Assessing the Impacts of Various Fleet Replacement Strategies on Air Quality and Health using AERMOD Dispersion Model – The Case of Trece Martires City, Cavite

Drexler B. SIBAL [a], Karl B. N. VERGEL [b]

[a] *College of Engineering and Architecture, Lyceum of the Philippines University Cavite, General Trias City, Cavite, 4107, Philippines*
[b] *Institute of Civil Engineering, University of the Philippines Diliman, Quezon City, Metro Manila, 1101, Philippines*
[a] *E-mail: drexler.sibal@lpu.edu.ph*
[b] *E-mail: knvergel1@up.edu.ph*

Abstract: This study assessed the potential air quality effects of public transport fleet replacement and incremental private vehicle electrification in Trece Martires City, Cavite using the AERMOD dispersion model. Multiple scenarios were simulated using local traffic data, vehicle-specific emission factors, roadway characteristics, and meteorological inputs. The current/no-intervention fleet condition was defined as the Business-as-Usual (BAU) reference scenario; no future traffic or fleet growth was projected. Model validation focused on $PM_{2.5}$ because continuous reference-grade monitoring data were unavailable for the other pollutants. The complete electrification of jeepneys and tricycles (ETEJ) reduced the maximum modeled 24-hour $PM_{2.5}$ concentration by 46.42% relative to BAU, while the EPV50 sensitivity scenario, which additionally electrified 50% of cars and motorcycles, reduced it by 70.49%. The results indicate that fleet replacement changes the modeled pollutant concentrations within the study domain, but the maximum concentration is a hotspot indicator rather than a city-wide exposure estimate. AirQ+ results were therefore interpreted as scenario-comparison estimates based on the selected exposure surrogate and population coverage rather than as direct individual or city-wide health-risk estimates.

Keywords: AERMOD, Fleet Electrification, Public Transport Modernization, $PM_{2.5}$, Air Quality, Health Impact

1. INTRODUCTION

Air pollution remains a major environmental and public health concern, particularly in developing countries such as the Philippines. According to the National Air Quality Status Report (2019–2020), mobile sources account for approximately 81% of total air emissions in the country, making the transportation sector the largest contributor to urban air pollution. Diesel-powered public utility vehicles emit pollutants such as carbon monoxide (CO), nitrogen oxides (NO_x), sulfur oxides (SO_x), and particulate matter (PM), which degrade ambient air quality and pose significant risks to human health. Studies have shown that prolonged exposure to these pollutants is associated with respiratory and cardiovascular diseases, premature mortality, and adverse environmental impacts (Manisalidis et al., 2020; Malana et al., 2019). These concerns highlight the need for sustainable transportation strategies that reduce emissions while maintaining efficient urban mobility.

To address these challenges, the Philippine government implemented the Public Transport Modernization Program (PTMP), formerly known as the Public Utility Vehicle Modernization Program (PUVMP), through Department Order No. 2017-011 and subsequently

Department Order No. 2023-022. The program seeks to replace aging public utility vehicles with safer, more efficient, and environmentally sustainable alternatives, including Euro 4-compliant and electric vehicles. Beyond improving vehicle safety and operational efficiency, the PTMP aims to reduce transport-related emissions and promote cleaner urban mobility.

The objectives of the PTMP are consistent with the ASIF (Activity–Structure–Intensity–Fuel) framework proposed by Schipper et al. (2000), which identifies travel activity, modal structure, energy intensity, and fuel carbon intensity as the primary determinants of transportation emissions. Through route rationalization, modernization of public transport fleets, improved fuel efficiency, and adoption of cleaner vehicle technologies, the PTMP addresses several components of the ASIF framework to reduce emissions from the transport sector (Schipper et al., 2000). However, the extent to which these fleet replacement strategies improve ambient air quality at the local scale remains insufficiently quantified.

Atmospheric dispersion models provide an effective approach for evaluating the impacts of transportation policies on ambient air quality. Among these, the American Meteorological Society/Environmental Protection Agency Regulatory Model (AERMOD) has been widely adopted for regulatory and research applications because of its capability to simulate pollutant dispersion under varying meteorological and terrain conditions. When coupled with health impact assessment tools such as the World Health Organization's AirQ+, atmospheric dispersion modeling can estimate not only changes in pollutant concentrations but also the corresponding health burden associated with long-term exposure to particulate matter.

Although previous studies have investigated the environmental, technological, and economic aspects of public transport modernization, most have focused on policy implementation, vehicle technology, or investment feasibility (Agaton et al., 2019). Local studies have likewise evaluated transport-related air pollution and roadside particulate matter (Malana et al., 2019), but limited research has quantified the localized effects of different fleet replacement strategies using atmospheric dispersion modeling and subsequently assessed their associated health impacts. Furthermore, the potential benefits of extending electrification beyond public transportation to include private vehicles have received little attention.

