



Published in final edited form as:

Environ Res. 2024 June 15; 251(Pt 2): 118697. doi:10.1016/j.envres.2024.118697.

Electric vehicles and health: a scoping review

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Abstract

Background: The health impacts of the rapid transition to the use of electric vehicles are largely unexplored. We completed a scoping review to assess the state of the evidence on use of battery electric and hybrid electric vehicles and health.

Methods: We conducted a literature search of MEDLINE, Embase, Global Health, CINAHL, Scopus, and Environmental Science Collection databases for articles published January 1990 to January 2024. We included articles if they presented observed or modeled data on the association between battery electric or hybrid electric cars, trucks, or buses and health-related outcomes. We abstracted data and summarized results.

Results: Out of 897 reviewed articles, 52 met our inclusion criteria. The majority of included articles examined transitions to the use of electric vehicles (n=49, 94%), with fewer studies examining hybrid electric vehicles (n=11, 21%) or plug-in hybrid electric vehicles (n=8, 15%). The most common outcomes examined were premature death (n=41, 79%) and monetized health outcomes such as medical expenditures (n=33, 63%). We identified only one observational study on the impact of electric vehicles on health; all other studies reported modeled data. Almost every study (n=51, 98%) reported some evidence of a positive health impact of transitioning to electric or hybrid electric vehicles, although magnitudes of association varied. There was a paucity of information on the environmental justice implications of vehicle transitions.

Conclusions: The results of the current literature on electric vehicles and health suggest an overall positive health impact of transitioning to electric vehicles. Additional observational studies would help expand our understanding of the real-world health effects of electric vehicles. Future research focused on the environmental justice implications of vehicle fleet transitions could

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CRediT author statement

Audrey Pennington: Conceptualization, Methodology, Investigation, Writing – original draft. Cheryl Cornwell: Investigation, Writing – review and editing. Kanta Sircar: Conceptualization, Investigation, Writing – review and editing. Maria Mirabelli: Investigation, Writing – original draft

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provide additional information about the extent to which the health benefits occur equitably across populations.

Keywords

electric vehicles; transportation; health; review

Introduction

Transportation-related air pollution is a major source of the emissions contributing to climate change. In the United States, the transportation sector was responsible for 28% of greenhouse gas emissions in 2021 (U.S. EPA, 2023b). To reduce these emissions, there is currently widespread support for electrification of vehicle fleets. Replacing internal combustion engine vehicles (ICEVs) with electric vehicles, which lack tailpipe emissions, has the potential to reduce transportation-related greenhouse gas emissions (Challa et al., 2022). Hybrid electric vehicles, which have both an internal combustion engine and a battery electric motor, can also produce fewer tailpipe emissions than standard ICEVs. The support for vehicle electrification includes current investments in electric vehicle charging infrastructure, programs to fund transitioning transit and school bus fleets, and consumer rebate incentives. These programs and incentives encourage individuals to purchase electric vehicles in lieu of ICEVs and motivate companies and municipalities to purchase electric vehicles for their car, truck and bus fleets. As a result, vehicle fleet transitions are occurring where fleets previously composed entirely of ICEVs now also include electric and hybrid electric vehicles.

While the reduction in tailpipe emissions from transitioning to electric vehicles can reduce greenhouse gas emissions, it also can benefit human health. Traffic-related air pollution is a major cause of morbidity and mortality worldwide and impacts a wide range of health outcomes such as respiratory health, cancer, and cardiovascular disease (HEI, 2022). The total impact of the transition to electric vehicles on health is determined by more than changes in tailpipe emissions alone. Factors like emissions from electric vehicle battery production, electricity generation for electric vehicle charging and non-combustion emissions due to tire and brake wear, which can be higher from electric vehicles due to their heavier weight, also contribute to the overall pollution associated with production and use and subsequent health impact of electric vehicles.

