Research Article

Electric Vehicle Fleet Penetration and Air Pollution Mortality in Europe

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The transition to electric vehicles is widely promoted as contributing to the reduction of urban air pollution and climate change. This study examines the correlation between electric vehicle fleet penetration and premature deaths from air pollution (PM2.5 exposure) across 28 European countries. Using 2023-2024 data on actual vehicle fleet composition, we find a statistically significant negative correlation (r = -0.465, p = 0.013). Nordic countries show high EV penetration (Norway 28%, Denmark 12.1%) with low mortality rates (6.6 and 18.3 deaths per 100,000 respectively), while Eastern European countries exhibit <1% EV penetration with 70-145 deaths per 100,000. This result was expected for several reasons, the main one being that car exhaust is a major factor in air pollution in urban areas. These findings are consistent with the hypothesis that higher electric vehicle fleet penetration is associated with lower air pollution mortality, even though there are other factors that influence the trend.

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Introduction

The European Union has set ambitious targets for vehicle electrification, requiring a 90% reduction in tailpipe CO_2 emissions from new passenger cars by 2035 (revised from the original 100% target in December 2025, with e-fuels now permitted)[1]. This policy is motivated by dual goals: climate change mitigation and urban air quality improvement. Fine particulate matter (PM2.5) from transportation contributes significantly to air pollution, with the European Environment Agency estimating over 180,000 premature deaths annually in the EU attributable to PM2.5 exposure above WHO guidelines. PM2.5 is used here as a proxy for the broader pollution envelope. Other pollutants, including NOx, PM10, and ozone also contribute to air pollution mortality, but are not captured in this analysis.

Battery electric vehicles (BEVs) are a fundamental element of the EU policy, but their adoption varies dramatically across Europe. Norway leads with 28% of its passenger car fleet being BEVs as of 2024, while most Eastern European countries remain below 1% fleet penetration. This variation provides a natural testing ground to examine the relationship between EV adoption and air pollution health outcomes.

Of course, the relationship between EV adoption and air quality is complex and mediated by multiple factors: fleet turnover rates (typically 15-20 years), the relative contribution of vehicles versus other emission sources (residential heating, industry, agriculture), meteorological and geographic conditions affecting pollutant dispersion, and the comprehensiveness of environmental policy beyond just transportation. Yet, the results of this study show that BEVs are associated with lower mortality in urban areas in Europe. These results for Europe broadly agree with those recently found for China[2] and for the US[3].

The individual links of the causal chain connecting EV adoption to reduced mortality are supported by a growing body of literature: EV adoption has been shown to reduce NOx, CO, and PM2.5 concentrations in observational studies[4][5], while the link between improved air quality and reduced mortality is well established[6]. This study does not establish the full causal chain itself, but provides population-level associational evidence consistent with these mechanisms at the European scale.

Methods

Data Sources

Air pollution mortality data were obtained from the European Environment Agency[7] estimates of premature deaths attributable to PM2.5 exposure above 5 $\mu g/m^3$, the threshold established in the WHO[6]air quality guidelines. Data are expressed as deaths per 100,000 inhabitants aged 30 years and above. Electric vehicle fleet data represent the actual percentage of battery-electric vehicles in the total passenger car fleet as of 2024, sourced from ACEA (European Automobile Manufacturers' Association) reports[8]. These data reflect accumulated vehicle stock, not annual sales, providing a more accurate measure of actual fleet electrification. For countries lacking comprehensive ACEA fleet data, estimates were derived from cumulative registration data and typical fleet turnover patterns. Although mortality data are from 2023 and fleet data from 2024, the one-year offset is negligible given the slow temporal dynamics of both variables and the cross-sectional nature of the analysis, examining spatial rather than temporal variation.

Statistical Analysis

Pearson correlation coefficients were calculated between EV fleet percentage and PM2.5 mortality rates across 28 European countries (EU member states, EFTA countries, and several Balkan nations). Statistical significance was assessed at $\alpha = 0.05$. Linear regression was used to visualize the relationship trend, though we recognize the relationship may not be strictly linear given the complex causal pathways involved.

Results

Air Pollution Mortality Patterns

Figure 1 shows the distribution of PM2.5-attributable deaths across Europe. Nordic countries (Finland 0.9, Sweden 3.0, Norway 6.6, Denmark 18.3 deaths per 100,000) demonstrate the lowest mortality rates, while Balkan countries exhibit the highest (North Macedonia 222.2, Bosnia and Herzegovina 199.0, Albania 196.1). The EU average is 56.8 deaths per 100,000. The distribution is highly non-linear, with a small cluster of Nordic countries at very low mortality and a long tail of Eastern and Balkan countries at high values, reflecting the diverse emission sources, governance structures, and geographic conditions across the continent.