This study addresses these gaps by evaluating the effects of various fleet replacement strategies on ambient concentrations of CO, NO_2, SO_2, and $PM_{2.5}$ in Trece Martires City, Cavite using AERMOD. The resulting $PM_{2.5}$ concentrations were further assessed using the World Health Organization AirQ+ model to estimate health impacts attributable to long-term exposure. In addition, a sensitivity analysis involving incremental electrification of private vehicles was conducted to examine the additional air quality improvements that may be achieved beyond public transport modernization. The findings provide quantitative evidence that can support transportation planning and policy development toward cleaner and more sustainable urban transport systems.

2. METHODOLOGY

2.1 Study Area and Data

The study was conducted in Trece Martires City, Cavite, Philippines, a rapidly urbanizing component city experiencing increasing transportation demand due to residential, commercial, and institutional developments. The selected study area is a signalized intersection with high traffic activity, representing one of the city's major transport corridors. The intersection accommodates public utility jeepneys (PUJs), tricycles, buses, private cars, motorcycles, and trucks, making it an appropriate location for evaluating traffic-related emissions under various

fleet modernization scenarios.

AERMOD was employed to simulate pollutant dispersion within the study area using site-specific road geometry, meteorological conditions, and traffic characteristics. Figure 1 presents the location of the study area.

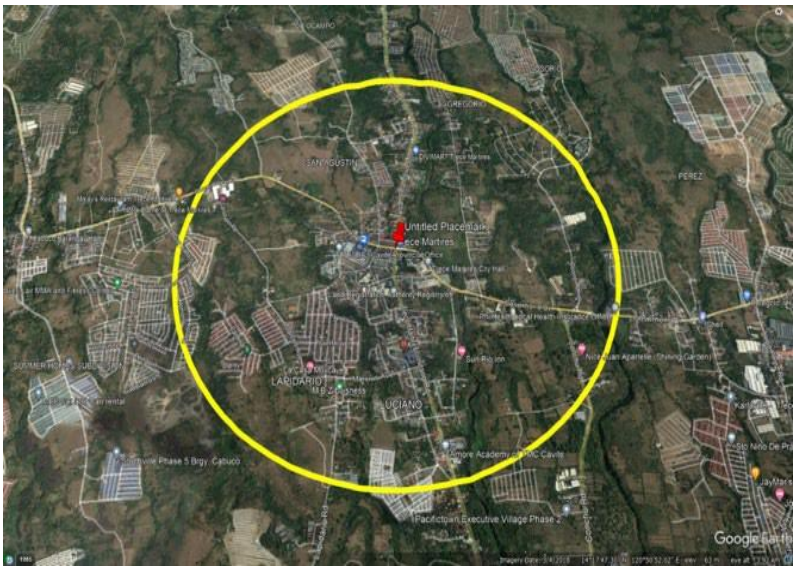


Figure 1. Study Area – Intersection at San Agustin, Trece Martires City, Cavite

2.2 Data Collection

Traffic volume, roadway geometry, meteorological data, emission factors, and mortality statistics were compiled to develop the air dispersion and health impact models.

Traffic counts were conducted during the morning peak hour to determine vehicle composition and traffic flow for each approach of the intersection. Annual Average Daily Traffic (AADT) data were obtained from the Department of Public Works and Highways (DPWH) Road and Bridge Information Application.

Road inventory included lane configuration, road width, and roadway dimensions required for defining the line sources in AERMOD.

Surface and upper-air meteorological observations were processed using AERMET to generate meteorological input files for dispersion modeling. Terrain characteristics were incorporated using digital elevation data to represent local topography.

Vehicle emission factors were compiled from locally available emission inventories and published literature. Separate emission factors were assigned for conventional diesel vehicles, Euro 4-compliant jeepneys, electric jeepneys, electric tricycles, and other vehicle classes. Population and mortality statistics required for the health impact assessment were obtained from government sources.

2.3 Emission Estimation

PM2.5-related health impacts were estimated using WHO AirQ+, which computes attributable Roadways were represented as line sources. Emission rates were estimated using traffic volume, vehicle composition, road length, and pollutant-specific emission factors. Pollutants considered in the analysis included:

- Carbon Monoxide (CO)

- Nitrogen Dioxide (NO_2)
- Sulfur Dioxide (SO_2)
- Fine Particulate Matter ($PM_{2.5}$)

Emission rates for each road segment were calculated under the BAU condition and for each modernization scenario. Source release height, plume height, initial vertical dimension, and road width were determined using average vehicle dimensions following recommendations in the literature and AERMOD guidance.

2.4 Fleet Replacement Scenarios

Several fleet replacement strategies were evaluated to quantify their effects on ambient air quality.

The scenario design followed a staged fleet-replacement framework intended to distinguish partial implementation, complete replacement, mixed technology, and broader fleet electrification. Because no future-year fleet composition or traffic demand was projected, the Business-as-Usual (BAU) scenario is defined in this study as the current/no-intervention reference condition, representing the existing vehicle fleet and traffic activity used in the analysis. It is therefore not a separate future-year forecast. The term baseline is used only to refer to this BAU reference condition when calculating percentage reductions. The 50% replacement scenarios (E4-50% and EJ-50%) were included as analytical intermediate cases between no replacement and complete replacement; 50% is an analytical midpoint and is not presented as a mandated policy target. E4EJ represents a mixed-technology pathway in which 50% of the jeepney fleet is represented by Euro 4 units and 50% by electric jeepneys. The ET scenario was included because the observed traffic count showed a substantial presence of tricycles, while ETEJ represents simultaneous complete electrification of both jeepneys and tricycles. The private-vehicle sensitivity analysis was conducted at 20%, 30%, 40%, and 50% electrification while retaining the ETEJ public-transport condition, allowing the incremental contribution of cars and motorcycles to be examined.