A 2018 review by Requia and colleagues on electric vehicles identified only 6 papers related to the health effects of electric vehicles (Requia et al., 2018b). A more recent systematic review focusing on the equity impact of electric vehicles identified 8 articles related to electric vehicles and health. However, they excluded papers that did not assess the distribution of health effects (Sharma et al., 2023). To our knowledge, despite the active research in this area, there has not been a recent comprehensive summary of the literature on electric vehicles and health. Therefore, we conducted this scoping review to assess the state of the evidence on use of battery electric and hybrid electric cars, trucks, and buses and health, identify knowledge gaps on this topic, and summarize the current understanding of related environmental justice implications.

Methods

We conducted a literature search of MEDLINE, Embase, Global Health, CINAHL, Scopus, and Environmental Science Collection databases for articles published between January 1, 1990 and January 9, 2024. Search criteria included terms related to health (i.e., asthma, cardio, disease, health, heart disease, illness, lung, respiratory) and terms related to electric and hybrid electric vehicles (i.e., bus, electric, electrification, hybrid, public transport, transportation, trolley, vehicle). Full search criteria are listed in eTable 1.

We included peer-reviewed articles in the review if they presented observed or modeled data on the association between battery electric or hybrid electric cars, trucks, or buses and health-related outcomes. The primary reasons for article exclusion were that an article was not related to health or the vehicle types of interest, did not present original research, or was not conducted on humans. Our primary interest was the impact of electric vehicle operation on health, so articles were excluded if they only assessed the impact of electric vehicle manufacturing, charging, or recycling, but not operation. Articles were also excluded if they did not define the health outcome of interest or did not quantify the isolated impact of electric vehicle adoption alone (e.g., only assessed the impact as part of a set of concurrent changes).

First, we screened the titles and abstracts of all search results. For any relevant abstracts, the full article text was reviewed. The references of all included articles and identified review articles were screened to identify additional articles meeting inclusion criteria. All authors participated in article screening. For included articles, two authors (AP, MM) abstracted data on study location, study timing, vehicle replacements of interest, emissions considered, whether the study was a lifecycle assessment, health outcomes, and main findings. Articles were separately screened to identify any results or discussion related to environmental justice (AP). The methods of this review were guided by the PRISMA extension for scoping reviews (PRISMA-ScR) (Tricco et al., 2018). This activity was reviewed by CDC and was conducted consistent with applicable federal law and CDC policy.¹

Results

The searches identified 897 non-duplicate articles (Figure 1). Of these, 781 were excluded after title and abstract review. The remaining 116 articles underwent full-text review. Of these, 52 met the inclusion criteria. The primary reasons for exclusion of 64 articles after full-text review were that an article was not related to electric or hybrid electric vehicles (n=9, 14%), no health outcome was examined (n=25, 39%), and the article did not present data from an original research study (n=15, 23%).

Studies were conducted in 20 different countries (Table 1); the countries with the most studies were the United States (n=15, 29%), China (n=10, 19%), and Canada (n=5, 10%). The majority of articles examined the replacement of ICEVs with electric vehicles (n=49, 94%) with fewer studies examining replacement with hybrid electric vehicles (n=11, 21%)

¹See e.g., 45 C.F.R. part 46, 21 C.F.R. part 56; 42 U.S.C. §241(d); 5 U.S.C. §552a; 44 U.S.C. §3501 et seq.

or plug-in hybrid electric vehicles (n=8, 15%). Only 11 studies (21%) included buses as one of the vehicle types examined. The most common outcome examined was premature death (n=41, 79%). There were also 33 studies (63%) that examined monetized health outcomes, such as medical expenditures, or monetized mortality, which was calculated using the value of statistical life. Other outcomes examined included disability adjusted life years (DALYs), cardiovascular and respiratory outcomes, and lost days of work and school (n=21, 40%). Nearly half of the studies (n=24, 46%) accounted for emissions from electricity generation for vehicle charging and 19 percent of the studies (n=10) were lifecycle analyses that accounted for factors such as vehicle production, maintenance, and recycling.

