Effect of Urban Electric Vehicle Adoption on Childhood Asthma Incidence

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Introduction

Asthma is a common childhood illness that affects 334 million people globally.[1] This condition is associated with substantial healthcare care costs, with the annual cost of asthma in the US accounting approximately $56 billion.[2] It is one of the primary hospitalization causes in the 0-5 years age group.[3] The incidence of childhood asthma has increased in the last four decades, concurrently with changes in the environment.[4]

One of the factors linked with the increased incidence of childhood asthma is environmental pollutants.[5] Specifically, studies have shown the link between childhood asthma and environmental pollutants such as Nitrogen Oxides (NOx) and Particulate Matter Sized 2.5 microns (PM2.5) concentration. The common metric used to quantify the incidence of asthma in these studies is Hazard Ratio (HR), defined as the ratio of reported incidence rates of the illness between the group under study and the control group. Khatri et al[6] measured the number of asthma-related emergency department pediatric visits for several home locations and found that HR doubled as NOx concentration increased from the first quartile range (Q1: 3 - 13 ppb) to fourth quartile range (Q4: 17 - 27 ppb). Similarly, several studies have highlighted incidence of asthma in young children due to increasing concentrations of PM2.5.[7-9] Specifically, Lavigne et al[7] showed that doubling of atmospheric PM2.5 concentration from 4 ug/m3 to 8 ug/m3 can increase asthma HR in young children by more than 20%. Additionally, Pennington et al[10] showed that NOx and PM2.5 concentrations had the strongest impact on respiratory symptoms in young children. Due to the impact of pollutants on health, in 2022, the United Nations declared that "every human has the right to a clean environment, including the right to clean air."[11] It is alarming that data from the American Lung Association's "State of the Air" 2023 report[12] noted that over 35% of all Americans, live in areas impacted by unhealthy levels of ozone and/or particle pollution. This underscores the immediate need to conduct research focusing on efforts to decrease particle pollution exposure.

In the US, one of the primary causes of particle pollution is the transportation sector; contributing to 45% of total NOx emissions and up to 10% of PM2.5 emissions.[13] In their meta-analysis that included 41 studies, Khreis et al[14] provided robust evidence about the association between exposure to traffic related air pollution and development of asthma. This clearly demonstrates the need for research on adoption of zero-emission or electric vehicles (EV) and childhood asthma incidence. As a result, the positive impact of EV adoption on pulmonary health has been recently highlighted.[15] Pan et al[15] analyzed the 2050 scenario of large-scaled EV adoption on broad public health benefits at US metropolitan cities. Furthermore, the American Lung Association[16] has highlighted the important role played by the low EV emissions on lung health. Data from American Lung Association[17] cites that a 100% adoption to EVs can lead to 57,200 fewer asthma-related emergency department visits, potentially saving 110,000 lives in US.

This study only examined the impact at 100% EV adoption, but did not provide comparative data for lung benefits associated with adoption levels between the current 5% EV adoption and the 100% limit. Another landmark study[18] conducted in California stated that the adoption of EV's was empirically shown to reduce asthma HR in California. The study made an important observation that an increase of 20 Zero Emission Vehicles per 1000 population within-zipcode was associated with 3.2% reduction in annual asthma HR. The asthma HR was measured using local hospital patient admission data. An important finding from the California-based study was that there is an adoption gap in EV between communities with different socio-economic status. This emphasizes the relevance of studies that cover varying levels of EV adoption and not just the extremes (i.e., 90-100% adoption).

There is well established literature showing the impact of NOx and PM2.5 concentration changes on childhood asthma HR.[6-10, 19] There is emerging evidence about the impact of 90-100% EV adoption on incidence of asthma.[18] However, there is a lack of research on determining the direct effects of NOx and PM2.5 resulting from EV adoption on childhood asthma HR. To isolate the impact of EVs on childhood asthma HR, it is important to understand how EV adoption affects local NOx and PM2.5 concentrations. In comparison to gasoline cars, EVs produce zero local NOx due to absence of an internal combustion engine. However, EVs are 34 - 41% heavier than gasoline vehicles and therefore lead to more brake/tire wear.[20] The brake/tire worn material ends up as PM2.5 in the atmosphere. The heavier the vehicle (ranging from passenger cars to commercial vehicles), the greater the material wear and PM2.5 emissions from the EV.[20] The PM2.5 non-exhaust emissions from braking and tire wear can increase from 0.0165 to 0.0169 g/km-vehicle for passenger cars and from 0.0226 to 0.0241 g/km-vehicle for commercial vehicles.[20] On the other hand, the exhaust-based emissions for EV are zero. As a result, the adoption of EVs can have positive effects on the environment but with different rates. While the non-particulate gas concentration such as NOx can rapidly decrease, the PM2.5 concentration may decrease at a slower rate. So, a higher rate of EV adoption may not offer the high proposed advantage in decreasing asthma rates compared to a lower rate of EV adoption. Also, given that brake/tire worn is dependent on the type of vehicle, one needs to study the effect of EV adoption, taking into account the type of vehicle. Therefore, it is vital to compare the different levels of EV adoption considering the type of vehicle (passenger cars versus commercial vehicle) when evaluating its potential effect on childhood asthma HR.

Collectively, all of the above work points to a need for a study that examines varying levels of EV adoption on incidence of asthma in urban cities with different particle pollution exposure. The focus on urban cities is to ensure US regions with high population and, therefore, vehicle density are both considered. To my knowledge, the effect of varying levels of EV adoption and their net effect on NOx and PM2.5 associated childhood asthma HR or incidence, has not been studied. The current study adds novel data and aims to fill this critical research gap. The effect of varying levels of EV adoption on NOx and PM2.5 concentration, and subsequently, on incidence (or HR) of childhood asthma, forms the primary premise of the current study. Additionally, the effects of EV adoption in passenger cars and commercial vehicles are studied to account for the heaviness of commercial vehicles and the resulting higher brake/tire wear.