Table 1. Fleet Replacement Scenarios

Scenario	Definition and analytical rationale
BAU	Current/no-intervention reference condition; existing fleet and traffic activity; no future growth projected.
E4-50%	50% of conventional jeepneys replaced by Euro 4 jeepneys; analytical midpoint for partial implementation.
E4-100%	100% of conventional jeepneys replaced by Euro 4 jeepneys; complete conventional modernization case.
EJ-50%	50% of conventional jeepneys replaced by electric jeepneys; analytical midpoint for partial electrification.
EJ-100%	100% of conventional jeepneys replaced by electric jeepneys; complete jeepney electrification.
E4EJ	50% Euro 4 jeepneys + 50% electric jeepneys; mixed-technology pathway.
ET	100% of tricycles replaced by electric tricycles; included because tricycles were substantial in observed traffic.
ETEJ	100% of jeepneys and 100% of tricycles replaced by electric vehicles; combined full public-transport electrification.
EPV20–EPV50	20%, 30%, 40%, and 50% electrification of cars and motorcycles while retaining ETEJ; sensitivity analysis.

2.5 AERMOD Dispersion Modeling

Atmospheric dispersion was simulated using the American Meteorological Society/Environmental Protection Agency Regulatory Model (AERMOD).

AERMOD was used as a steady-state atmospheric dispersion model to estimate pollutant concentrations generated by the modeled road-traffic sources. The model configuration followed the documented inputs used in the full study: AERMET was used to preprocess surface and upper-air meteorological data, AERMAP was used to incorporate terrain information, and the four road approaches were represented as LINE sources. Traffic emission rates were calculated in a spreadsheet from traffic flow, vehicle composition, pollutant-specific emission factors, and road width. The modeled road network covered the roads within approximately a 1.5-km radius of the study intersection, and the principal modeling domain was approximately 3 km × 3 km. A uniform Cartesian receptor grid with 20-m spacing was used, producing 23,409 receptors. Source release height, plume height, and initial vertical dimension were derived from traffic-weighted vehicle heights; the modeled road width included the physical roadway width plus 3 m on each side to represent the additional turbulence associated with vehicle movement.

$$ER = \frac{TFxEF}{Wx1000x3600} \tag{1}$$

where,

ER : emission rate ($gg/ss - mm2$),
EF : emission factor (g/km-veh),
TF : traffic flow for the road link (veh/hr),
W : road width of the modelled road link (m).

Table 2. AERMOD Model Components and Configurations

Model component	Documented configuration
Meteorological processor	AERMET; PAGASA Sangley Point data, March 2022–March 2023
Terrain processor	AERMAP using digital elevation/terrain data
Emission source	LINE sources representing the four road approaches
Road network	Roads within approximately 1.5-km radius of the study intersection
Primary model domain	Approximately 3 km × 3 km
Receptor grid	20-m Cartesian spacing; 153 × 153 receptors = 23,409 receptors
Source release inputs	Traffic-weighted vehicle height, plume height, initial vertical dimension, and road width
Road width treatment	Physical road width + 3 m on each side
Pollutants	CO, NO_2, SO_2, and $PM_{2.5}$
Model outputs	Predicted concentration fields and spatial maximum concentrations for scenario comparison
Calibration	Not performed because continuous reference-grade monitoring was unavailable

The meteorological inputs were obtained from PAGASA's Sangley Point station for March 2022 through March 2023 and processed through AERMET. Separate AERMOD runs were performed for CO, NO_2, SO_2, and $PM_{2.5}$ for each fleet scenario. The model outputs were concentration fields over the receptor network. The study retained the documented AERMOD

formulation and input configuration used in the thesis; software-specific options that were not explicitly varied in the study are not treated as calibrated parameters. This is important because the absence of continuous reference-grade monitoring prevented formal calibration and limits confidence in the absolute concentration estimates, particularly for pollutants other than $PM_{2.5}$.

For scenario comparison and AQI assessment, the study reports the spatial maximum concentration produced over the receptor domain for the pollutant-specific averaging period used by the AQI: 8 hours for CO, 1 hour for NO_2, 1 hour for SO_2, and 24 hours for $PM_{2.5}$. The use of the maximum was intended to identify the modeled hotspot and provide a conservative, common basis for comparing fleet scenarios. It should not be interpreted as the average concentration experienced by residents, a statistical estimate of typical exposure, or a complete description of city-wide air quality. Because the maximum is selected from the modeled receptor field, its value can also be sensitive to receptor spacing, source configuration, and meteorological conditions. The WHO Air Quality Guidelines and the US EPA AQI serve different purposes in the analysis: the former provides health-based guideline values, while the latter converts concentrations over specified averaging periods into an air-quality communication index.