We identified only one observational study that measured changes in health associated with the transition to electric or hybrid electric vehicles. The study, conducted by Garcia and colleagues, assessed the relationship between zero-emission vehicle adoption (i.e., electric vehicle, plug-in hybrid electric vehicle, and hydrogen fuel cell vehicle) at the zip code level in California and changes in asthma emergency department visits (Garcia et al., 2023). They observed that an increase of 20 zero-emission vehicles per 1,000 residents was associated with a 3.2% decrease (95% CI: -5.4%, -0.9%) in the age-adjusted rate of asthma emergency department visits per year when adjusting for education, year, and zip code.

All other included articles modeled what changes in health might occur with vehicle electrification in the future or what might have occurred if these transitions had occurred in the past. Generally, studies first described the intervention and health outcome of interest. For example, how many deaths would be prevented if 100% of passenger cars in a region were replaced with electric vehicles. Next, they quantified changes in emissions (e.g., from tailpipes, tire and brake wear, electricity generation for vehicle charging) that would occur from these changes. Lastly, using the estimated changes in emissions they employed previously published concentration response functions to quantify prevented cases of the health outcome of interest attributable to these changes. There was great variation between studies in all study attributes, such as in the size of the region considered (ranging from a part of a city to a whole country), the number of emissions factors considered (ranging from a single tailpipe pollutant to a lifecycle analysis quantifying changes in emissions from across a vehicle's lifespan), and the models used for estimation.

Almost every study observed some evidence of a positive health impact of transitioning to electric or hybrid electric vehicles (Table 1). The studies that estimated the largest impact of electric vehicles on health estimated effects across large geographic areas. For example, Liang and colleagues considered several scenarios, the one with the largest impact estimated that 52% electrification of private passenger vehicles in China would prevent 25,459 (95% CI: 15,664, 32,210) premature deaths in 2030 (Liang et al., 2019). At the other end the spectrum, studies restricted to a single city, region, or part of a city estimated results with much smaller magnitudes. For example, in the United States, Filigrana and colleagues estimated that in 2035 in Seattle, Washington, 35% electrification of gasoline powered passenger cars and light duty trucks would prevent 11 deaths (95% CI: 0, 22) in individuals aged ≥ 15 years and 11 incident asthma cases (95% CI: 4, 16) in children aged ≤ 14 years (Filigrana et al., 2022). The most notable exception to generally positive impacts of electric vehicles on health was a study conducted by Ji and colleagues (Ji et al., 2012). The study

found that, in the majority of 34 Chinese cities examined, transitioning to electric vehicles would lead to more deaths than gasoline cars due to larger emissions from coal used to generate electricity for vehicle charging.

A common theme of results across many studies was that impacts varied across regions or cities. This variability was due to factors such as baseline rates of morbidity and mortality, population density, and type and location of electricity generation operations. Of these, 5 studies estimated that mortality impacts could increase in some areas under certain modeling assumptions while they would decrease in other areas (Fang et al., 2023; Gai et al., 2020; Hata and Tonokura, 2019; Mousavinezhad et al., 2024; Segersson et al., 2021). The hypothesized cause of these increases included an increase in emissions from electricity generation, an increase in ozone concentrations due to reductions in nitrogen oxides titration because of decreased emissions, and increases in emissions from traffic wear due to the increased weight of electric vehicles.

While the uneven distribution of benefits of electric vehicle transitions suggests that not all populations will benefit equally from these changes, only a handful of studies quantified environmental justice implications. One study that addressed environmental justice directly was conducted by Gai and colleagues in the greater Toronto and Hamilton area of Canada (Gai et al., 2020). They observed that reductions in premature death associated with transitioning to electric vehicles were larger in areas with lower incomes than in areas with higher incomes because neighborhoods with lower access to resources were more likely to be located near major roads and thus more impacted by reductions in tailpipe emissions. Minet and colleagues mentioned a similar finding that reductions in tailpipe emissions were primarily near busy roads that often cross through areas with lower socioeconomic status in a study conducted in the same metropolitan area (Minet et al., 2021). A study by Camilleri and colleagues found that mortality benefits of heavy duty vehicle electrification differed depending on the racial/ethnic composition of neighborhoods in Chicago; communities with a high proportion of Black residents in some regions benefitted most. Differences by race and ethnicity were due to heterogeneous reductions in air pollution and underlying mortality rates across areas (Camilleri et al., 2023). Two studies conducted in China observed that the health benefits of electric vehicle transitions were greatest among older adults in some scenarios (Lu et al., 2022; Zhu et al., 2023). The only included observational study assessed trends in vehicle adoption and observed that in California zero-emission vehicle adoption during 2013–2019 was lower in zip codes with lower educational attainment (Garcia et al., 2023).