Research Questions, Hypothesis, Outcomes

1. To compare the effect of varying levels of EV adoption on incidence of childhood asthma as measured by HR related to NOx pollution for three urban cities with different year-round pollution levels.

<u>Hypothesis 1.1</u>

The childhood asthma HR related to NOx will decrease significantly as rate of EV adoption increases from the current 5% to 75% in passenger cars. This may vary dependent on the pollution level of the city.

<u>Hypothesis 1.2</u>

For each of these EV adoption levels, the childhood asthma HR related to NOx is significantly lower for the adoption of passenger cars and commercial vehicles as compared to the adoption case of only passenger cars.

<u>Expected outcome:</u> The outcome of this study will provide data on the impact of varying levels of EV adoption in passenger cars/commercial vehicles on childhood asthma HR. This is beneficial to consider since communities with differing socioeconomic criteria may need data of varying levels of EV adoption.

2. To compare the effect of varying levels of EV adoption on incidence of childhood asthma as measured by HR related to PM2.5 pollution for three urban cities with different year-round pollution levels.

<u>Hypothesis 2.1</u>

The childhood asthma HR related to PM2.5 will decrease significantly as rate of EV adoption increases from the current 5% to 75% in passenger cars. This may vary dependent on the pollution level of the city.

<u>Hypothesis 2.2</u>

For each of these EV adoption levels, the childhood asthma HR related to PM2.5 is significantly lower for the adoption of passenger cars and commercial vehicles as compared to the adoption case of only passenger cars.

<u>Expected outcome:</u> The outcome of this study will encourage research initiatives on developing materials for brakes and tires that cause less wear and PM2.5 pollution.

Materials and Methods

This simulation-based study leverages the following data (mean, SD) from literature: (a) Correlation between NOx concentration and asthma HR in children[6, 10, 14, 21] (b) Correlation between PM2.5 concentration and asthma HR in children[7-9] (c) fraction of environmental NOx and PM2.5

attributed to environment from road transport[13] (d) within transportation, the fraction of environmental NOx and PM2.5 attributable to passenger cars and commercial vehicles (e) increase in PM2.5 non-exhaust emission per vehicle per mile for EVs (compared to gasoline cars) for passenger cars and commercial vehicles.[20] Combining these data, the study simulated the effect of varying levels of EV adoption on childhood asthma HR. The detailed methods/steps for both research questions 1 and 2 are described below.

1. Using literature data,[6] a least-squares regression line (LSRL) (and the confidence interval for each concentration level) modeling the correlation between NOx concentration and childhood asthma HR was calculated. Table 1 shows the data utilized in this study.[6] The following correlation equation was derived for the data: *HR = 0.042 * NOx Concentration + 0.854*

Table 1. NOx and childhood asthma HR data

NOx Concentration (ppb)	HR	%Conf. Int. (-)	%Conf. Int. (+)
8	1	-	-
14.5	1.316	13.9%	16.1%
16	1.922	13.9%	16.2%
22	1.893	16.1%	19.2%

2. Using literature data,[7] a LSRL (and the confidence interval for each concentration level) modeling the correlation between PM2.5 concentration and childhood asthma HR was calculated. Table 2 shows the data utilized in this study.[7] The following correlation equation was derived for the data: *HR = 0.068 * PM2.5 Concentration + 0.504*

Table 2. PM2.5 and childhood asthma HR data

PM2.5 Concentration (ug/m3)	HR	%Conf. Int. (-)	%Conf. Int. (+)
4	1.01	-	-
5	1.06	0.9%	0.9%
6	1.11	2.7%	1.8%
7	1.17	2.6%	2.6%
8	1.2	1.7%	3.3%
9	1.24	3.2%	4.0%
10	1.28	3.9%	4.7%
11	1.3	3.9%	5.4%

3. The following three cities were chosen based on different levels of year-round pollution (ranging from ‘cleanest’ to ‘polluted’): Rochester, NY; Nashville, NY; Fresno, CA.[22]

4. The PM2.5 concentration in ug/m3 and NOx concentration in ppb were determined for the three cities.[23]
5. Using literature data,[13] the fraction of environmental NOx and PM2.5 attributable to road transport was obtained for the three cities.
6. Using literature data on number of vehicles in each category,[24] the fraction of environmental NOx and PM2.5 concentration attributable to passenger cars and commercial vehicles, as sub-fraction of the step 5 fraction, was obtained. See Tables 3 and 4.

Table 3. NOx concentration and percentage of the concentration related to passenger cars (PC) and commercial vehicles (CV)[13, 23, 24]

City	NOx Annual Mean (ppb)	% contribution from PC	% contribution from CV
Rochester, NY	7	39.8%	2.8%
Nashville, TN	13	46.8%	3.3%
Fresno, CA	20	39.8%	2.8%

Table 4. PM2.5 concentration and percentage of the concentration related to passenger cars (PC) and commercial vehicles (CV)[13, 23, 24]

City	PM2.5 Annual Mean (ug/m^3)	% contribution from PC	%contribution from CV
Rochester, NY	6.3	4.2%	0.3%
Nashville, TN	9.3	4.2%	0.3%
Fresno, CA	14.8	1.4%	0.1%

7. Using literature data,[20] the percentage reduction of PM2.5 emissions between fully electric and gasoline for passenger and commercial vehicles was calculated. Refer to Table 5.