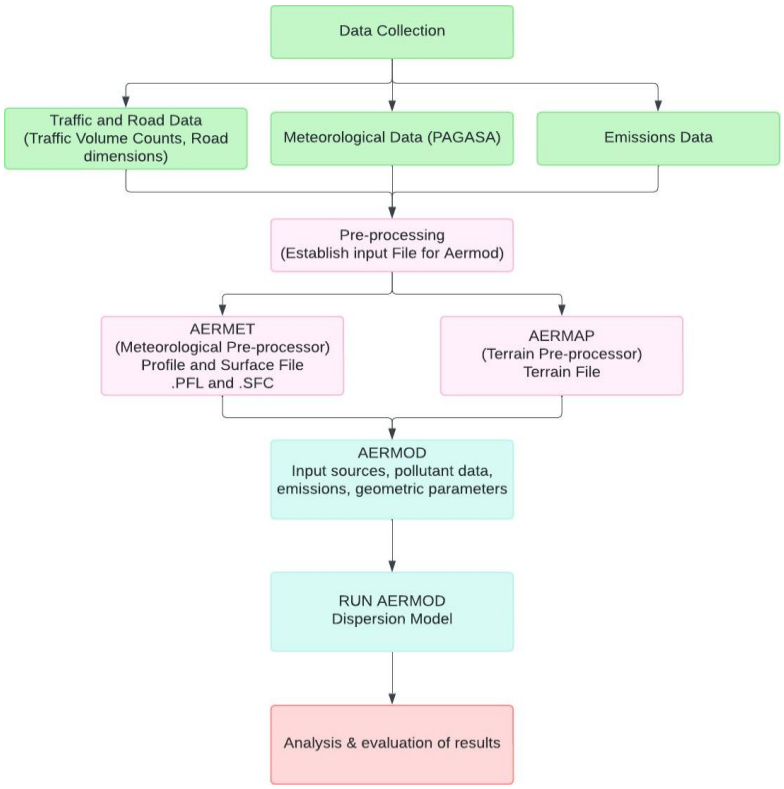


Figure 2. AERMOD Model Application Diagram

2.6 Air Quality Assessment

Predicted pollutant concentrations were evaluated using the United States Environmental Protection Agency Air Quality Index (AQI). Pollutant-specific averaging periods were applied in accordance with regulatory guidelines:

CO – 8-hour average
NO_2 – 1-hour average
SO_2 – 1-hour average

$PM_{2.5}$ – 24-hour average

AQI categories were used as a communication metric for the modeled pollutant concentrations at the specified averaging periods. They were not treated as direct measures of population exposure or individual health risk.

2.7 Health Impact Assessment

Health impacts associated with $PM_{2.5}$ exposure were estimated using the World Health Organization AirQ+ software.

The health impact assessment used the six barangays nearest the study area as the population coverage, with a combined 2020 population of 84,257 (40.03% of the city's total population). The population denominator was therefore tied to the selected six-barangay coverage, not to the full city population and not to individual AERMOD receptor cells. Mortality data, however, were obtained at the city level from the Trece Martires City Health Office for 2022 because barangay-specific mortality data were not available in the study. No separate population was assigned to individual receptor points. For AirQ+, the scenario-specific maximum modeled 24-hour $PM_{2.5}$ concentration was used as the exposure surrogate in the original analysis. This represents a conservative hotspot-based exposure assumption used consistently across scenarios rather than a population-weighted or time-activity-weighted exposure estimate. Accordingly, the attributable proportions and cases should be interpreted as modeled scenario-comparison estimates for the selected population coverage, not as direct estimates of individual-level risk or city-wide health burden.

The assessment therefore provides a comparative estimate of the potential change in health burden across the modeled scenarios under a consistent exposure assumption; it is not a receptor-level exposure assessment.

2.8 Model Validation

Model validation was conducted by comparing BAU $PM_{2.5}$ predictions with 87 short-term field measurements collected at four approaches of the intersection using the TM-380 Multi IAQ Monitor at approximately 1.5 m above ground. A 1-hour averaging period was used for the comparison to match the field measurements. Different model-domain sizes were tested, including 3 km × 3 km, 2 km × 2 km, 1 km × 1 km, 500 m × 500 m, and 250 m × 250 m. The 250 m × 250 m domain produced the highest reported r^2 value of 0.9438. This result indicates strong agreement under the tested conditions but does not establish that the model is universally accurate or calibrated. The production scenario analysis used the approximately 3 km × 3 km domain. Because continuous reference-grade monitoring was unavailable, formal calibration was not performed, and CO, NO_2, and SO_2 were not directly validated. The model also excludes non-road emission sources and uses estimated traffic activity and older/generalized emission factors, which introduce uncertainty in absolute concentrations. The principal value of the modeling results is therefore the consistent comparison of relative changes among scenarios.

The validation analysis used Pearson-based r^2 values to assess agreement between modeled and observed $PM_{2.5}$ concentrations across the tested model-domain sizes.

