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Dual Impact of Wildfire Smoke in Peoria, AZ: Environmental and Economic Implications

INTRODUCTION

Wildfires have become an increasingly urgent environmental and public health crisis, with their frequency and severity escalating due to climate change (Thompson and Calkin 2011). These events are no longer confined to remote wilderness areas, as wildfire smoke spreads across communities, significantly impacting air quality and public health. In recent years, Peoria, AZ, has faced growing levels of wildfire smoke, resulting in deteriorating air quality and posing serious health risks to its residents. Part 1 of this analysis highlighted the magnitude of this challenge, revealing the significant threat that wildfire smoke presents to public health in Peoria (EPA "Wildland Fire Research: Health Effects Research").

The implications of wildfire smoke extend beyond health concerns. Smoke disrupts daily life and can have profound economic consequences, particularly for local businesses and workers in key industries such as healthcare, retail, and construction. These disruptions include lost productivity, increased worker absences, and operational challenges, all which strain Peoria's economic resilience. Despite these clear risks, the economic impact of wildfire smoke in Peoria remains largely unquantified. This lack of actionable data leaves policymakers and businesses without a clear understanding of how to address the dual challenges of public health and economic stability.

This project seeks to bridge this critical gap by integrating environmental and economic analyses to provide a holistic understanding of wildfire smoke's impact on Peoria. Specifically, the study focuses on two key questions:

1. Environmental Impact: How does wildfire smoke affect air quality in Peoria, and can this impact be quantified using historical data?
2. Economic Impact: How does wildfire smoke affect local companies, and can these impacts be predicted to help stakeholders prepare for future challenges?

By addressing these questions, the study aims to provide Peoria's leadership with data-driven projections of future vulnerabilities related to wildfire smoke. These insights are intended to guide resource allocation, the development of contingency plans, and policy interventions to protect both public health and the local economy. Ultimately, this approach highlights the connection between environmental and economic challenges, emphasizing the importance of informed, data-driven decision-making to mitigate the consequences of wildfire smoke.

Background and Related Work

The increasing frequency and severity of wildfires have prompted extensive research into their environmental, health, and economic impacts. Numerous studies have established that wildfire smoke significantly degrades air quality, leading to adverse health outcomes such as respiratory and cardiovascular issues and increased mortality rates. Research by the U.S. Environmental Protection Agency (EPA) has emphasized the risks associated with fine particulate matter (PM2.5), a key component of wildfire smoke. These particles can penetrate deep into the lungs and bloodstream, exacerbating conditions like asthma, chronic obstructive pulmonary disease (COPD), and heart disease (EPA, "Wildland Fire Research: Health Effects Research"). The EPA's WF-ASPIRE initiative further underscores the disproportionate burden of these health risks on vulnerable populations, including children, the elderly, and individuals with preexisting respiratory conditions (EPA, "WF-ASPIRE").

Beyond health implications, recent studies have begun quantifying the economic repercussions of wildfire-induced air pollution. A working paper by Borgschulte et al. (2022) from the National Bureau of Economic Research (NBER) revealed that each additional day of smoke exposure reduces quarterly earnings by approximately 0.1%. The study attributes these losses to a combination of employment reductions and labor force exits, accounting for 13% of the overall decline in earnings. These findings highlight the significant economic burden that wildfires impose on communities, particularly those reliant on outdoor labor or physical operations.

However, existing research often focuses on national or regional scales, leaving localized impacts underexplored. In the context of Peoria, AZ, the city's proximity to wildfire-prone areas makes it particularly vulnerable to smoke-related air quality degradation. While Peoria residents face heightened health risks, the economic ramifications for local businesses remain poorly quantified. This lack of localized data impedes effective policymaking and resilience planning.

To address these gaps, this project builds upon methodologies and datasets from prior research. Geospatial analyses of wildfire proximity were informed by Dr. David W. McDonald's Wildfire Proximity Computation Example, which provided key techniques for calculating distances and filtering fires based on relevance. Dr. McDonald's EPA Air Quality System API Example offered practical guidance for structuring AQI data to validate smoke impact estimates. Additionally, insights from the Alpha Vantage Stock Data API enabled the integration of economic data, facilitating the analysis of smoke-related disruptions to local businesses (McDonald, "Wildfire Proximity Computation Example"; McDonald, "US EPA Air Quality System API Example").

This study adapts and extends these methodologies to Peoria's unique context, integrating historical wildfire data, air quality measurements, and economic indicators. By combining geospatial analysis with machine learning models, the research aims to quantify both the environmental and economic impacts of wildfire smoke, bridging the gap between national studies and localized, actionable insights. In doing so, the study contributes to a growing body of literature emphasizing the connection of environmental, health, and economic systems, while addressing the urgent need for community-specific data to inform proactive interventions.

METHODOLOGY

To quantify wildfire smoke's impact on Peoria, geospatial methods were used to calculate the proximity of wildfire perimeters to the city. Inspired by Dr. David W. McDonald's *Wildfire Proximity Computation Example*, the Pyproj library was utilized to compute geodetic distances for all recorded fires from the USGS dataset. Only fires occurring during the fire season (May 1 to October 31) and within a 650-mile radius of Peoria were included. This threshold was informed by prior research indicating that significant smoke effects are generally confined to this range (McDonald, *Wildfire Proximity Computation Example*).

The smoke impact estimate was designed to prioritize fires that were both large on acreage and close in proximity to Peoria. The intuition behind the metric reflects the understanding that smoke density diminishes with distance and that larger fires contribute to more significant smoke emissions. The formula used was Smoke Impact $= \frac{\text{Acres Burned}}{\text{Distance to Peoria}^2}$.

This metric integrates fire size and proximity, reflecting the inverse-square relationship between smoke intensity and distance. Larger fires closer to Peoria were weighed more heavily, as they are likely to contribute more significantly to air quality degradation. This formula aligns with existing geospatial filtering methods and was validated against Air Quality Index (AQI) data from the EPA.

To evaluate the validity of the smoke impact estimates, historical AQI data for pollutants such as PM2.5 and ozone were retrieved using the EPA's AQS API. Peaks in smoke impact metrics were compared with corresponding AQI spikes during wildfire seasons to assess the strength of the relationship. The EPA's API documentation and examples by Dr. McDonald guided the handling of data gaps, bounding-box searches, and structuring for efficient analysis (McDonald, *US EPA Air Quality System API Example*).