Table 5. Reduction in PM2.5 emission between gasoline and electric vehicles related to passenger cars (PC) and commercial vehicles (CV)[20]

	Gasoline			Electric			
Type	Non-exhaust PM2.5 (g/vehicle-mile)	Exhaust PM2.5 (g/vehicle-mile)	Total (g/vehicle-mile)	Non-exhaust PM2.5 (g/vehicle-mile)	Exhaust PM2.5 (g/vehicle-mile)	Total (g/vehicle-mile)	% change in PM 2.5
PC	0.0143	0.0038	0.0181	0.0147	0.0000	0.0147	19%
CV	0.0196	0.0029	0.0225	0.0211	0.0000	0.0211	6%

8. For incremental percentage/fraction values ranging from 5-75%, representing EV adoption in passenger cars and commercial vehicles, reduction in environmental PM2.5 and NOx was estimated using linear proportionality on data from steps 4, 5, 6, and 7 for the three cities. Refer to Tables 6 – 8. Note that the current EV adoption level is 5% across the US.[25]

Table 6. Estimated change in environmental NOx and PM2.5 with EV adoption in (a) passenger cars (PC) and (b) both, passenger cars (PC) and commercial vehicles (CV) for Rochester, NY

% EV adoption	NOx level (ppb) with only PC adoption	NOx level (ppb) with adoption in both	PM2.5 level (ug/m3) with only PC adoption	PM2.5 level (ug/m3) with adoption in both
5% - current	7.000	7.000	6.300	6.300
25%	6.413	6.372	6.289	6.289
50%	5.826	5.744	6.279	6.278
75%	4.946	4.802	6.263	6.262

Table 7. Estimated change in environmental NOx and PM2.5 with EV adoption in (a) passenger cars (PC) and (b) passenger cars (PC) and commercial vehicles (CV) for Nashville, TN

% EV adoption	NOx level (ppb) with only PC adoption	NOx level (ppb) with adoption in both	PM2.5 level (ug/m3) with only PC adoption	PM2.5 level (ug/m3) with adoption in both
5% - current	13.000	13.000	9.300	9.300
25%	11.719	11.629	9.284	9.284
50%	10.438	10.258	9.269	9.268
75%	8.516	8.201	9.245	9.244

Table 8. Estimated change in environmental NOx and PM2.5 with EV adoption in: passenger cars (PC) and, passenger cars (PC) and commercial vehicles (CV) for Fresno, CA

% EV adoption	NOx level (ppb) with only PC adoption	NOx level (ppb) with adoption in both	PM2.5 level (ug/m3) with only PC adoption	PM2.5 level (ug/m3) with adoption in both
5% - current	20.000	20.000	14.800	14.800
25%	18.323	18.205	14.791	14.791
50%	16.647	16.411	14.783	14.783
75%	14.132	13.719	14.771	14.770

9. Randomized simulations (using mean and standard deviation), using the data from steps 1 and 2, was run to calculate childhood asthma HR separately for PM2.5 and NOx for varying incremental adoption of EV in passenger cars and commercial vehicles for the three cities.
10. Two-way ANOVA was performed on the data set using EV adoption (levels: 5, 25, 50, 75%) and vehicle type (levels: passenger cars only, passenger cars and commercial vehicles), as two independent variables.

Results

Statistical Analysis

All of the simulations and proportionality calculations were performed using MS Excel ToolPak. The statistical analyses (2-way ANOVA) were performed using SPSS 28.0. The alpha level was set priorly at $P < 0.05$. Descriptive statistics for all the variables were calculated. Given the 2-way factorial design, a 2-way ANOVA (EV adoption level x Vehicle Type) with Bonferroni's post-hoc testing was used to assess if varying levels of EV adoption and type of vehicle had an effect on childhood asthma ratio HR at the chosen urban cities (Rochester, Nashville, and Fresno). The two between-subject factors were: 1) EV adoption, with 4 levels: 5% vs. 25% vs. 50% vs. 75% and 2) Type of vehicle with 2 levels" (a) passenger cars only (b) passenger cars and commercial vehicles. The dependent variable was childhood asthma HR.

Effect of varying levels of EV adoption on childhood asthma HR related to NOx pollution for three urban cities

Table 9. ANOVA results for effects of EV adoption on NOx-related childhood asthma HR§

	Source of variation	SS	df	MS	F	Significance	Power
Rochester	EV adoption	0.506	3	0.169	18.620	<0.001	1.000
	Vehicle (PC vs. both)	0.000	1	0.000	0.014	0.907	0.052
	Interaction	0.004	3	0.001	0.138	0.937	0.075
	Total error	2.103	232	0.009			
Nashville	EV adoption	3.103	3	1.034	70.243	<0.001	1.000
	Vehicle (PC vs. both)	0.000	1	0.000	0.004	0.951	0.050
	Interaction	0.121	3	0.040	2.737	0.044	0.659
	Total error	3.416	232	0.015			
Fresno	EV adoption	4.825	3	1.608	51.747	<0.001	1.000
	Vehicle (PC vs. both)	0.001	1	0.001	0.019	0.891	0.052
	Interaction	0.047	3	0.016	0.504	0.680	0.152
	Total error	7.210	232	0.031			

§SS: Type III Sum of Squares; df: degrees of freedom; MS: Mean Squares; F: F statistic; PC: passenger cars, both: passenger cars and commercial vehicles

There was no interaction effect between % of EV adoption and vehicle groups (PC and both) observed for cities of Rochester ($P = 0.937$) and Fresno ($P = 0.680$); however, for Nashville ($P = 0.044$) it existed. For the main effects, the effect of EV adoption on NOx-related HR was significant and vehicle groups was insignificant across all three cities (see Table 9). Tables 10 - 12 shows pairwise comparison for varying EV adoption levels for Rochester and Fresno. Except for the change of HR between 25% to 50% EV adoption for Rochester ($P = 1.000$), all pairwise comparisons showed statistical significance ($P < 0.05$).