Because continuous reference-grade monitoring data were unavailable, validation focused on $PM_{2.5}$. CO, NO_2, and SO_2 were interpreted primarily as comparative scenario estimates. The validation result should therefore be read as evidence of agreement under the tested conditions, not as proof of calibrated absolute accuracy.

3. RESULTS AND DISCUSSION

3.1 Traffic Characteristics and Emission Sources

The study intersection exhibited heterogeneous traffic consisting of private cars, motorcycles, public utility jeepneys (PUJs), tricycles, buses, trucks, and other utility vehicles. Traffic counts showed that motorcycles and private cars comprised the largest shares of traffic, while PUJs and tricycles represented substantial additional components of the traffic stream. The resulting emission rates varied by road segment according to traffic volume, vehicle composition, emission factors, and roadway characteristics.

Under the defined BAU reference condition, the modeled road network produced the highest emissions for the assessed pollutants. Replacing conventional jeepneys and tricycles with cleaner technologies reduced the modeled emission rates, with the magnitude depending on the pollutant and the vehicle classes affected.

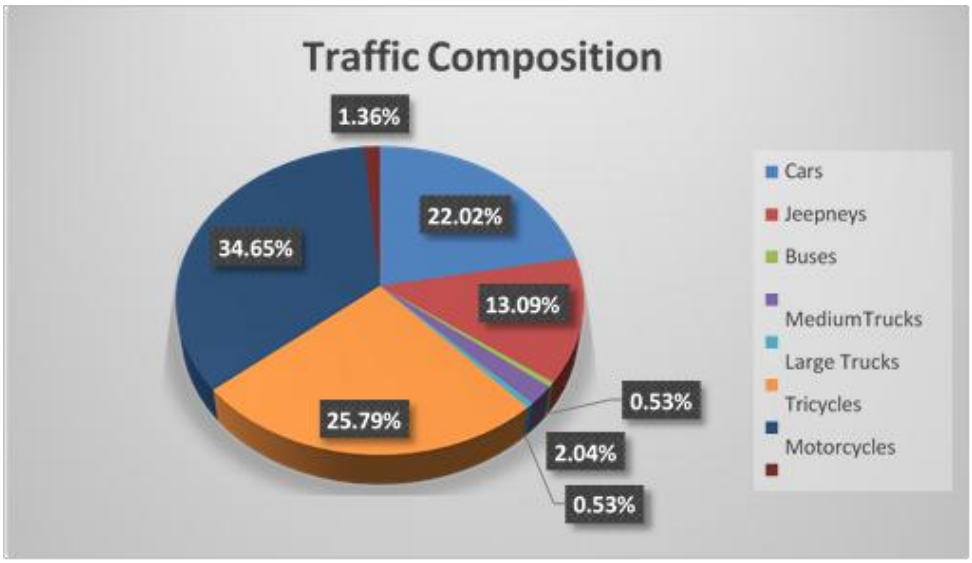


Figure 3. Intersection Traffic Flow Composition

3.2 Air Quality Assessment under Fleet Replacement Scenarios

AERMOD simulations were performed for all fleet replacement scenarios to estimate pollutant concentrations across the receptor domain. Results are reported using the spatial maximum for the pollutant-specific averaging period used in the AQI assessment. These maxima identify modeled hotspots and are used here for consistent scenario comparison; they should not be interpreted as city-wide average concentrations.

3.2.1 Carbon Monoxide (CO)

Carbon monoxide concentrations decreased under all modernization scenarios relative to the BAU condition. Euro 4-compliant jeepneys produced measurable reductions due to improved combustion efficiency, while electric jeepneys and electric tricycles further reduced concentrations through the elimination of tailpipe emissions.

Although CO concentrations were already below regulatory thresholds under most scenarios, fleet modernization further improved ambient air quality and demonstrated the environmental benefits of cleaner vehicle technologies.

Table 3. Maximum Modeled CO Concentration (8-hour Averaging) and Reduction under Fleet Replacement Scenarios

Scenario	Maximum Concentration (ppm)	Reduction (%)	AQI Category
BAU	4.887	0.00	Moderate
E4-50%	4.868	0.39	Moderate
E4-100%	4.850	0.76	Moderate
EJ-50%	4.867	0.41	Moderate
EJ-100%	4.847	0.82	Moderate
E4EJ	4.848	0.80	Moderate
ET	3.281	32.86	Good
ETEJ	3.241	33.68	Good

Note: Maximum concentration denotes the highest modeled receptor value for the stated averaging period; it is a hotspot indicator, not a city-wide average exposure.

The modeled maximum CO concentration changed only slightly for the jeepney-focused scenarios, while the ET and ETEJ cases produced larger reductions because tricycles represented an important gasoline-powered component of the observed traffic stream. The reductions should be interpreted as changes in the modeled hotspot concentration relative to the BAU reference condition, rather than as a uniform change across the entire city.

3.2.2 Nitrogen Dioxide (NO_2)

Nitrogen dioxide exhibited consistent reductions as conventional diesel-powered jeepneys were progressively replaced with cleaner technologies. Full electrification scenarios achieved the greatest decrease because electric vehicles do not generate combustion-related nitrogen oxides.