The economic analysis extended the environmental metrics to examine their influence on Peoria-based businesses. Stock performance was chosen as a proxy for economic health, focusing on companies headquartered in Maricopa County. Historical monthly stock data were retrieved using the Alpha Vantage API, while the S&P 500 index served as a baseline to isolate local trends (Alpha Vantage, *Stock Data API Documentation*). Adjusted stock changes were computed by detrending individual company performance from broader market movements, revealing deviations associated with wildfire smoke exposure.

Industries such as retail, construction, and healthcare were prioritized for analysis due to their susceptibility to smoke-related disruptions. Time-series models examined correlations between smoke impacts and economic performance, with lagged variables capturing delayed effects on operations, consumer behavior, and workforce productivity.

To forecast future vulnerabilities, machine learning models were developed to project both smoke impacts and economic outcomes. A simple linear regression model was first implemented for smoke impact projections from 2025 to 2050. Gradient Boosting Regression (GBR) and Long Short-Term Memory (LSTM) networks were then employed to model the relationship between smoke impacts and stock performance. **Gradient Boosting Regression (GBR)** is a more interpretable model that captured nonlinear relationships and emphasized features contributing to deviations in stock performance. While the **Long Short-Term Memory (LSTM)** is designed for sequential data, the LSTM model aimed to capture temporal dependencies and lagged effects. However, its performance was limited by the small data set, highlighting the need for more extensive training data for complex models.

Throughout the study, ethical considerations were central to the study's design. Data accuracy and reliability were prioritized by sourcing from trusted organizations like the USGS, EPA, and Alpha Vantage. Potential biases, such as gaps in AQI coverage or unrelated stock market fluctuations, were acknowledged and strived to be mitigated through robust preprocessing and validation steps. The inclusion of vulnerable populations in the analysis emphasized the disproportionate effects of wildfire smoke on low-income residents and individuals with preexisting health conditions (EPA, "Wildland Fire Research: Health Effects Research"; Venn and Calkin, 2011).

Human-centered considerations also informed decisions about transparency and reproducibility. Detailed documentation of data sources, thresholds, and modeling assumptions ensures that the methodology can be replicated or adapted for other regions. Moreover, the study prioritized actionable insights to support equitable resource allocation and resilience planning for Peoria's stakeholders.

FINDINGS

The analysis revealed critical insights into the environmental and economic impacts of wildfire smoke on Peoria, AZ, using data from 1961 through 2021, and extended into economic modeling for industry-specific stock performance. Part 1 provided foundational environmental analysis, while Part 2 built upon it by assessing how wildfire smoke translates to economic disruptions for local industries.

The first step was to quantify the proximity and intensity of wildfire events. Figure 1 highlights the distribution of wildfires by distance from Peoria. The histogram reveals that most fires are clustered within the 250–650 mile range, with a significant cutoff applied at 650 miles for modeling purposes. This threshold captures fires that are most likely to impact Peoria through wind-driven smoke dispersion, while excluding distant events are less likely to influence local air quality. The high concentration of fires within this range validates the smoke estimate's focus on proximity. The results emphasize that localized impacts can be captured effectively by prioritizing nearby fires and demonstrate the need for spatial filtering when analyzing wildfire smoke impacts.

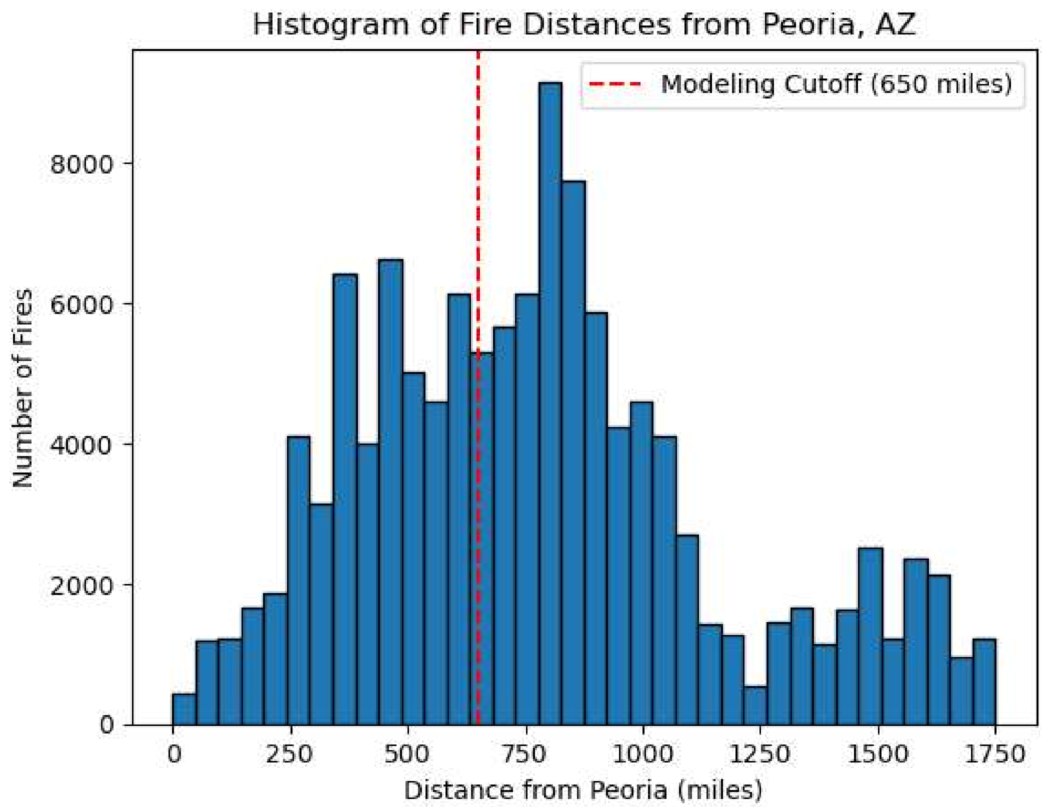

Figure 1: Histogram of Wildfire Distances from Peoria.

The time-series analysis comparing smoke impact estimates and Air Quality Index (AQI) values further underscored the interplay between wildfires and air quality in Peoria. Figure 2 (Time Series: Smoke Impact and AQI Comparison) illustrates a strong alignment in peaks during severe fire seasons, suggesting that wildfire smoke is a substantial contributor to deteriorating air quality in the region. However, divergences in some years point to the influence of other environmental or industrial factors.