Some studies mentioned issues related to the transfer of pollution from urban areas with a high population density to non-urban less populated areas as a decrease in tailpipe emissions from vehicles was offset by an increase in power plant emissions used to create electricity for electric vehicle charging (Choma et al., 2020; Ji et al., 2012; Liang et al., 2019; Moglia et al., 2022). Ji and colleagues discussed that this shift in emissions could potentially increase emissions in lower income rural areas (Ji et al., 2012). Additionally, several articles noted awareness of the environmental justice implications of transitioning to electric vehicles and noted that while they lacked the data to address this topic, future studies

on the issue were needed (Filigrana et al., 2022; Maizlish et al., 2022; Peters et al., 2020; Tobollik et al., 2016).

Discussion

The results of the current literature on electric vehicles and health suggest an overall positive health impact of transitioning to electric vehicles. Our findings support the conclusions described by Requia and colleagues by providing additional evidence that clean electricity generation can increase the benefits of transitioning to electric vehicles and that the shift of air pollution from urban centers to rural areas where electricity generation occurs can lead to differential health impacts (Requia et al., 2018b). Our findings, based on a larger number of studies (52 versus 6), also extend those findings by reviewing recent studies conducted in a diverse range of study locations and by highlighting the results of additional studies that have addressed environmental justice.

The strength of the current literature on electric vehicles and health is the breadth of the studies on this topic. Taken together, the studies were conducted in 20 countries and examined a wide range of interventions related to electric and hybrid electric vehicles. They also examine a wide range of different emissions related to electric vehicles, such as different air pollutants, emissions from electricity generation, and non-tailpipe emissions from tire, brake, and road wear. While the results of any individual study are affected by a range of study limitations, as a whole, this body of literature provides evidence of how transitions to electric vehicles can impact health.

What the current literature does not provide is robust data quantifying the observed health impact of transitions to electric vehicles. We only identified one observational study on the health impact of electric vehicles (Garcia et al., 2023). Outside the scope of this review, but related to this topic, two additional observational studies have been completed on clean diesel vehicles and health outcomes (Adar et al., 2015; Beatty and Shimshack, 2011). Both studies observed some evidence of an association between adoption of clean diesel technology and positive health outcomes. The current rapid transitioning of vehicle fleets to electric vehicles provides a unique opportunity to conduct natural experiments to quantify the health impacts of electric vehicles. Given the many factors that can impact the true health effect of electric vehicles in a region, observational data could be a valuable supplement to the current modeling data on this topic. For example, for a school district deciding whether to invest in electric school buses, the availability of data showing how asthma exacerbations or school absenteeism changed in another area after making a similar transition could be useful to guide decision making.

Few studies on electric vehicles and health mention the environmental justice implications of vehicle fleet transitions and even fewer studies included data detailed enough to assess these implications. The included articles that did examine differences in health impacts by income, gender, race, ethnicity, or age found that health impacts varied by these factors (Camilleri et al., 2023; Gai et al., 2020; Lu et al., 2022; Minet et al., 2021; Zhu et al., 2023). Given the differences in the health impacts of electric vehicles by region, it seems likely that the environmental justice impacts will also vary by region dependent on local factors such as the

geographic distribution of populations and electricity generation sources. This is supported by the findings of a 2015 study by Ji and colleagues focused on electric vehicle-related emissions across 34 cities in China (Ji et al., 2015). It found that the majority of inhalation of emissions related to electric vehicles were in rural communities with lower incomes, but that environmental justice impacts varied greatly across cities. A recent review by Sharma and colleagues discussed the analytic challenges of assessing the impact of electric vehicle transitions on equity (Sharma et al., 2023). Future studies on electric vehicles and health would benefit from an environmental justice focus to help ensure that these vehicle transitions are not exacerbating existing environmental and health inequities.