Compared with Euro 4 modernization alone, electric fleet replacement produced substantially greater reductions, highlighting the additional benefits of complete electrification.

Table 4. Maximum Modeled NO_2 Concentration (1-hour Averaging) and Reduction under Fleet Replacement Scenarios

Scenario	Maximum Concentration (ppm)	Reduction (%)	AQI Category
BAU	539.105	0.00	Unhealthy
E4-50%	531.317	1.44	Unhealthy
E4-100%	523.528	2.89	Unhealthy
EJ-50%	506.359	6.07	Unhealthy
EJ-100%	473.614	12.15	Unhealthy
E4EJ	498.571	7.52	Unhealthy
ET	502.995	6.70	Unhealthy
ETEJ	437.504	18.85	Unhealthy

Note: Maximum concentration denotes the highest modeled receptor value for the stated averaging period; it is a hotspot indicator, not a city-wide average exposure.

Despite reductions in NO_2 concentrations across different scenarios, the AQI category remains in the "Unhealthy" range rather than improving to "Moderate" or "Good." This limited improvement can be explained by the overall distribution of vehicle types in the traffic flow, as shown in Figure 3.

The ETEJ scenario produced the largest modeled NO_2 reduction among the public-transport cases, but the reported AQI category remained “Unhealthy.” The continued presence of other vehicle classes in the traffic stream limits the change that can be attributed to jeepney and tricycle replacement alone. These results indicate that the modeled benefit of a public-transport-only intervention is spatially and source dependent.

3.2.3 Sulfur Dioxide (SO_2)

SO_2 concentrations decreased considerably across modernization scenarios due to reduced sulfur emissions associated with cleaner fuels and electric propulsion systems. The largest reductions were observed under scenarios involving complete replacement of conventional diesel vehicles.

These findings demonstrate the effectiveness of fleet modernization in mitigating sulfur emissions, particularly in urban environments where diesel-powered public transport remains a dominant source.

The modeled SO_2 maximum decreased substantially under scenarios that replaced diesel-powered jeepneys, while ET produced only a small reduction. ETEJ produced the largest reduction (43.20%) relative to the BAU reference condition. Because the reported values are spatial maxima, the results identify changes in the modeled hotspot rather than a uniform city-wide SO_2 reduction.

Table 5. Maximum Modeled SO_2 Concentration (1-hour Averaging) and Reduction under Fleet Replacement Scenarios

Scenario	Maximum Concentration (ppb)	Reduction (%)	AQI Category
BAU	13.223	0.00	Good
E4-50%	10.962	17.10	Good
E4-100%	8.701	34.20	Good
EJ-50%	10.690	19.16	Good
EJ-100%	8.157	38.31	Good
E4EJ	8.429	36.25	Good
ET	12.577	4.89	Good
ETEJ	7.511	43.20	Good

Note: Maximum concentration denotes the highest modeled receptor value for the stated averaging period; it is a hotspot indicator, not a city-wide average exposure.

3.2.4 Fine Particulate Matter ($PM_{2.5}$)

$PM_{2.5}$ showed the largest response among the assessed pollutants under the modeled public-transport scenarios. The ETEJ scenario reduced the maximum modeled 24-hour $PM_{2.5}$ concentration by 46.42% relative to the BAU reference condition.

Table 4. Maximum Modeled $PM_{2.5}$ Concentration (24-hour Averaging) and Reduction under Fleet Replacement Scenarios

Scenario	Maximum Concentration (µg/m³)	Reduction (%)	AQI Category
BAU	119.899	0.00	Unhealthy
E4-50%	117.325	2.15	Unhealthy
E4-100%	114.751	4.29	Unhealthy
EJ-50%	111.783	6.77	Unhealthy
EJ-100%	109.185	8.94	Unhealthy
E4EJ	109.353	8.80	Unhealthy
ET	72.800	39.31	Unhealthy
ETEJ	64.237	46.42	Unhealthy

Note: Maximum concentration denotes the highest modeled receptor value for the stated averaging period; it is a hotspot indicator, not a population-weighted exposure estimate.

The contour maps indicate a reduction in both the magnitude and spatial extent of elevated modeled $PM_{2.5}$ concentrations around the study intersection. The highest-concentration areas under BAU became smaller under the electrification scenarios. These maps provide spatial evidence of localized changes within the receptor domain, rather than evidence of a uniform change in city-wide exposure.

Although ETEJ reduced the reported maximum 24-hour $PM_{2.5}$ concentration by 46.42%, the corresponding AQI category remained "Unhealthy." This result indicates that public-transport electrification alone did not eliminate the modeled hotspot under the assumptions of the study.