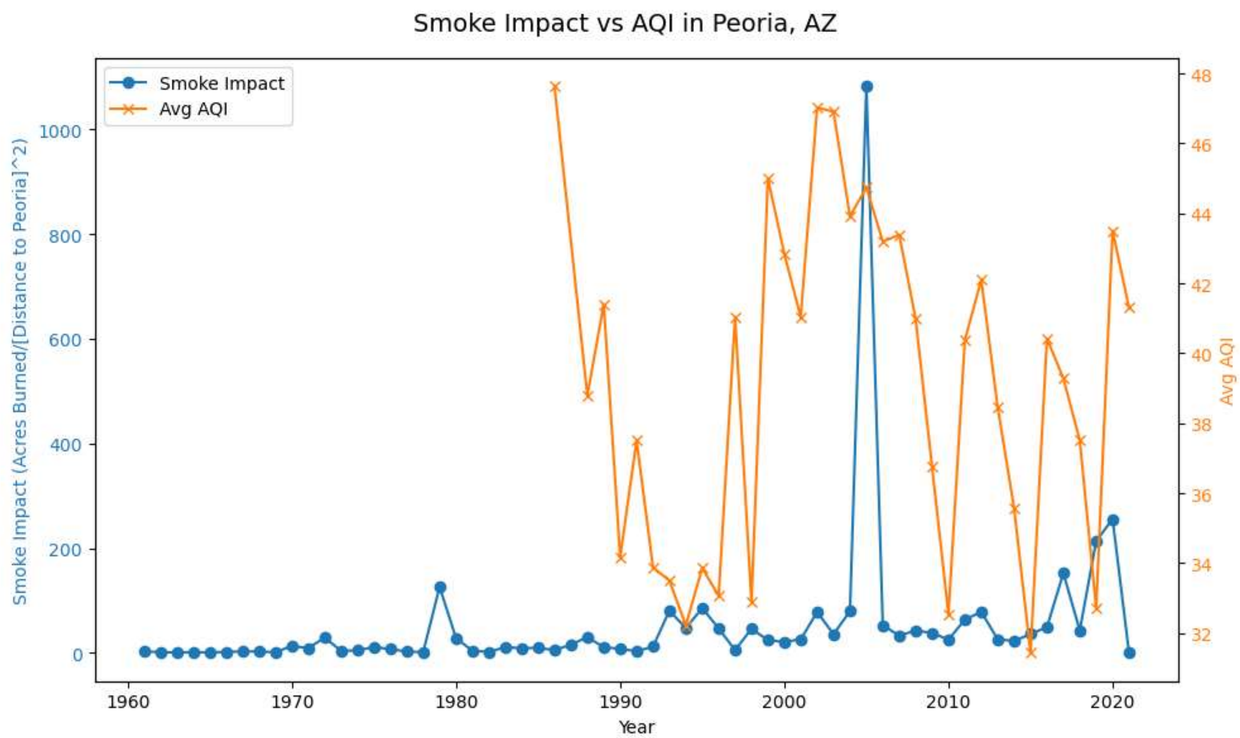

Figure 2: Time-Series Comparison of Smoke Impact and AQI in Peoria.

The analysis also investigated historical burn severity. Figure 3 (Total Acres Burned per Year) provides a temporal perspective on fire severity, showing fluctuations in annual burned acreage. Trends in the total acres burned each year showed a marked increase over recent decades, with periodic spikes indicating particularly severe wildfire seasons. These trends align with projections of increased fire activity due to climate change, highlighting the growing environmental challenge for Peoria.

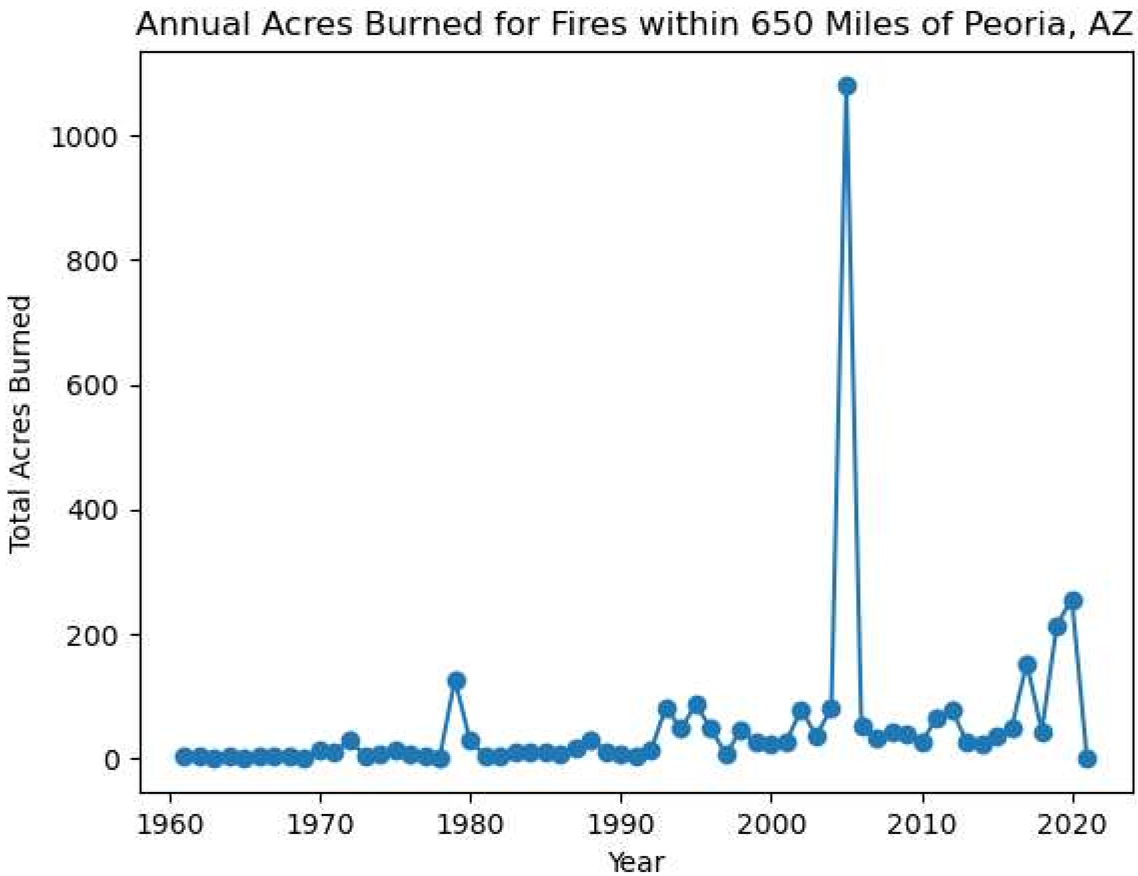

Figure 3: Annual Total Acres Burned for Wildfires Near Peoria.

Looking forward, the analysis projected smoke impacts from 2025 to 2050 using a linear regression model. The results suggested a steady increase in smoke impact over the next 25 years, emphasizing the need for proactive measures to mitigate health and environmental consequences.