In addition to the lack of observational studies on electric vehicles and health, and lack of assessment of environmental justice, the current literature is limited based on the vehicle types and health outcomes studied. The majority of articles are focused on passenger cars, with less information available on transit and school buses. Given the large-scale bus transitioning currently happening, such as through the U.S. Environmental Protection Agency's \$5 billion over 5 years (fiscal year 2022–2026) Clean School Bus Program (U.S. EPA, 2023a), information on health impacts of the ongoing transition to electric buses is needed. The health outcomes examined in current studies were limited with the majority focusing on death and monetized outcomes. Less information was available on respiratory health outcomes where we may expect to see an even larger impact, and outcomes such as school absenteeism.

For this review, we used a methodological search and review process to identify relevant studies. Despite the strengths of our review process, readers should interpret the findings of our review with several potential limitations in mind. First, while we identified and screened over 800 publications, studies that assessed health as a secondary outcome may not have been picked up by our review if they reported, for example, lifecycle, economic, or policy analyses that focused primarily on non-health outcomes. Second, because we only included peer-reviewed publications, publication bias may have impacted our findings. Third, we did not complete a systematic review of study quality given the variability in study methodology and modeling approaches used. However, one important factor to consider when interpreting the results of the included studies is the range of limitations of studies that projected future health impacts compared with those of studies that calculated past health impacts. Studies that projected future impacts had to make additional assumptions about future fuel economy, traffic patterns, and electricity generation that may make them more prone to miscalculations.

This review focused on the health effects of electric vehicle operation primarily due to inhalation of air pollution with some studies also assessing the impact of noise. Surprisingly, none of the studies we reviewed evaluated increases in roadway injuries and deaths due to the increased weight of electric vehicles (National Transportation Safety Board, 2023). This impact could be substantial given that one estimate found electric cars to be 24% heavier than their ICEV counterparts (Timmers and Achten, 2016); this weight disparity can be even larger for trucks and sport utility vehicles. Although some of the included studies quantified lifecycle factors such as electric vehicle manufacturing or recycling, we excluded studies that did not include electric vehicle operation as one of the factors

they considered. No studies looked at potential injuries due to fires from electric vehicle's lithium-ion batteries, for example after damage by flooding or severe weather (National Fire Protection Association, 2022). Of particular importance is occupational safety in battery manufacturing plants, refineries of nickel and other raw materials for battery production, and in battery recycling centers. In addition to occupational safety concerns, are the environmental impacts, and subsequent health impacts, related to battery production and recycling. These environmental impacts include emissions from battery manufacturing and energy use and environmental degradation from mining of minerals. Additional information about these impacts would allow us to estimate the impact of electric vehicles on health more comprehensively. These environmental impacts occur in different geographic locations than in locations of the currently completed health studies and are often ignored.

Electric vehicles are changing the landscape of traffic-related air pollution and its resulting health effects. As vehicle fleets continue to transition, data on the health impact of electric vehicles can be used to determine equitability and inform local, state, territorial, and national decision-making. The complexity of factors that determines health effects suggest that observational data on this topic could be valuable to augment the current knowledge gained from modeling data.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgements

The authors thank Joanna Taliano, MA, MLS for her development and completion of the literature searches for this study. The findings and conclusions in this report are those of the authors and do not necessarily represent the official position of the Centers for Disease Control and Prevention.