For Nashville, an interaction between the two independent variables was observed. Simple main effects revealed that while EV adoption level in passenger cars has significant impact on childhood asthma HR, the incremental effect of EV adoption in commercial vehicles is insignificant.

Table 10. Pairwise comparison of NOx related childhood asthma HR for Rochester

EV adoption % (I)	EV adoption % (J)	Mean difference (I - J)	Significance
5	25	0.047	0.047
	50	0.066	0.001
	75	0.128	0.001
25	5	-0.047	0.047
	50	0.020	1.000
	75	0.081	0.001
50	5	-0.066	0.001
	25	-0.020	1.000
	75	0.062	0.003
75	5	-0.128	0.001
	25	-0.081	0.001
	50	-0.062	0.003

Table 11. Pairwise comparison of NOx related childhood asthma HR for Nashville

EV adoption % (I)	EV adoption % (J)	Mean difference (I - J)	Significance
5	25	0.069	0.012
	50	0.171	0.001
	75	0.302	0.001
25	5	-0.069	0.012
	50	0.102	0.001
	75	0.233	0.001
50	5	-0.171	0.001
	25	-0.102	0.001
	75	0.131	0.001
75	5	-0.302	0.001
	25	-0.233	0.001
	50	-0.131	0.001

Table 12. Pairwise comparison of NOx related childhood asthma HR for Fresno

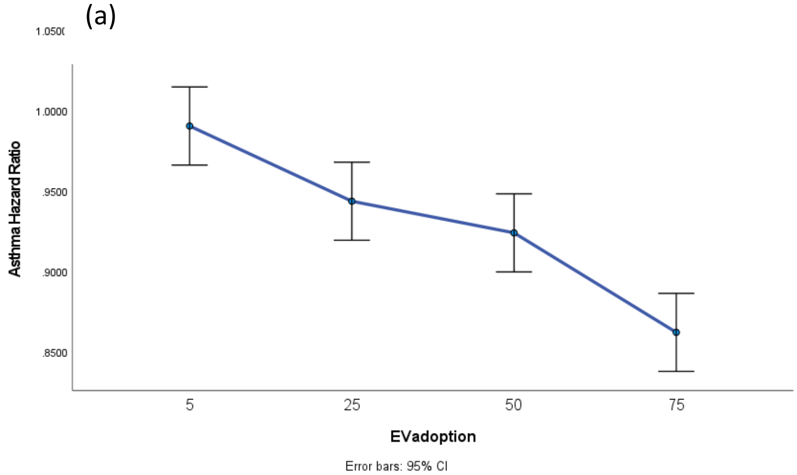
EV adoption % (I)	EV adoption % (J)	Mean difference (I - J)	Significance
5	25	0.088	0.042
	50	0.205	0.002
	75	0.379	0.001
25	5	-0.088	0.042
	50	0.118	0.001
	75	0.291	0.001
50	5	-0.205	0.001
	25	-0.118	0.002
	75	0.173	0.001
75	5	-0.379	0.001
	25	-0.291	0.001
	50	-0.173	0.001

Effect of EV adoption in passenger cars on NOx-related HR

Figure 1 demonstrates the significant impact of varying EV adoption in passenger cars on childhood asthma HR. As the EV adoption increases from 5% (the current level of adoption) to 75%, the HRs decrease significantly and across all three cities. Table 13 provides relative (in terms of percentage change from current) variation of HR with respect to EV adoption. At 75% adoption of EV, a 20% and higher decrease in NOx-related HR is observed for Nashville and Fresno.

Figure 1. Effect of EV adoption on NOx related mean childhood asthma HR (a) Rochester (b) Nashville (c) Fresno. Error bars denote 95% confidence interval.

(a)



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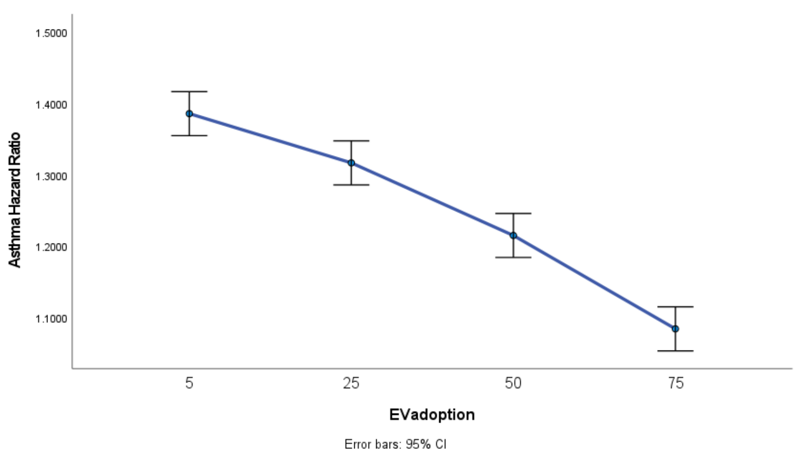