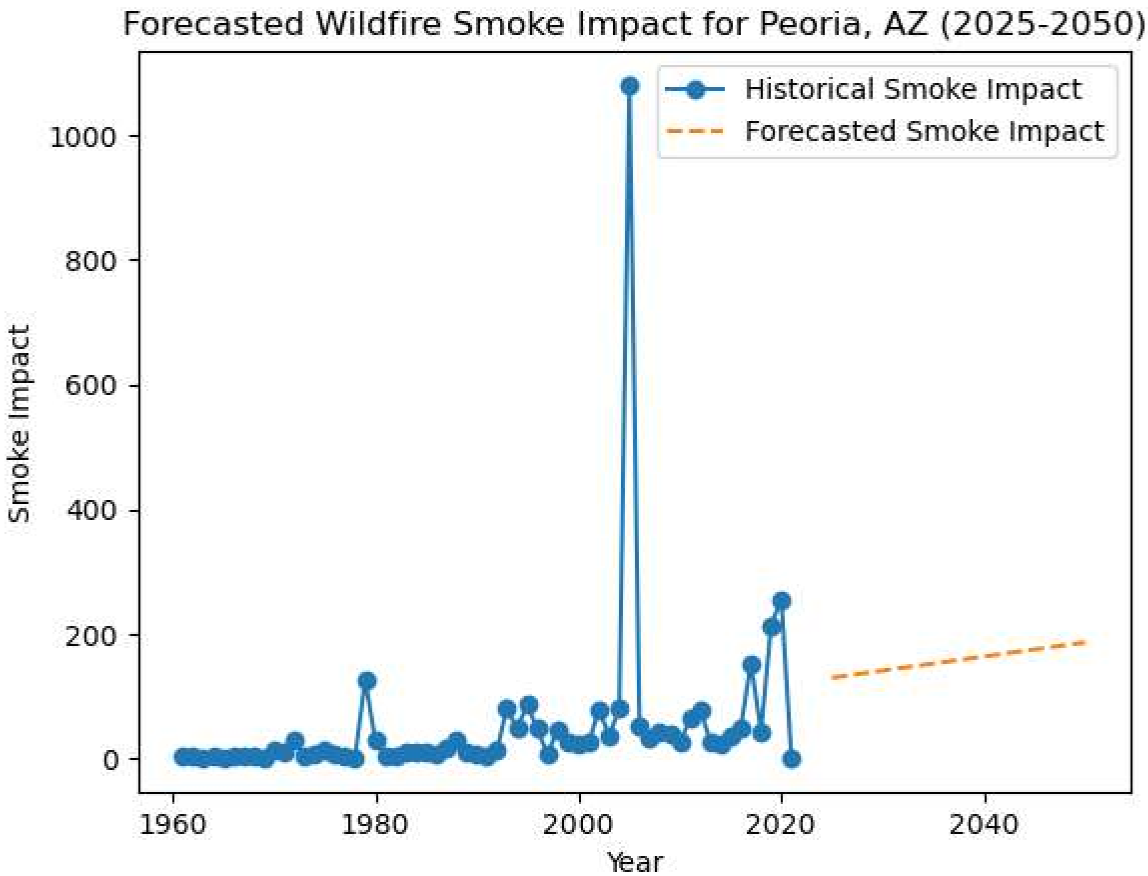

Figure 4: Forecasted Smoke Impact for Peoria (2025–2050).

The second phase extended the analysis to evaluate the economic consequences of wildfire smoke, focusing on Peoria-based businesses. By comparing normalized stock closing prices of local companies with the S&P 500 (Figure 5), the analysis identified deviations in performance during high-smoke years. Notably, industries such as retail (SFM, WAL) and construction (KNX) exhibited unique patterns, highlighting their sensitivity to smoke-related disruptions. These disruptions are likely driven by reduced consumer activity, operational delays, and health-related absences among workers.

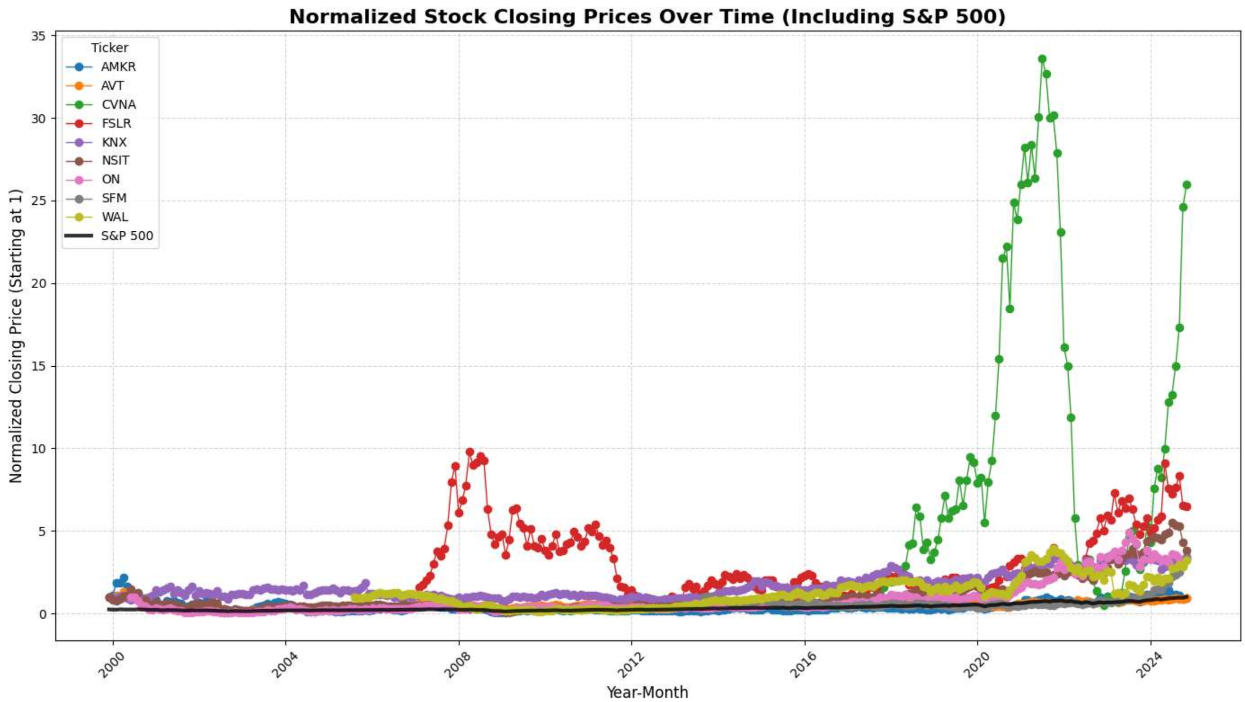

Figure 5: Normalized Stock Closing Prices Over Time (Including S&P 500).