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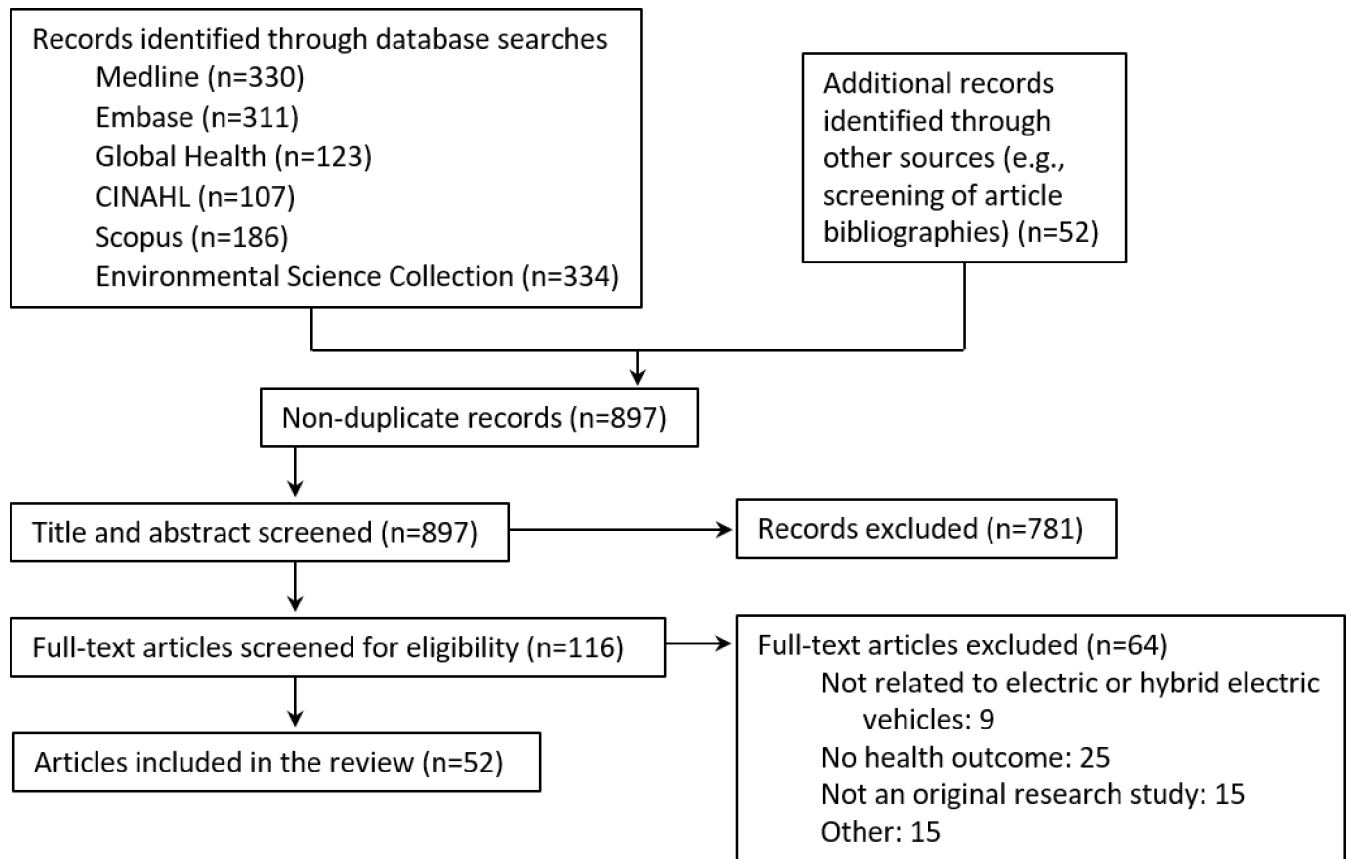


Figure 1.
Flow chart of study selection for scoping review

Table 1.