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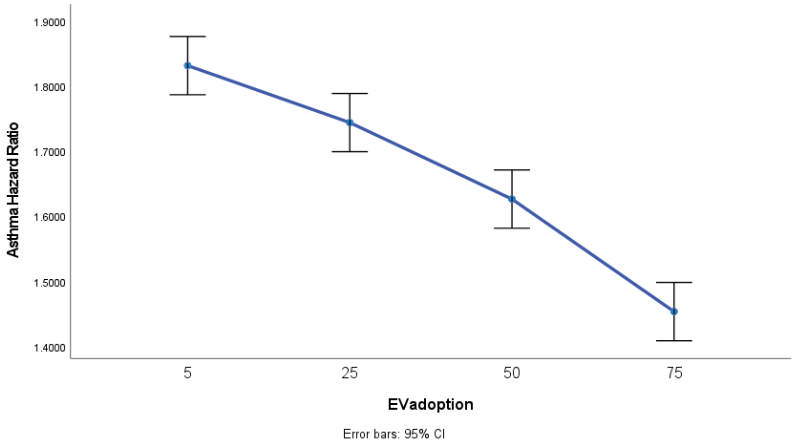


Table 13. Overall impact (% change from current value) of EV adoption on NOx related childhood asthma HR

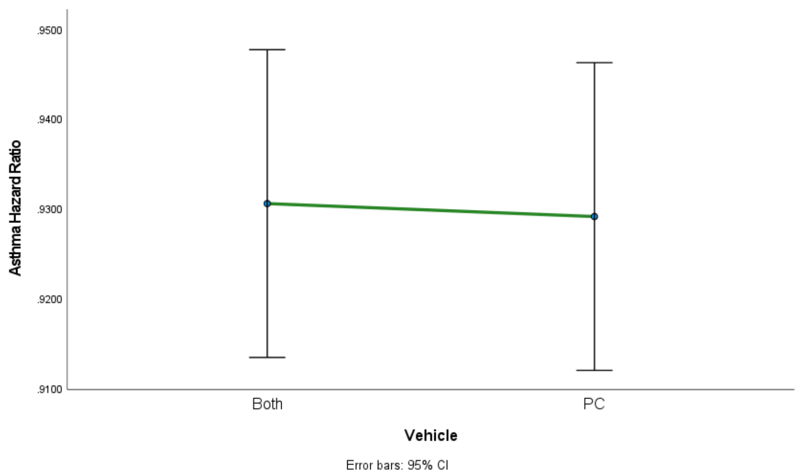
	EV adoption	Total Sample Mean	% Change from current
Rochester	5% - current	0.989	0
	25%	0.943	-5%
	50%	0.923	-7%
	75%	0.862	-13%
Nashville	5% - current	1.385	0
	25%	1.316	-5%
	50%	1.214	-12%
	75%	1.083	-22%
Fresno	5% - current	1.833	0
	25%	1.745	-5%
	50%	1.627	-11%
	75%	1.454	-21%

Effect of EV adoption in passenger cars and commercial vehicles on NOx-related HR

Figure 2 shows that incremental adoption of EV within commercial vehicles has no significant effect on childhood asthma HR. This corroborates the P values observed in Table 9.

Figure 2. Changes of NOx related childhood asthma HR between two groups: passenger car (PC) only, and both, passenger cars and commercial vehicles (a) Rochester (b) Nashville (c) Fresno. Error bars denote 95% confidence interval.

(a)



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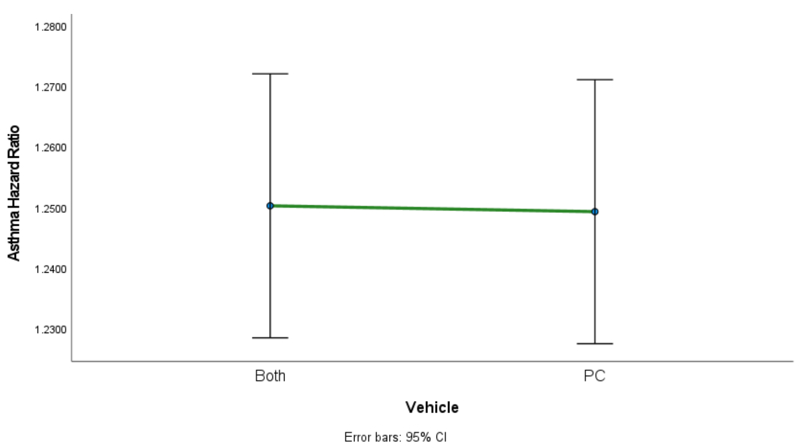

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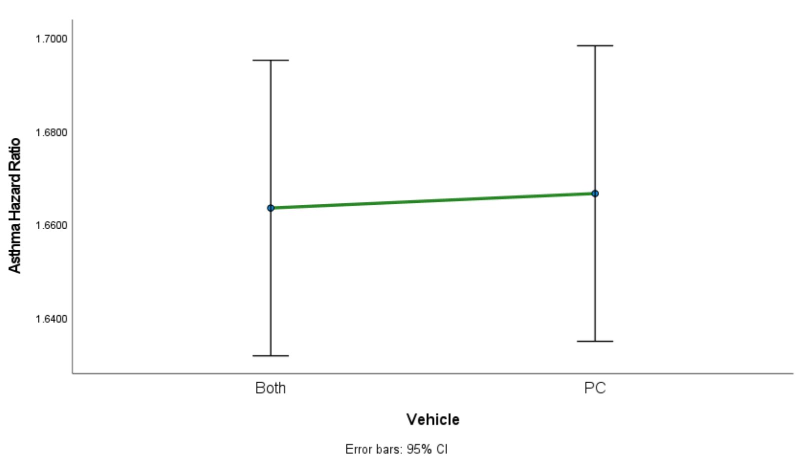


Effect of varying levels of EV adoption on childhood asthma HR related to PM2.5 pollution for three urban cities

There was no interaction effect between EV adoption and vehicle groups (PC and both) observed for cities of Rochester (P=0.05), Nashville (P = 0.994) and Fresno (P = 0.396) (refer to Table 14). Even in the main effects, EV adoption and vehicle group (passenger cars only and both) have non-significant impact on the PM2.5-related childhood asthma HR, as denoted by $P \geq 0.05$.