To isolate the local effects of wildfire smoke, detrended stock data was analyzed by adjusting for overall market trends using the S&P 500 as a baseline (Figure 6). The adjusted data revealed significant variability in stock performance during the years of high smoke. These findings underscore the heightened vulnerability of physical operations, such as retail and construction, to environmental disruptions. This analysis emphasizes the need for industry-specific resilience measures, such as flexible work policies and supply chain adjustments.

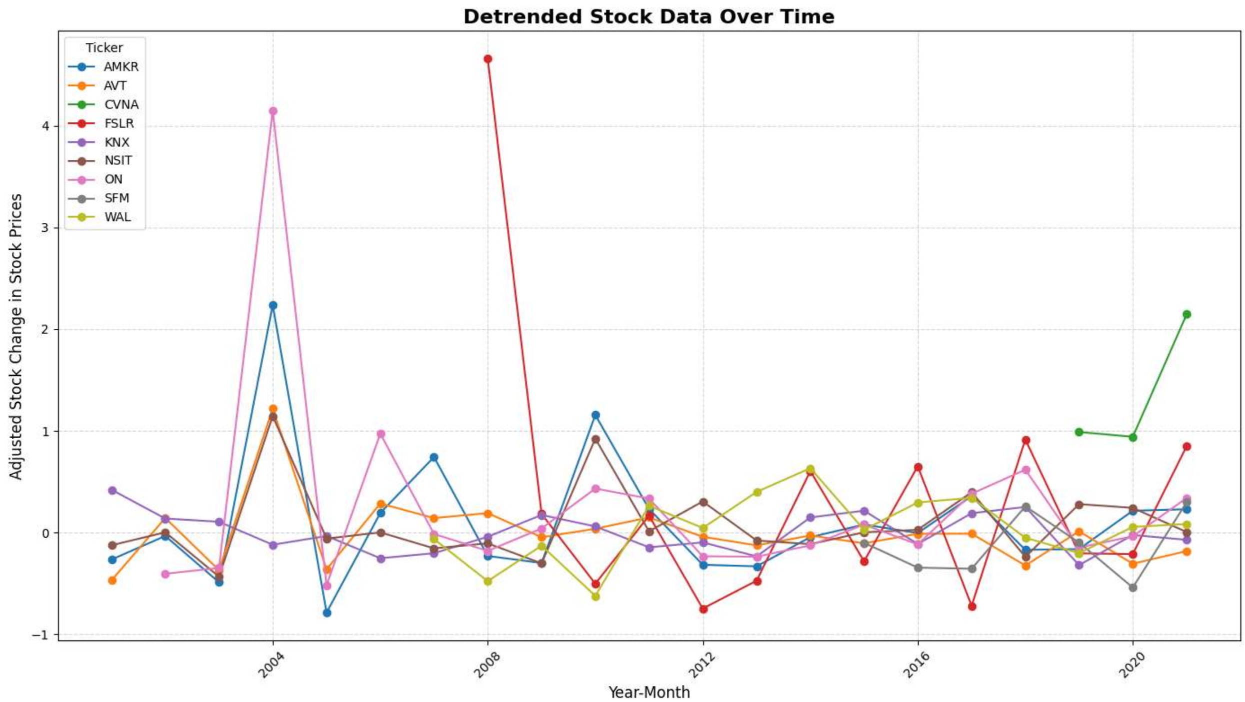

Figure 6: Detrended Stock Data Over Time for Peoria-Based Companies.

Further analysis directly compared smoke impact estimates to stock performance (Figure 7), revealing an inverse relationship. High smoke impact years corresponded to declining stock values, particularly in sectors reliant on local operations and consumer engagement. This direct link highlights the economic risks of increasing wildfire activity and underscores the importance of targeted interventions to safeguard Peoria's economic stability.

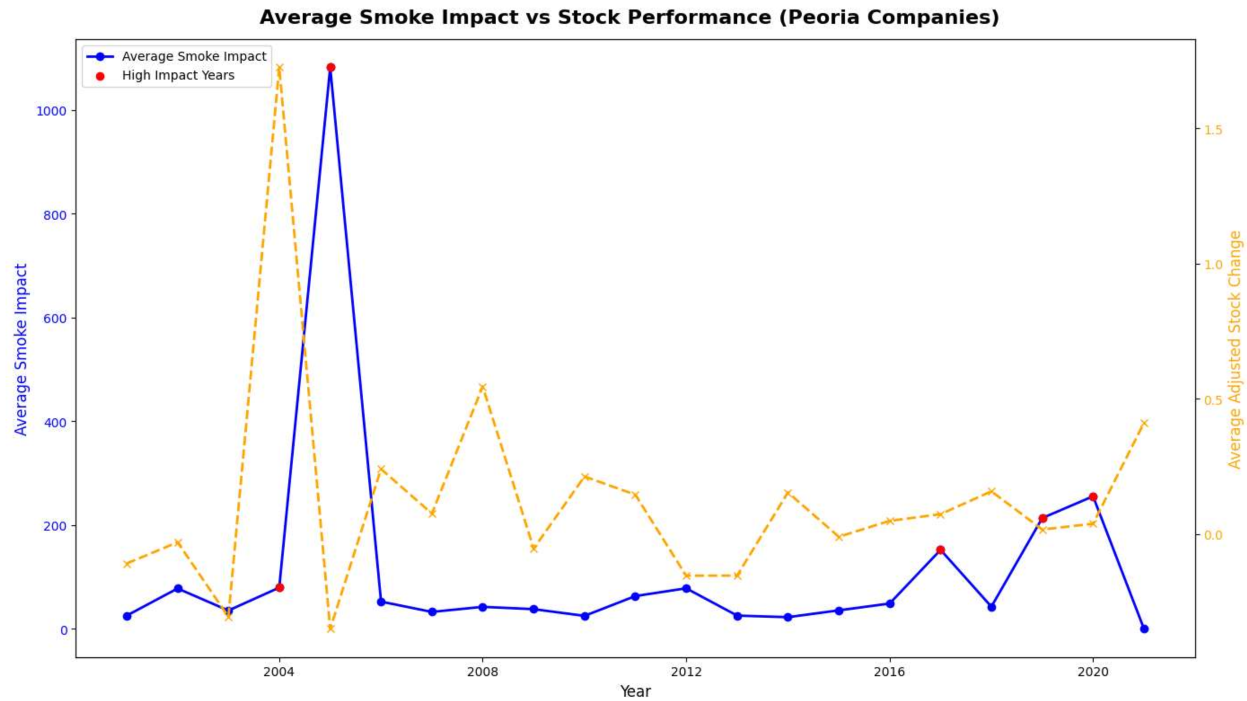

Figure 7: Average Smoke Impact vs. Stock Performance (Peoria Companies).