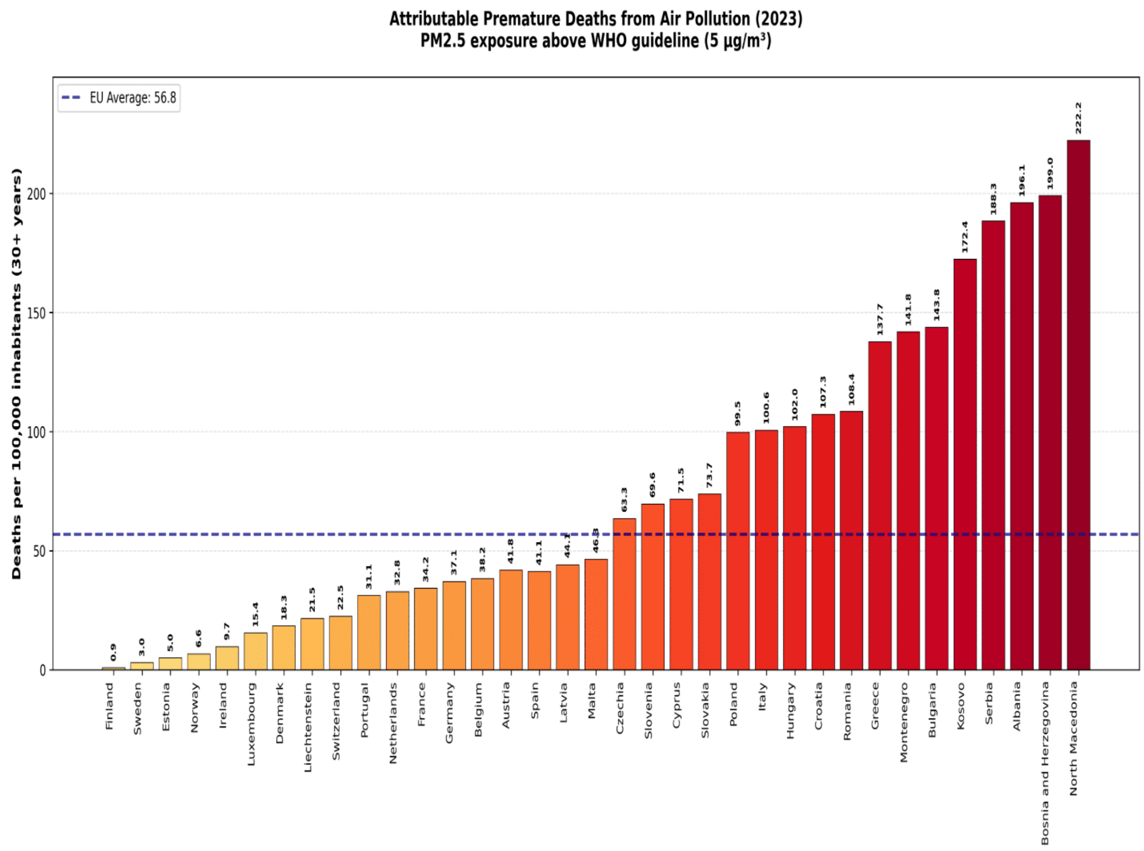

Figure 1. *Attributable premature deaths from PM2.5 air pollution per 100,000 inhabitants (30+ years) across European countries, 2023.*

EV Fleet Penetration and Air Quality Correlation

Figure 2 presents the correlation between actual EV fleet penetration (percentage of all passenger cars on the road) and PM2.5 mortality rates. The analysis reveals a statistically significant negative correlation (Pearson r = -0.465, p = 0.013), indicating that countries with higher EV fleet penetration tend to have lower air pollution mortality rates.

The correlation strength is moderate, as it should be expected given the number of different factors involved. Norway is the strongest performer in terms of electrification, with 28% of its fleet. It also has a low mortality rate with 6.6 deaths per 100,000. On the opposite side of EV penetration, Eastern European countries cluster at <1% EV in their vehicle fleet, with larger mortality rates, of the order of 70-145 deaths per 100,000.

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Norway is so much more electrified than all the other countries that it may be considered an outlier. So, the data was re-analyzed excluding Norway. The results strengthen the correlation (Pearson r = −0.575, p = 0.0017, n = 27; Figure 2B). Within some limits, Norway is an outlier, but the correlation between EVs and health becomes even stronger. The non-parametric Spearman rank correlation for the full dataset is ρ = −0.835 (p < 0.0001), indicating a robust monotonic association across the full distribution of countries.