Table 14. ANOVA results for effects of EV adoption on PM2.5 related childhood asthma HR§

	Source of variation	SS	df	MS	F	Significance	Power
Rochester	EV adoption	0.001	3	0.000	0.259	0.855	0.099
	Vehicle (PC vs. both)	0.003	1	0.003	3.008	0.084	0.408
	Interaction	0.009	3	0.003	2.636	0.050	0.640
	Total error	0.259	232	0.001			
Nashville	EV adoption	0.004	3	0.001	1.013	0.388	0.274
	Vehicle (PC vs. both)	0.000	1	0.000	0.154	0.695	0.068
	Interaction	0.000	3	0.000	0.026	0.994	0.055
	Total error	0.324	232	0.001			
Fresno	EV adoption	0.003	3	0.001	0.539	0.656	0.160
	Vehicle (PC vs. both)	0.000	1	0.000	0.012	0.913	0.051
	Interaction	0.006	3	0.002	0.995	0.396	0.269
	Total error	0.442	232	0.002			

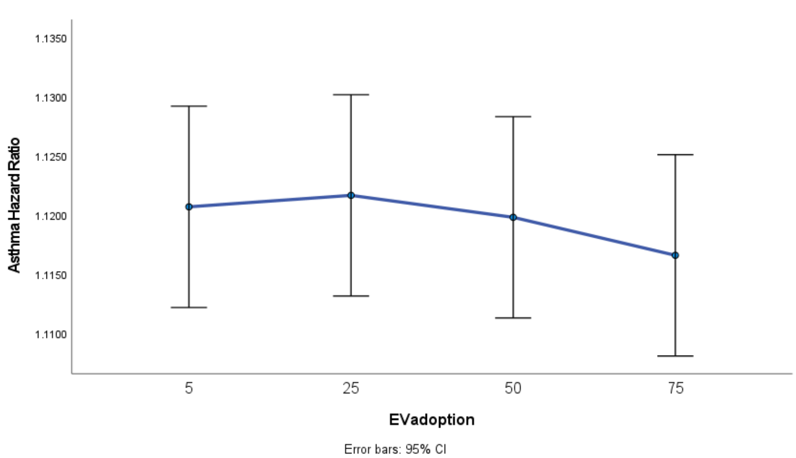
§SS: Type III Sum of Squares; df: degrees of freedom; MS: Mean Squares; F: F statistic, PC: passenger cars, both: passenger cars and commercial vehicles

Effect of EV adoption in passenger cars on PM2.5-related HR

The insignificant impact of EV adoption on PM2.5 related childhood asthma HR is also evident from Figure 3.

Figure 3. Effect of EV adoption on PM2.5 related mean childhood asthma HR (a) Rochester (b) Nashville (c) Fresno. Error bars denote 95% confidence interval.

(a)



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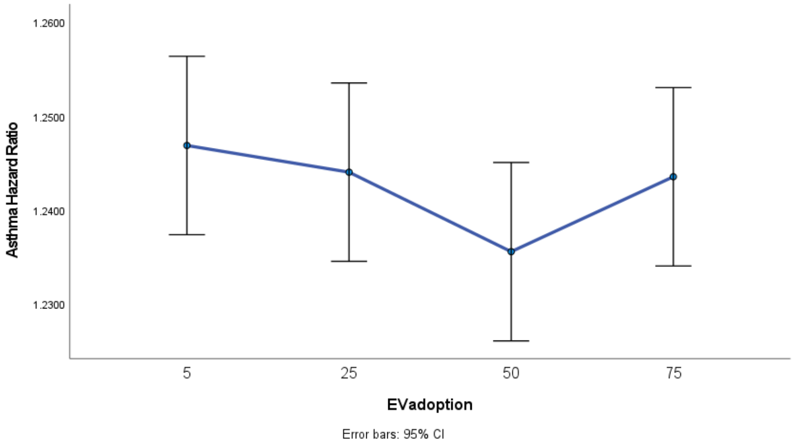

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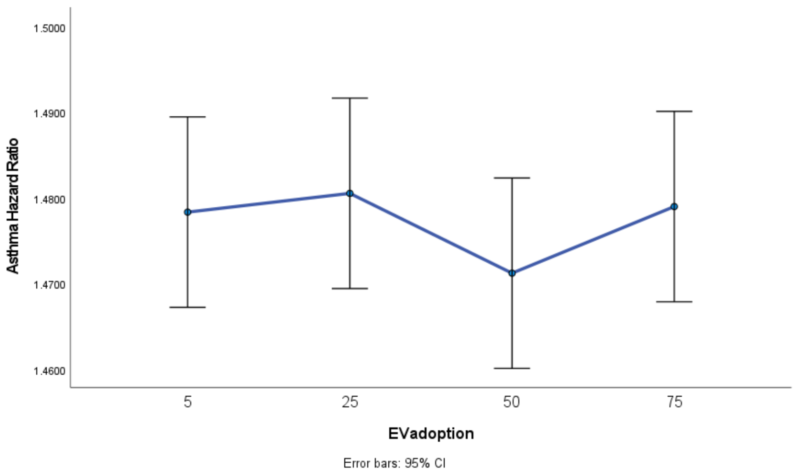
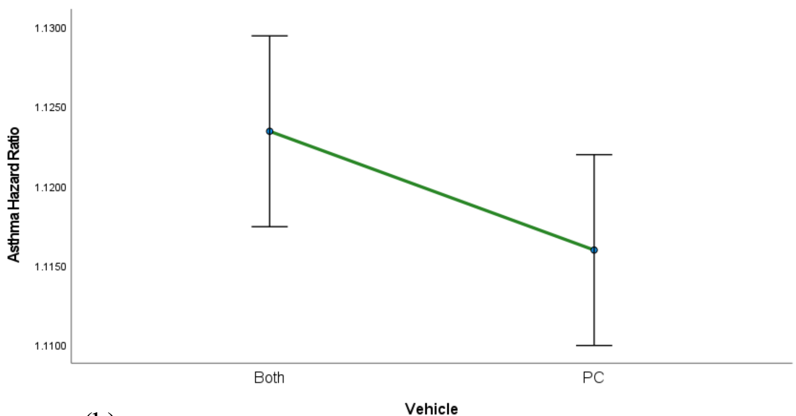