To predict future economic impacts, Gradient Boosting and LSTM models were developed using smoke impact data as a key feature. The Gradient Boosting model, with an MSE of 0.0014 and an R^2 of 0.4790, successfully captured linear relationships in the data (Figure 8). However, the LSTM model, despite being optimized for sequential data, struggled with generalization, yielding an MSE of 0.0013 and an R^2 of -1.8486. This underperformance likely stemmed from the limited temporal dataset, highlighting the importance of robust training data for complex models. The results suggest that simpler, interpretable models like Gradient Boosting may be more effective for predicting economic outcomes in this context.

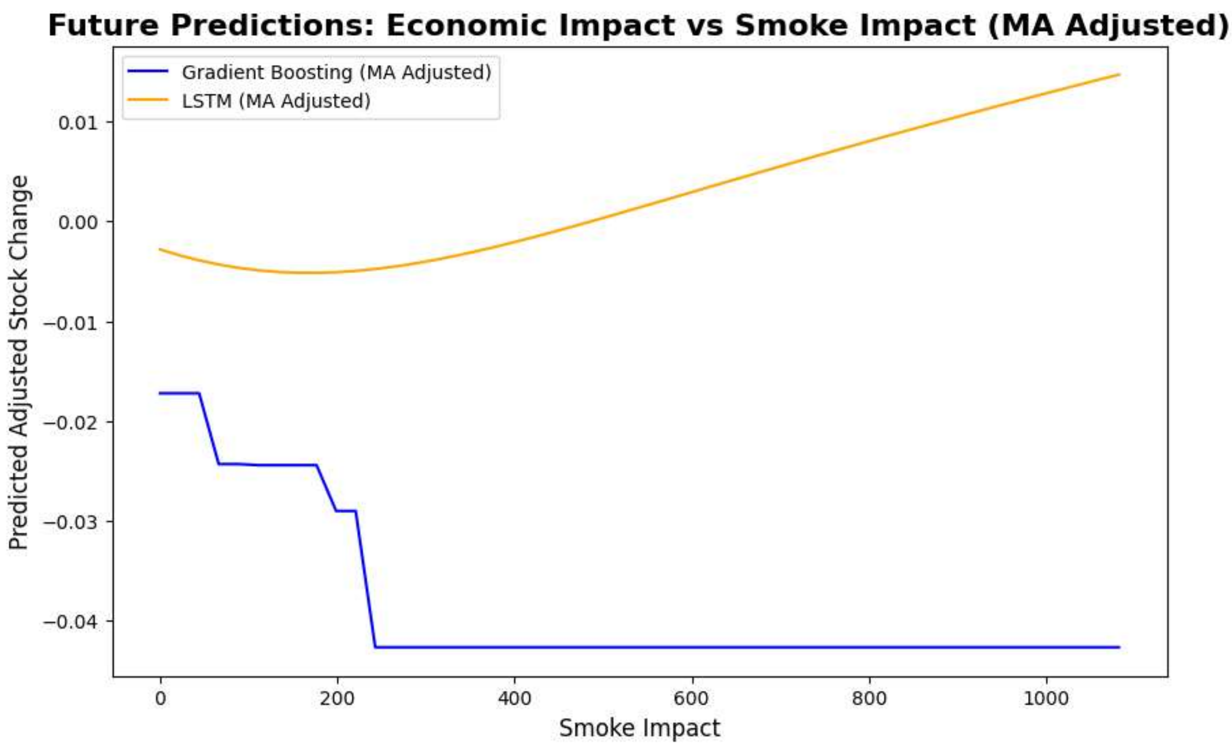

Figure 8: Future Predictions: Economic Impact vs. Smoke Impact (MA Adjusted).

Finally, combining smoke impact forecasts with Gradient Boosting model predictions, the study projected worsening economic outcomes for Peoria's industries if wildfire trends persist. This finding is critical for policymakers, as it emphasizes the economic risks posed by increasing wildfire activity.

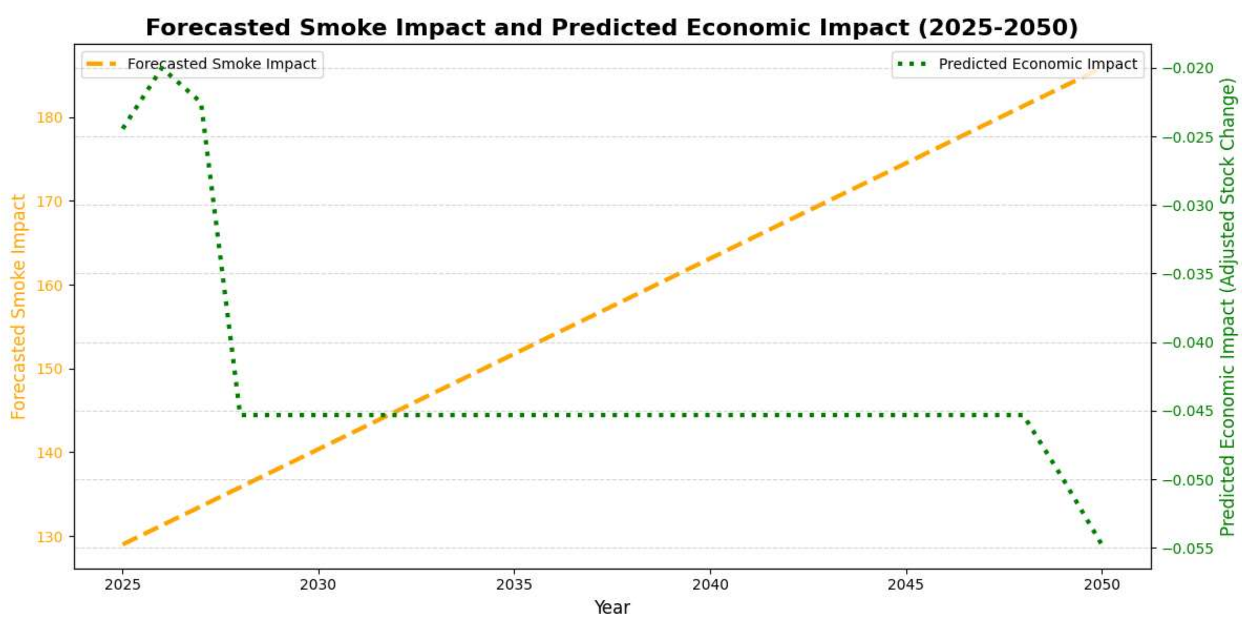

Figure 9: Forecasted Smoke Impact and Predicted Economic Impact (2025–2050).