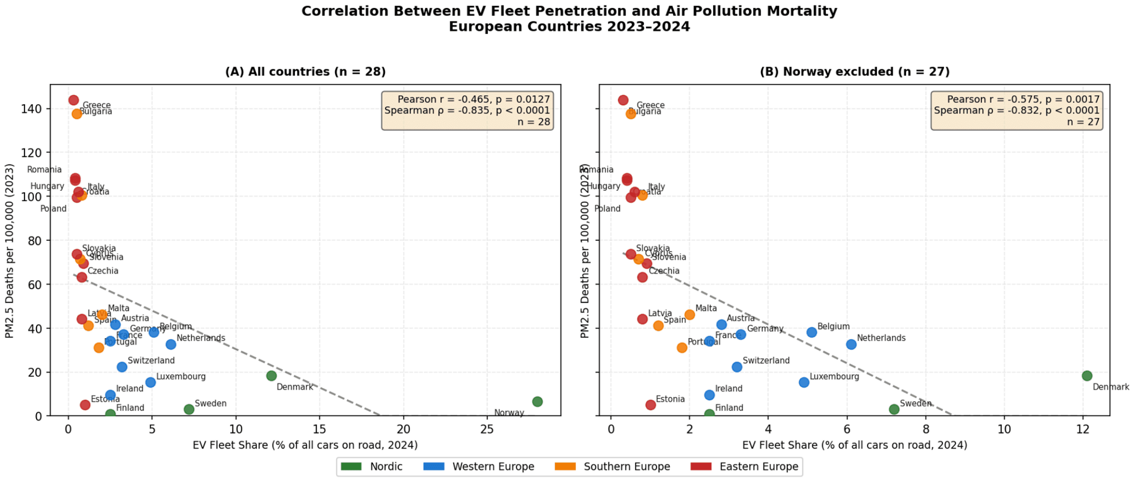

Figure 2. *Correlation between electric vehicle fleet penetration (% of total passenger cars) and PM2.5 mortality rates across European countries, 2024. Colors indicate geographic regions: Nordic (green), Western Europe (blue), Southern Europe (orange), Eastern Europe (red). (A) Full dataset (n = 28); (B) Norway excluded as a robustness check (n = 27). Regression lines are clipped at zero. Pearson and Spearman statistics are shown in each panel.*

Discussion

The observed moderate correlation strength can be considered as expected, given the multiple confounding factors that affect the relationship between EV adoption and air quality. Since this analysis uses actual fleet share rather than sales data, in most cases, the effect of EV adoption is weak because of the multi-decadal transition period during which the majority of vehicles remain combustion-powered. Sweden, despite 7.2% fleet electrification representing two decades of accumulated adoption, still has 93% of its fleet as conventional vehicles. Even in Norway, despite the near-zero sales of new combustion engine vehicles, EVs still represent a minority of the circulating cars and transport vehicles. In addition, non-transport PM2.5 sources, socioeconomic and governance differences across countries, and geographic factors all play a role. In countries such as Poland, for instance, the 0.5% of EV fleet share is essentially irrelevant to air quality when coal furnaces remain the primary heating and electric power source. Despite recent reductions, coal still accounts for roughly 41% of the total primary energy consumption in Poland. This suggests regionally differentiated transition strategies based on local emission source profiles.

Several other EU countries have less than 1% of EV penetration. Italy is a good example of a theoretically advanced EU country that has been slow in adopting EVs. Its persistently high mortality rate (100.6 deaths per 100,000) can be attributed at least in part to this adoption delay, although other factors, such as extensive wood stove usage for residential heating, particularly in rural areas, probably play a role.[9]. Agricultural burning, industrial emissions, and cross-border pollution transport further complicate the causal pathway from vehicle electrification to air quality improvement. Even complete vehicle fleet electrification would leave these other sources unaddressed.

It should also be noted that electric vehicles, while eliminating exhaust emissions, may contribute to non-exhaust particulate matter through increased brake and tire wear, owing to their greater weight compared to equivalent internal combustion engine vehicles[10]. This partially offsets the PM2.5 benefits of electrification, but more recent data show that regenerative braking can reduce the emission factors of EVs well below those of equivalent ICEVs[11].