<u>Effect of EV adoption in passenger cars and commercial vehicles on PM2.5 related HR</u>

The effect of vehicle group (passenger cars vs. both) on PM2.5-related HR is insignificant since $P > 0.05$ for all three cities (Table 14).

Figure 4. Changes of PM2.5 related childhood asthma HR between two groups: passenger car (PC) only, and both, passenger cars and commercial vehicles (a) Rochester (b) Nashville (c) Fresno. Error bars denote 95% confidence interval.

(a)



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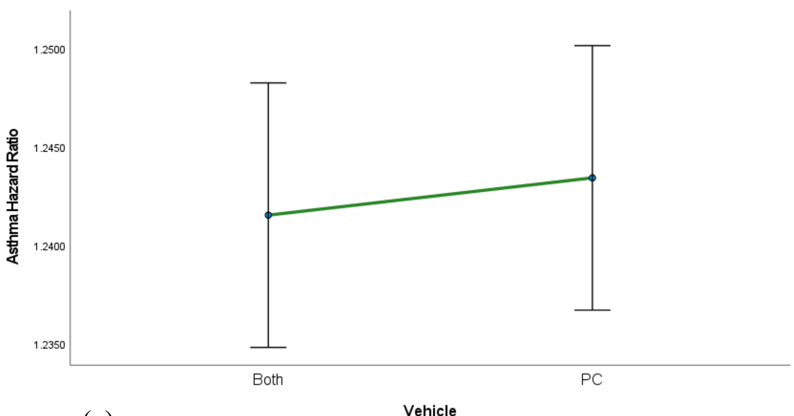

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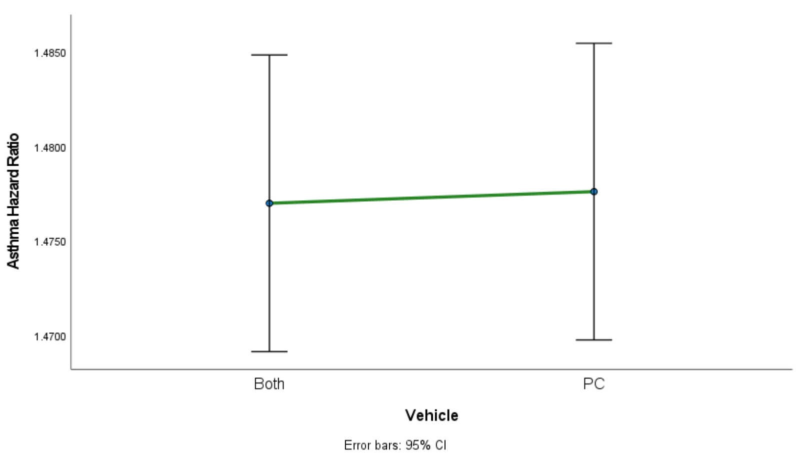

Discussion

Transitioning to EV to decrease childhood asthma incidence in the US is a critical public health issue warranting immediate research. The current study uses an innovative approach by comparing the effect of varying levels (5, 25, 50 and 75%) of EV adoption on childhood asthma HR related to NOx and PM2.5 using analytical and numerical simulation approach. This study contributes to the existing literature by providing preliminary data that varying EV adoption levels have significant differences on childhood asthma HR related to NOx for passenger cars. The degree of impact varies with the city based on the existing NOx concentration and the fraction of it coming from transportation.

The first outcome of the study is that compared to current EV adoption levels (5%), higher rates of EV adoption led to significant change in the HR associated with NOx in young children. At a 25% EV adoption level, the reduction in HR remains below 10% for all three cities, but at a 50% adoption level, this impact increased significantly in Nashville and Fresno (12% and 11%, respectively). At the higher end of EV adoption (75%), a 13-22% impact on childhood asthma HR is observed in all three cities. There is lack of studies that have examined discrete EV adoption levels, their systematic impact on NOx/PM2.5, and finally, impact on asthma HR for children. Pan et al[15] showed using theoretical methods that for the city of Greater Houston, as EV adoption reaches 50-95%, the NOx levels can reduce by 1 – 4 ppb. Their NOx reduction interpolated to EV adoption levels of 50% and 75% is in overall agreement to the NOx reductions reported in the present study. Their study predicted that this improvement may prevent asthma exacerbation in 7500 cases. Their study, however, focused on only one city and did not report findings in terms of HR. The findings of another recent study in California, which was conducted across several zip codes within the state, was that an addition of 20 EVs per 1000 population reduced asthma related visits by 3.2%.[18] Since the California-based study reported their EV adoption in terms of vehicles per 1000 people, their data cannot be directly compared to the current study because the number of vehicles owned per 1000 people is unknown. The California-based study[18] only considered one geographical region and did not conduct separate assessment on the health impact contributions from NOx and PM2.5 with different levels of adoption. The first finding underscores the importance of incrementally promoting increased level of EV adoption beyond the current 5%. One of the key points from Garcia et al[18] was the disparity in adoption gap based on socio-economic status. This result helps understand the impact created by intermediate levels of EV adoption (25-50%), which may be more realistic in the near term due to socio-economic challenges in EV adoption.