The final visualization (Figure 10) integrates historical and forecasted smoke impacts with economic predictions, providing a comprehensive overview of Peoria's vulnerability. This integrated perspective emphasizes the interconnected nature of environmental and economic challenges, serving as a foundation for actionable policy recommendations.

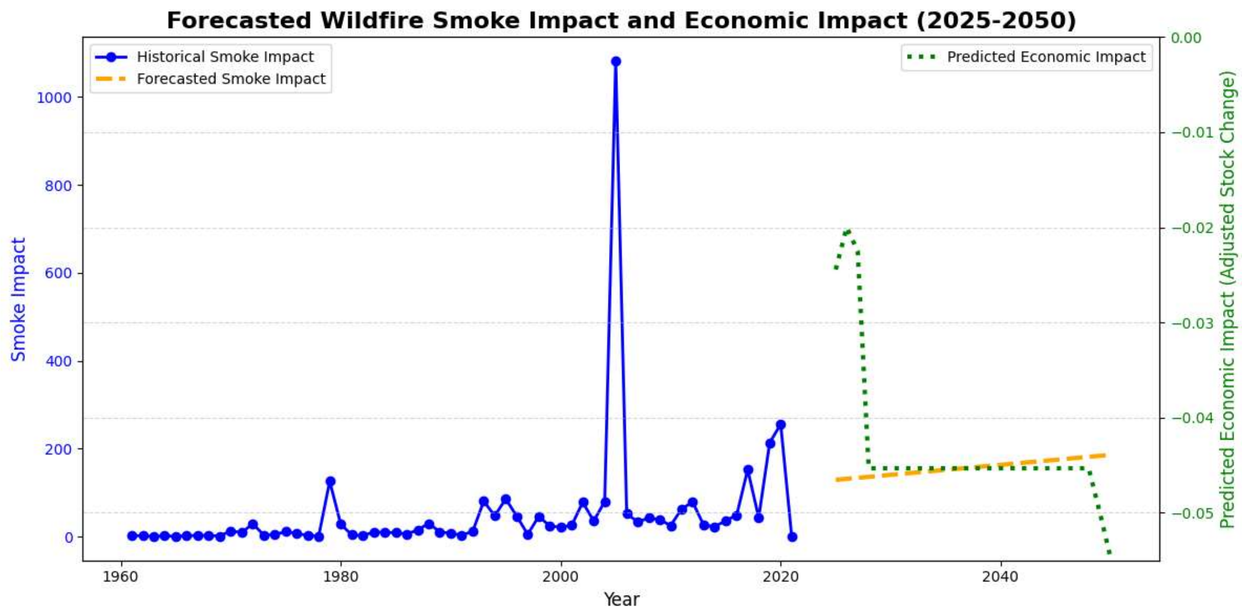

Figure 10: Historical and Forecasted Wildfire Smoke Impact and Economic Impact (2025–2050).

The findings reveal a complex interplay between wildfire smoke and its impact on Peoria's environment and economy. Historical trends underscore the escalating challenges posed by climate change, while predictive models highlight the urgent need for mitigation strategies.

Discussion and Implications

The findings from this analysis underscore the threats posed by wildfire smoke to Peoria's environment and economy. While the environmental challenges are significant, the economic disruptions revealed through this study offer a convincing case for immediate action. These findings have critical implications for Peoria's policymakers, businesses, and residents, highlighting the need for both short-term mitigations and long-term strategies to build resilience against the growing impacts of wildfires.

The increasing intensity and frequency of wildfires near Peoria present a clear and present danger to public health. The projected rise in smoke impacts, as shown by this study, points to worsening air quality and its associated health risks, particularly for vulnerable populations such as children, the elderly, and those with preexisting respiratory conditions. The city council should prioritize investments in air quality monitoring infrastructure to ensure real-time tracking and public broadcasting of data. Expanding the availability of air filtration systems in public spaces, such as schools and community centers, can also provide relief during high-smoke periods. Transitioning to renewable energy sources and promoting energy-efficient practices within the community are essential long-term measures to address the root causes of climate change and its cascading effects on wildfire frequency and intensity.

The economic analysis revealed the vulnerability of Peoria's industries, particularly retail and construction, to the operational disruptions caused by wildfire smoke. Declining stock performance during high smoke years underscores the need for industry-specific resilience strategies. Local businesses should explore flexible work arrangements, including remote operations, to mitigate productivity losses during high-smoke events. Additionally, investing in enhanced indoor air filtration systems for workplaces can protect employee health and minimize absenteeism.

At the municipal level, the city should establish an emergency fund specifically for smoke-related disruptions to provide short-term financial support to businesses and workers during severe wildfire seasons. The establishment of public-private partnerships can also help facilitate the adoption of protective measures, such as offering funding for air filtration systems or creating incentives for businesses to implement smoke-resilient practices. Policymakers should continue this human-centered approach by involving community members in decision-making processes, conducting outreach to understand their needs, and ensuring that resources are distributed equitably. For example, small businesses and low-income workers, who may lack the resources to implement protective measures independently, should be prioritized for financial and technical support.

The projected increase in smoke impacts over the next 25 years underscores the urgency of implementing proactive measures. Policymakers and businesses have a narrow window to act before these impacts escalate further. Short-term actions, such as enhancing air quality monitoring and establishing an emergency fund, should be implemented within the next two years to address immediate risks. Concurrently, long-term measures, including renewable energy transitions and urban planning strategies to improve resilience, should be developed and enacted within the next five to ten years.

In conclusion, the findings from this analysis present a clear call to action for Peoria's leadership and residents. By leveraging data-driven insights and adopting a human-centered approach, the city can mitigate the impacts of wildfire smoke, protect its economy, and ensure the well-being of its community in the face of escalating climate risks.

LIMITATIONS

Despite the valuable insights derived from this analysis, several limitations must be acknowledged to provide a balanced perspective on the findings and their applicability. These limitations arise from the data, methods, and assumptions used throughout the study and highlight areas where further research and refinement are necessary.