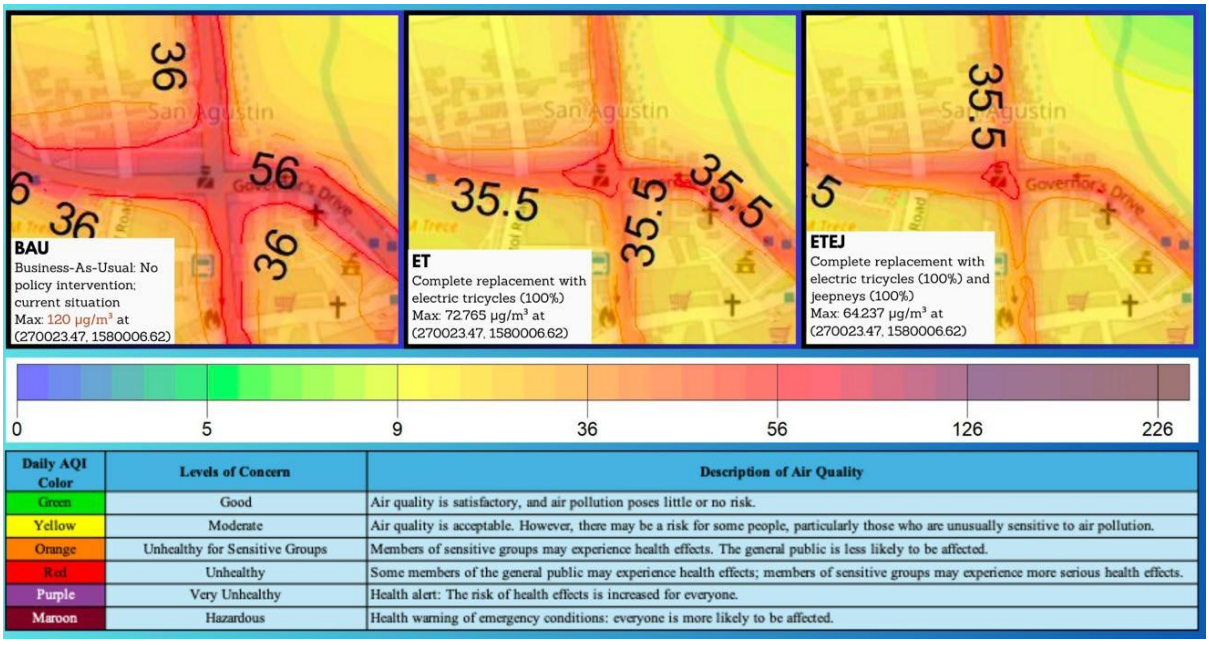


Figure 4. Contour Maps for PM2.5 Concentration Distributions

3.3 Sensitivity Analysis: Private Vehicle Electrification

Because motorcycles and private cars accounted for the largest shares of the observed traffic volume, an additional sensitivity analysis evaluated 20%, 30%, 40%, and 50% electrification of these private vehicles while retaining the ETEJ public-transport condition.

Under BAU, elevated modeled $PM_{2.5}$ concentrations were concentrated along the major roadway and particularly around the signalized intersection. Under ETEJ, the intensity and spatial extent of these elevated areas decreased. Further electrification of private vehicles produced additional reductions, with progressively smaller high-concentration areas in the modeled domain. These spatial changes describe the receptor-domain response to the assumed fleet composition and should not be interpreted as direct population exposure.

The EPV scenarios showed progressively lower maximum modeled $PM_{2.5}$ concentrations as the assumed share of electrified cars and motorcycles increased. EPV50 produced a 70.49% reduction relative to the BAU reference condition.

The reported AQI category improved from "Unhealthy" under BAU to "Unhealthy for Sensitive Groups" under EPV20 and to "Moderate" under EPV50. These categories apply to the reported 24-hour $PM_{2.5}$ maximum and therefore characterize the modeled hotspot metric rather than the exposure of every resident.



Figure 5. Comparative AQI Maps for $PM_{2.5}$ Under Different Scenarios Relative to BAU

The sensitivity analysis indicates that the large numerical share of motorcycles and private cars in the observed traffic stream can materially affect the modeled concentration field. This finding supports examining broader fleet composition when interpreting the localized air-quality effects of public-transport modernization.

The sensitivity analysis shows that changes in the composition of the private-vehicle fleet can materially alter the modeled $PM_{2.5}$ concentration field; this finding is specific to the traffic composition and modeling assumptions of the study site.

Table 5. Simulated $PM_{2.5}$ Concentrations, Air Quality Index, and Percentage Reduction under Private Vehicle Electrification (EPV) Scenarios

Scenario	Maximum Concentration (μg/m³)	Reduction (%)	AQI Category
BAU	119.899	0.00	Unhealthy
ETEJ	64.237	46.42	Unhealthy
EPV20	52.966	55.82	Unhealthy for Sensitive Groups
EPV30	48.109	59.87	Unhealthy for Sensitive Groups
EPV40	41.743	65.18	Unhealthy for Sensitive Groups
EPV50	35.378	70.49	Moderate

3.4 Health Impact Assessment

The health impacts associated with $PM_{2.5}$ were assessed using WHO AirQ+. The analysis used the six nearby barangays as the population coverage (84,257 residents, 40.03% of the city's 2020 population) and city-level 2022 mortality statistics. The AirQ+ exposure input was the scenario-specific maximum modeled 24-hour $PM_{2.5}$ concentration. Because no population was assigned to individual AERMOD receptors and no population-weighted exposure field was constructed, the resulting attributable proportions and cases represent comparative scenario estimates under a conservative hotspot-based exposure assumption.