The present study showed that the level of impact of EV adoption on NOx related childhood asthma HR between cities differing in year-round pollution levels can be different. This is because the NOx concentration reduction in any city is influenced by two factors: (a) current/baseline NOx concentration of the city (b) percentage contribution of NOx coming from vehicles. As a result, the impact of EV adoption on childhood asthma HR in already cleaner (based on NOx concentration) cities (like Rochester) is expected to be lower than those such as Fresno with a higher current NOx concentration. Secondly, although Nashville has a medium-level year-round pollution in terms of NOx concentration, it has a higher percentage (46.8%) associated with passenger cars, compared to Fresno (39.8%). Therefore, the impact of 75% EV adoption on Nashville's HR is 20% or higher, similar to Fresno, which has a higher NOx concentration but a lower percentage (39.8%) associated with passenger cars. One possible explanation is Fresno's NOx concentration is influenced by other environmental pollutant sources (like power plants and industries) more than Nashville.

Based on prior results,[18] we expected to see a higher impact coming from EV adoption in commercial vehicles. Interestingly, the data in this study showed that comparison between the impact of EV adoption in passenger cars and commercial vehicles was the same. There are several factors that can explain this finding. While the contribution of passenger cars to NOx concentration ranges between 39.8 – 46.8%, the contribution of commercial vehicles to NOx concentration ranges between 2.8 – 3.3%. This results in a relatively low incremental NOx concentration impact resulting from commercial vehicles. For example, at a 75% EV adoption level, the NOx concentration reduces from 4.946 to 4.802 (by 2.9%) for Rochester when adoption in both types for vehicles is considered. The change for Fresno for the same change of adoption from passenger cars to both is also 3%. This small change becomes diluted when converted to HR because the standard deviation for the obtained HR is ~15% overall. This leads to the incremental benefit of EV adoption in commercial vehicles to being an insignificant factor impacting the NOx-related HR for childhood asthma. Neither of the past studies have discerned the impact of commercial vehicles. These data are important while considering EV adoption and prioritizing passenger cars, versus commercial vehicles.

Finally, changing EV adoption levels did not impact PM2.5 associated HR in any of the cities for both types of vehicles studied. This could be accounted by the variable contributions of both vehicle types to NOx vs PM2.5 concentrations. In comparison to NOx, the percentage contribution of passenger cars to PM2.5 concentration in the three cities is substantially low (ranging between 1.4 – 4.2%), and the contribution from commercial vehicles is even lower (0.1 – 0.3%). Furthermore, while the NOx concentration associated with vehicles can be 100% eliminated by EV adoption, PM2.5 concentration can only be reduced only by 19% and 6% by EV adoption in passenger cars and commercial vehicles, respectively. This is due to the fact that EV adoption eliminates exhaust-based emissions for PM2.5 but not non-exhaust based PM2.5 emissions from increased brake and tire wear.[20] The combination of these effects is evident from the fact that even for a relatively PM2.5-polluted city like Fresno, 75% EV adoption only reduces PM2.5 concentration from 14.80 to 14.77 ug/m3. This explains the insignificant impact observed by EV adoption across passenger cars and commercial vehicles on PM2.5 related childhood asthma HR across all three cities. A possible explanation of this finding could be that PM2.5 concentration is constituted of other factors than vehicles, such as forest fires, power generation exhaust, industrial exhaust, and dust storms. This finding is relevant because it indicates that better brake and tire materials may be needed to reduce wear and thereby non-exhaust emissions from EVs. This could become a potential path to making EV adoption impact on PM2.5 more significant.

Limitations and Future Work

The results of this study should be interpreted with caution due to the following limitations. The study did not include the impact of EV adoption on PM10 and other oxides (such as CO and SO2), as part of the evaluation. The NOx and PM2.5 reductions in this study do not consider changes to pollutant concentrations from shifting weather patterns and atmospheric air convection events (like storms, winds, etc.).

The present study is focused on local, urban PM2.5 and NOx concentration and does not account for the pollutant near rural/sub-rural areas where power plants that generate power for EV are located. Additional research is needed to account for emissions and health impact in non-urban areas. We did not account for emissions generated during the manufacturing and recycling of the EV, especially the batteries. The manufacturing and recycling plants are also located in rural areas and require future investigation on emissions and health effects.

Conclusions

Preliminary findings from the study showed that comparison of different levels of EV adoption in passenger cars led to a significant effect on NOx-related childhood asthma incidence for all the three urban cities studied. In general, the level of impact on NOx related incidence of childhood asthma is dependent on the current NOx concentration in a city and the fraction of the city's NOx concentration attributable to passenger cars. Another contribution of this study is that the incremental effect of EV adoption in commercial vehicles, compared to passenger cars alone, was found to be insignificant. Current data shows that different levels of EV adoption had an insignificant effect on the PM2.5 related childhood asthma incidence.

Public health initiatives for clean air demand urgent research on EV adoption related to the incidence of childhood asthma in US. The current study adds novel data about the effect of levels of EV adoption and not just the 90%-100% adoption to account for socio-economic based challenges related to adoption. Findings from this study may also be helpful while considering EV adoption of passenger cars versus commercial vehicles in cities with differing particle pollution. The findings are vital given the health care cost and burden associated with childhood asthma in the US.

Risk and Safety

Since the proposed study is purely analytical (computer simulations) involving no use of live matter or personal data, I do not anticipate any risk associated with this study.

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