One of the key limitations relates to the availability and quality of the data. The EPA AQI data lacked sufficient historical coverage for certain years, particularly during the early parts of the analysis period, which may have introduced inaccuracies in assessing the correlation between wildfire smoke and air quality. Similarly, the stock data used to analyze economic impacts focused on a limited selection of companies based in Peoria, which may not fully capture the broader economic effects of wildfire smoke on other industries or smaller businesses that are not publicly traded. While the USGS wildfire dataset provided comprehensive coverage, it is possible that smaller or less documented fires were omitted. Furthermore, the dataset does not include detailed meteorological data, such as wind patterns, which are critical for understanding smoke dispersion.

The study also relied on several modeling assumptions that simplified complex events. The smoke impact metric, calculated as acres burned divided by the square of the distance to Peoria, does not account for factors like wind direction, atmospheric stability, or variations in fuel composition, which could significantly influence smoke dispersion and concentration. Similarly, the Gradient Boosting and LSTM models relied on assumptions about the relationships between smoke impacts and stock performance. The LSTM model, in particular, underperformed ($R^2 = -1.8486$), suggesting that temporal dependencies were not adequately captured, potentially due to the limited amount of training data available.

Another limitation is the temporal scope of the study. The analysis uses historical data spanning from 1961 to 2020 to project future trends. However, the linear regression models employed for smoke impact forecasting assume a consistent rate of increase, which may not hold true given the unpredictability of climate change and wildfire dynamics. Additionally, the study does not address the disproportionate effects of wildfire smoke on low-income or marginalized populations, who may face greater challenges in accessing protective measures like air filtration or healthcare. Nor does it fully capture the differences in the ability of industries to adapt to smoke disruptions, as some industries, such as retail and construction, may face more immediate operational challenges compared to sectors like technology or finance, which are more conducive to remote work.

The findings of this study are also specific to Peoria, AZ, and its local industries. While the methodology can be adapted for other regions, the results may not generalize to areas with different climates, wildfire dynamics, or economic compositions. Ethical considerations also played a role in the study, as the selection of specific distance thresholds and modeling parameters could inadvertently introduce biases. For instance, excluding fires beyond 650 miles may overlook long-range smoke transport events. Moreover, the emphasis on publicly traded companies in assessing economic impacts may overlook the challenges faced by smaller, privately owned businesses, which are often less resilient to disruptions.

The projections for future smoke impacts and economic outcomes rely heavily on historical trends and do not incorporate potential technological advancements or policy interventions that could mitigate these impacts. Similarly, the projections do not account for extreme climate scenarios that could worsen wildfire activity. Furthermore, the metrics used to evaluate smoke impacts and economic outcomes are inherently subject to uncertainty. For example, the use of normalized stock prices and detrended data to assess economic impacts assumes that these adjustments fully account for broader market trends, which may not be entirely accurate.

Finally, although this study adopted a human-centered data science approach, the involvement of local stakeholders in defining metrics and validating assumptions was limited. Greater community engagement in future work could ensure that findings align more closely with lived experiences and local priorities.

In summary, while this analysis provides valuable insights into the environmental and economic impacts of wildfire smoke on Peoria, AZ, these limitations underscore the need for caution when interpreting the results. Addressing these limitations in future studies will improve the accuracy, inclusivity, and applicability of findings, ultimately supporting more effective policymaking and resilience planning.

Conclusion

This study set out to address two primary research questions: (1) How does wildfire smoke affect air quality in Peoria, AZ, and can this impact be quantified using historical data? (2) How does wildfire smoke affect local companies, and can these impacts be predicted to help stakeholders prepare for future challenges? By extending the analysis from an environmental focus in Part 1 to include economic outcomes in Part 2, this research provides a comprehensive view of the impacts of wildfire smoke on Peoria's community and economy.

The findings reveal a significant relationship between wildfire smoke and air quality, with smoke impact metrics closely correlating with peaks in the Air Quality Index during severe fire seasons. Historical data demonstrated an increase in wildfire activity over the years, consistent with the broader implications of climate change. Forecasting models predict that smoke impacts will continue to rise in the coming decades, highlighting the urgency for proactive mitigation and adaptation strategies. On the economic front, the study uncovered an inverse relationship between wildfire smoke and the performance of Peoria-based companies, particularly in sectors such as retail and construction, which rely heavily on physical operations. This economic vulnerability underscores the broader societal consequences of environmental disruptions.

The predictive modeling component of the analysis provided further insights. While the Gradient Boosting model showed reasonable performance in predicting economic impacts based on smoke data, the LSTM model struggled with the granularity of the data, indicating the complexity of accurately modeling sequential data with limited temporal records. These results point to opportunities for improving predictive accuracy by incorporating more diverse and granular data in future analyses.

This study demonstrates the principles of human-centered data science by integrating environmental and economic perspectives to address a real-world problem that affects both public health and local livelihoods. Ethical considerations informed the methodology, from selecting distance thresholds to ensure relevance for Peoria to acknowledging the limitations of data quality and the need for community engagement. By emphasizing actionable insights, the study empowers policymakers, city planners, and business leaders to make informed decisions about resource allocation, resilience planning, and economic mitigation strategies.

In conclusion, this analysis highlights the connection of environmental and economic systems, illustrating how data-driven approaches can uncover relationships and inform better decision-making. By combining the analytical results with human-centered considerations, this research not only contributes to the understanding of wildfire impacts but also underscores the importance of equitable, inclusive, and actionable data science in addressing societal challenges. The study serves as a call to action for proactive measures to mitigate the consequences of wildfire smoke, ensuring a healthier, more resilient future for Peoria and similar communities.

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United States Environmental Protection Agency (EPA). "Outdoor Air Quality Data." https://www.epa.gov/outdoor-air-quality-data.

Data Sources

1. **USGS Wildland Fire Combined Dataset**
   Link: [https://www.sciencebase.gov/catalog/item/61aa537dd34eb622f699df81]
   Description: Comprehensive dataset of wildfire events, including fire names, locations, sizes, and dates. Used for proximity calculations and smoke impact estimation.
2. **EPA Air Quality System (AQS) Data**
   Link: [https://aqs.epa.gov/aqsweb/documents/data_api.html]
   Description: Air quality data from monitoring stations, including AQI values for particulate and gaseous pollutants. Used to compare air quality trends with wildfire smoke impacts.
3. **Alpha Vantage Stock Data API**
   Link: [https://www.alphavantage.co/]
   Description: Monthly stock data for companies based in Maricopa County, AZ, as well as S&P 500 index data. Used to analyze the economic impact of wildfire smoke on local industries and benchmark performance against market trends.
4. **Monitoring Stations Metadata**
   Link: [https://www.epa.gov/outdoor-air-quality-data]
   Description: Metadata on monitoring stations near Peoria, AZ. Includes station IDs, locations, and pollutants monitored. Supports AQI analysis.