Under the BAU reference condition, the estimated attributable proportion was 3.33%, corresponding to 12 attributable cases, or 14 cases per 100,000 population at risk. The estimated attributable proportion declined as the modeled $PM_{2.5}$ input decreased across the fleet scenarios. These values should not be interpreted as direct estimates of the number of residents who experienced the modeled maximum concentration.

Under ETEJ, the attributable proportion decreased to 1.30%, corresponding to 5 attributable cases or 5 cases per 100,000 population at risk. The reduction is a scenario-comparison result based on the selected exposure surrogate and population coverage. It does not establish individual-level causation, nor does it imply that the same risk applies uniformly across all barangays or receptor locations.

The health assessment therefore provides an indication of how the modeled fleet scenarios could change the estimated $PM_{2.5}$-attributable burden under the study assumptions. Its interpretation is limited by the use of a maximum modeled concentration as the exposure surrogate, city-level mortality data, and the absence of receptor-level population weighting.

Table 6. Summary of Health Impact Assessment under Fleet Replacement Scenarios

Scenario	Attributable Proportion (%)	Attributable Cases	Attributable Cases per 100,000 Population
BAU	3.33	12	14
E4-50%	3.24	11	13
E4-100%	3.15	11	13
EJ-50%	3.04	11	13
EJ-100%	2.95	10	13
E4EJ	2.96	10	12
ET	1.62	6	7
ETEJ	1.30	5	5

3.5 Model Validation

Several model-domain sizes were evaluated. The 250 m × 250 m domain produced the highest reported r^2 value (0.9438). This strong agreement supports the use of the AERMOD framework for scenario comparison under the tested conditions, but it should not be interpreted as evidence that the model is calibrated or that absolute concentrations are free of uncertainty.

The production scenario analysis used the approximately 3 km × 3 km domain, while the 250 m × 250 m domain was used only for the validation comparison. The distinction is important because the validation-domain size and the production modeling domain serve different purposes.

Only $PM_{2.5}$ was directly validated because suitable continuous monitoring data were unavailable for CO, NO_2, and SO_2. In addition, the model excludes non-road sources and uses

generalized emission factors and estimated traffic activity. Consequently, absolute concentrations should be interpreted cautiously, while consistent percentage differences among scenarios provide the primary basis for comparison.

4. CONCLUSIONS

This study assessed the modeled air-quality implications of public transport fleet replacement and incremental private-vehicle electrification at a high-traffic intersection in Trece Martires City, Cavite. Under the defined current/no-intervention BAU reference condition, the ETEJ scenario reduced the modeled maximum concentrations by 33.69% for CO, 18.85% for NO_2, 43.20% for SO_2, and 46.42% for 24-hour $PM_{2.5}$. The private-vehicle sensitivity analysis, applied while retaining the ETEJ condition, showed progressively lower modeled $PM_{2.5}$ concentrations as the assumed electrification share of cars and motorcycles increased; the EPV50 case produced a 70.49% reduction relative to BAU and an AQI category of "Moderate" for the reported $PM_{2.5}$ metric.

These results describe conditions within the modeled road network and receptor domain and should not be interpreted as uniform city-wide concentrations. The spatial patterns indicate that the largest modeled concentrations were concentrated near the high-traffic intersection and that fleet changes reduced both concentration magnitude and the extent of elevated-concentration areas in the model. The results therefore support interpretation at the study-site/domain level rather than as a direct estimate of exposure for every resident of Trece Martires City.

The AirQ+ analysis estimated lower attributable proportions and cases as the modeled $PM_{2.5}$ input decreased. Under BAU, the central estimate was 3.33% attributable proportion and 12 attributable cases, compared with 1.30% and 5 cases under ETEJ. These estimates were based on 84,257 residents in six nearby barangays and city-level mortality statistics; they did not assign population to individual receptor cells. In addition, the AirQ+ exposure input was the scenario-specific maximum modeled 24-hour $PM_{2.5}$ concentration. The health results should therefore be interpreted as comparative estimates under a conservative hotspot-based exposure assumption, rather than direct individual-level or city-wide health-risk estimates.

Finally, model validation was limited to $PM_{2.5}$ because continuous reference-grade monitoring was unavailable. The reported strong agreement at the 250 m × 250 m validation domain supports the use of the modeling framework for scenario comparison, but the absence of calibration and the use of generalized emission factors limit the certainty of absolute concentration estimates. Future studies should incorporate longer-term monitoring, locally validated emission factors, population-weighted exposure assessment, and broader road-network coverage to strengthen the spatial and health interpretation of fleet-replacement scenarios.

In conclusion, this research affirms that fleet replacement strategies, particularly those centered on electrification, can significantly reduce urban air pollution and associated health risks. The findings clearly demonstrate that replacing conventional public utility vehicles with electric alternatives leads to substantial improvements in air quality, especially when complemented by interventions targeting high-emitting private vehicles like cars and motorcycles. Overall, the study provides compelling evidence of the effectiveness of integrated vehicle modernization strategies in improving air quality in urban settings.

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