Characteristics of included articles on electric vehicles and health

Study (^a =received funding from industry)	Location	Estimation Year	Vehicle Type	Replacing (percentage replacing or fleet percentage)	Emissions and other pollutants considered (* = lifecycle assessment)	Health Outcome	Main findings
Bhat et al. (2022)	Delhi, India	2020	EV	Public bus fleet (100%)	PM _{2.5}	Mortality (all- cause, respiratory, cardiovascular), hospitalizations (COPD, lung cancer, respiratory), monetized mortality and hospitalizations	Replacing the public bus fleet with electric buses would prevent: • 67–1,370 all-cause deaths, 5–100 respiratory deaths, and 40–736 cardiovascular deaths • 17–342 COPD hospitalizations, 4–82 lung cancer hospitalizations, and 137–2,808 respiratory hospitalizations • USD \$18.7 million–\$383 million avoided costs
Calatayud et al. (2023)	Valencia, Spain	2018	EV	ICEVs (10%–70%)	NO ₂ , PM _{2.5} , PM ₁₀ , O ₃ , non-exhaust emissions	Mortality	20% vehicle electrification resulted in: • 65 (95% CI: 31, 101) fewer deaths due to changes in NO ₂ 50% vehicle electrification resulted in: • 179 (95% CI: 84, 274) fewer deaths due to changes in NO ₂ • 2 (95% CI: 1, 3) additional deaths due to changes in O ₃ • 8 (95% CI: 3, 12) fewer deaths due to changes in PM ₁₀ • 9 (95% CI: 5, 14) fewer deaths due to changes in PM _{2.5}
Camilleri et al. (2023)	Chicago, United States	2015–2019	EV	Heavy-duty vehicles (30%)	NO ₂ , PM _{2.5} , O ₃ , non-exhaust emissions, electricity generation	Mortality, monetized health impacts	Electrification of 30% of the vehicle fleet resulted in, annually: • 590 (95% CI: 150, 900) prevented deaths and \$5.7 billion avoided in health damages due to changes in NO ₂ • 70 (95% CI 20, 110) prevented deaths and \$0.6 billion avoided in health damages due to changes in PM _{2.5} • 50 (95% CI: 30, 110) additional deaths and an additional \$0.5 billion in health damages due to changes in O ₃ The impact of vehicle electrification on mortality differed by county and census tracts. In some models, benefits of vehicle electrification also differed by location racial/ethnic composition. The monetary benefit of reductions in PM _{2.5} and NO ₂ increased when electricity for vehicle charging was from emission-free sources.
Chen et al. (2014)	China	2007	PHEV	Personal ICEVs (100%)	O ₃ , PM _{2.5} , PM _{10–2.5}	Mortality, medical expenditures	Replacement of 2007 fleet of personal ICEVs with PHEVs: • Prevents 5,331 deaths • Saves 8,597 billion RMB Yuan in medical expenditures
Choma et al. (2020)	53 large metropolitan areas (MSAs), United States	2017	EV	Passenger light-duty ICEVs (cars and trucks) (per mile calculations)	Tailpipe: primary PM _{2.5} , SO ₂ , NO _x , NH ₃ , VOCs, Power	Mortality, monetized mortality	• EVs estimated to lead to mortality reductions in all metropolitan areas; magnitudes varied by city. • Vehicle miles travelled-weighted mean benefits in the 53 MSAs were 65 × 10 ⁻⁶ deaths/10,000 miles monetized to 6.6 cents/mile.