Geographic factors also create systematic patterns largely independent of policy choices. The Po Valley in Northern Italy traps pollutants due to topographic basin effects and frequent atmospheric inversions. Balkan mountain valleys similarly concentrate emissions regardless of source. Conversely, Nordic countries benefit from Atlantic wind patterns that disperse pollutants effectively.

Denmark's relatively high mortality rate (18.3 per 100,000), despite 12.1% EV penetration, partially reflects continental European weather patterns that occasionally trap pollution, unlike Norway's more consistent Atlantic ventilation. These meteorological differences create ceiling and floor effects on achievable air quality improvements.

The most successful countries in both EV adoption and air quality demonstrate comprehensive environmental policy portfolios. Norway's low mortality rate reflects not just vehicle electrification but also district heating systems powered by hydroelectric generation, strict industrial emission standards, and effective agricultural waste management. Vehicle electrification serves as a marker of overall environmental governance quality rather than being independently causal.

These results represent a classic systemic insight: complex problems rarely yield to single-lever solutions. From this perspective, the moderate correlation between EV penetration and air quality is exactly what systems thinking would predict – vehicle electrification is necessary but insufficient, and must be bundled with complementary policies addressing all emission sources.

These findings have important implications for the energy transition strategy. First, the fleet turnover lag means that even aggressive EV adoption policies require 15-20 years to substantially affect fleet composition and air quality. This multi-decadal timeline must inform public expectations and policy persistence.

Second, vehicle electrification alone cannot solve air quality crises in countries where transportation is not the dominant PM2.5 source. Poland, for instance, would see minimal air quality improvement from vehicle electrification without addressing residential coal heating and coal-based electricity production.

Third, the success of Nordic countries in achieving both high EV penetration and low mortality rates demonstrates the value of comprehensive, multi-sector environmental policy. Rather than treating vehicle electrification as a standalone solution, it must be integrated into broader strategies addressing heating, industry, agriculture, and electricity generation simultaneously.

Limitations

This analysis has several limitations. First, fleet penetration data for some countries required estimation based on sales patterns and typical turnover rates, introducing measurement uncertainty. Second, the cross-sectional design cannot establish causality – the correlation could reflect confounding by overall governance quality or economic development. Indeed, confounding is likely a central explanation for a portion of the observed association: countries with high EV fleet shares tend also to have higher GDP per capita, stronger environmental governance, and cleaner energy systems. A robustness check excluding Norway (the most extreme data point at 28% fleet electrification) shows that the correlation is not driven by this outlier: without Norway, the Pearson r strengthens to -0.575 ($p = 0.0017$, $n = 27$). Furthermore, the non-parametric Spearman rank correlation for the full dataset is $\rho = -0.835$ ($p < 0.0001$), confirming that the association is robust across the distribution and not an artefact of a single influential observation. Future analyses should nonetheless incorporate multivariate controls to disentangle the independent contribution of EV fleet share from correlated governance and socioeconomic factors. Third, PM2.5 mortality estimates themselves carry uncertainty, particularly in countries with less developed monitoring networks.

Fourth, this analysis does not account for the electricity generation mix. Countries charging EVs primarily with coal-fired power may see smaller air quality benefits than those with cleaner grids. This is not an important point, right now, because countries which still depend largely on coal for their electricity production (e.g. Poland), have a negligible EV fleet. In any case, even for these countries, urban health impacts of EV are likely to be positive due to emission displacement from cities to power plants, where the emissions of particulate matter can be more efficiently filtered than for single cars.

Conclusions

Electric vehicle fleet penetration shows a statistically significant negative correlation with air pollution mortality across European countries (r = -0.465, p = 0.013). This relationship is mediated by fleet turnover lag, multi-source emission dynamics, geographic factors, and policy comprehensiveness.

From a systemic perspective, these findings illustrate the limitations of single-lever interventions in complex socio-technical systems. Vehicle electrification represents a necessary component of air quality improvement, but cannot independently solve pollution crises. Successful countries bundle vehicle policies with comprehensive approaches to residential heating, industrial emissions, and agricultural practices.

The multi-decadal fleet turnover timeline means that even aggressive EV adoption policies require sustained commitment over 15-20 years to substantially affect air quality. Policymakers must manage public expectations accordingly while simultaneously addressing non-transportation emission sources to achieve meaningful mortality reduction in the near term.

The 246-fold difference in mortality rates between best (Finland, 0.9 per 100,000) and worst (North Macedonia, 222.2 per 100,000) performing countries demonstrates that substantial improvement is achievable. However, achieving Nordic levels of air quality requires comprehensive environmental policy extending well beyond vehicle electrification alone.

Statements and Declarations

Acknowledgments

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Declarations

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