde vertical column densities from 2004 to 2022 across the Permian Basin, which spans both Texas and New Mexico. They averaged the data across space and time to generate regional monthly averages. They then conducted a trend analysis to evaluate changes in formaldehyde vertical column densities over time.

KEY RESULTS

The investigators found that, in general, long-term trends in nonmethane hydrocarbon and NO_x concentrations across air quality monitoring sites in UOGD regions of Texas increased during the years of production growth in each area, which then stabilized or declined over time. Those trends largely correlated with UOGD production volumes in the different



Statement Figure. Air quality monitoring station sites used in this study in Texas (triangles) and Colorado (circles). UOGD basins and shale plays located in each state are depicted in blue.

regions. For example, trends in benzene concentrations at one air quality monitoring site in the Permian Basin demonstrated a correlation of 0.82 with gas production volumes. At a different site in the Barnett Basin, trends in benzene concentrations showed a correlation of 0.91 with gas production volumes.

In contrast, Helmig and colleagues found that nonmethane hydrocarbon and NO_x concentrations generally exhibited decreasing long-term trends in Colorado, despite increasing UOGD production in the state. For example, slopes of long-term trend lines (indicating the rate of change) in ethane and propane demonstrated concentration decreases ranging from −0.2 to −0.8 ppb per year across air quality monitoring sites. They additionally found elevated concentrations and an upward trend in methane across sites in Colorado. This trend was smaller in magnitude when compared with methane data from a more remote reference location in North America, indicating that the rate of atmospheric methane accumulation in Colorado is slower than in background air, which the investigators attribute to a declining contribution of methane from the oil and gas sector.

In comparing long-term trend curves from ethane data at one site in each state, the investigators noted no major differences between the long-term trend curves that were found using two different statistical techniques.

In assessing long-term trends in formaldehyde vertical column densities as a proxy for nonmethane hydrocarbon emissions in the Permian basin, the investigators found a small, increasing trend until 2020 that coincided with increasing UOGD in this basin. However, they reported slightly decreasing concentrations throughout 2021 and 2022, which diverged from continued increases in UOGD during those years, though the investigators note uncertainty in the results reported due to the aging of the satellite instrument, leading to increased error bands on the formaldehyde measurements.

INTERPRETATION AND CONCLUSIONS

The investigators found that long-term trends in air pollutant concentrations decreased over time in Colorado despite increased UOGD production volumes, whereas trends in air pollutant concentrations generally correlated with UOGD production in Texas. The investigators indicated that their findings suggested that emissions per quantity of oil and gas produced near UOGD in Colorado were likely declining, but had not improved in Texas. They also suggested that these findings may be driven by differences in regulatory frameworks in each state, noting that Texas relies on federal regulation while Colorado has state-specific measures, but they did not conduct formal analyses to assess such conclusions. The investigators could not draw strong conclusions that were based on the long-term trends in formaldehyde in the Permian Basin, given the uncertainties associated with the data and subsequent observed trends.

In its independent review of the study, the HEI Energy Review Committee identified as a key strength of this work the comparison of long-term trends in air pollutants associated with UOGD in Colorado and Texas, each with varying local and regional contexts and different regulatory frameworks. The Committee also highlighted the importance of evaluating ambient air pollutant concentrations using long historical records of air quality data from multiple air quality monitoring sites, which was an improvement from prior research.

The observed differences in long-term trends in air quality in UOGD regions in both states and their relationship to UOGD production volumes were instructive, indicating that some UOGD operations were able to reduce emissions while simultaneously increasing production. However, the Committee noted that the investigators' interpretation of their findings seemed to overemphasize the influence of differences in regulatory frameworks in each state, given that no formal analysis was done.

The Committee appreciated the value of comparing long-term ethane air quality trends at a single site in each state. However, it questioned whether the use of two different statistical methods may have influenced the findings between states, particularly given the lack of a comprehensive quantitative comparison of the methods. Although overall differences in trends between the approaches were minor, the rationale for using two methods was not clearly justified, leading the Committee to question the potential effect of method choice on the results.

In addition, the Committee appreciated the use of long-term satellite-derived records of formaldehyde vertical column density. However, it was determined that this analysis of long-term formaldehyde trends in the Permian Basin did not contribute strongly to the overall study given the many limitations associated with the satellite-derived data.

In summary, this study contributed to our knowledge about long-term trends in air quality near UOGD in Texas and Colorado. It demonstrated that long-term trends in ethane, propane, benzene, and NO_x near UOGD basins differed between these two large oil and gas regions. This work enhances previous research on long-term air quality trends near UOGD by analyzing a long historical record of air quality monitoring data

among multiple sites in different states. The Committee generally agreed with the reported results, although it underscored that the results likely reflect differences in a combination of local and regional factors in each state and emphasized that the unique effect of regulation remains difficult to disentangle from many other factors.