Study ([†] =received funding from industry)	Location	Estimation Year	Vehicle Type	Replacing (percentage replacing or fleet percentage)	Emissions and other pollutants considered (* =lifecycle assessment)	Health Outcome	Main findings
					plant: primary PM _{2.5} , SO ₂ , NO _x		
Deaman et al. (2023)	United Kingdom	2035	EV	Passenger vehicles (25% by 2025, 70% by 2030, 100% by 2035)	NO _x , electricity generation	Mortality, monetized health impact	The incremental increase in vehicle electrification was associated with a projected gain of 3.5 million life years and 82.9 billion GBP.
Demetriou et al. (2022)	Nicosia, Cyprus	2030	EV	Passenger vehicles (20%, 50%, 80%)	NO _x , PM _{2.5}	Mortality (total, cardiovascular, respiratory)	Replacing 20%, 50% or 80% of passenger vehicles with EVs estimated to decrease total, cardiovascular, and respiratory mortality compared to 2017 data, however, confidence intervals overlapped. Results varied based on vehicle replacement percentage and modeling decisions (e.g., pollutant, risk coefficient used).
Fang et al. (2023)	31 provinces, China	2018	EV	Passenger vehicles (100%)	PM _{2.5} , electricity generation	Mortality, morbidity, monetized health impacts of COPD, lower respiratory tract infection, ischemic heart disease, lung cancer, and stroke	Vehicle electrification was estimated to: - prevent 638,599 morbidities and 3,167 deaths when accounting for improved electricity generation technology - save USD \$4.3 billion in health benefits Impacts varied by region; vehicle electrification was associated with an increase in morbidity and mortality in some regions.
Filigrana et al. (2022)	Seattle, United States	2035	EV	Gasoline powered passenger cars and light duty trucks (35%)	PM _{2.5} , NO ₂	Mortality (cardiovascular, cardiopulmonary), asthma incidence	Prevents 11 deaths (95% CI: 0, 22) per year in the estimated 691,000 individuals aged ≥15 years in 2035 and 11 incident asthma cases (95% CI: 4, 16) per year in the estimated 95,000 children aged ≤14 years in 2035.
Gabriel et al. (2021)	Bangkok, Thailand	—	EV	Diesel buses (100%)	*lifecycle factors	DALY	54% decrease in DALYs with electric vs. diesel buses
Gai et al. (2020)	Greater Toronto and Hamilton area, Canada	—	EV (electric passenger trucks only for natural gas scenarios)	Passenger cars and trucks (25%, 100%)	PM _{2.5} , NO ₂ , O ₃ , SO ₂ , non-exhaust emissions, electricity generation	Premature death, monetized mortality among individuals aged ≥25 years	25% EV penetration with all additional energy for EVs from natural gas prevents 27–57 premature deaths per year 100% EV penetration with all additional energy for EVs from natural gas prevents 132–261 premature deaths per year 100% EV penetration with all additional energy for EVs from renewable sources prevents 168–331 premature deaths per year - Health benefits ranged from \$83 million to \$3.8 billion 2016\$CAD per year depending on scenario - Small increases in mortality estimated for some areas in natural gas scenarios
Gamarra et al. (2021)	Spain	2030	EV	Diesel and gasoline powered passenger cars (except HEVs) (100%)	NO ₂ , PM _{2.5} , PM ₁₀ , O ₃ , electricity generation	Premature death, monetized mortality	- Not accounting for changes in electricity generation, EV penetration will prevent 6,467 (95% CI: 6,329, 6,607) premature deaths, which is estimated as a cost savings associated with mortality of 25,860 million €2019. - Accounting for the increase in renewable electricity generation, EV penetration will prevent 7,113 (95% CI:

Study ([†] =received funding from industry)	Location	Estimation Year	Vehicle Type	Replacing (percentage replacing or fleet percentage)	Emissions and other pollutants considered (* =lifecycle assessment)	Health Outcome	Main findings
Garcia et al. (2023)	California, United States	Observed 2013–2019	EV, PHEV (also included hydrogen fuel cell vehicles in calculation)	Light duty vehicles		Asthma ED visits	6,963, 7,266) premature deaths, which is estimated as a cost savings associated with mortality of 28,444 million €2019. An increase of 20 zero-emission vehicles per 1,000 residents in a zip code was associated with a 3.2% (95% CI: -5.4%, -0.9%) decrease in the age-adjusted rate of asthma ED visits per year when adjusting for education, year, and zip code.
Hata et al. (2019)	Kanto region, Japan	2013	HEV	Gasoline powered passenger vehicles, heavy- duty vehicles (100%)	O ₃	Premature mortality rate	- Replacing passenger vehicles with HEVs would result in a -0.01% to 0.03% change in the mortality rate in summer months, depending on region. - Replacing passenger vehicles and heavy-duty vehicles with HEVs would result in a -0.09% to 0.14% change in the mortality rate in summer months, depending on region. - The estimated increases in mortality for some urban areas were due to a decrease in NO_x titration.
House et al. (2019)	Toronto, Canada	—	EV	ICEVs		Monetized sum of lost productivity, healthcare costs, quality of life, and loss of life	The total health-related benefits of one EV are \$219,10 CAD per year.
Hsieh et al. (2022)	29 provinces, China	2030	EV	ICEVs (37%, 74%)	*lifecycle emissions, PM _{2.5} , O ₃ , electricity generation	Monetized mortality, premature death, cardiorespiratory hospitalization, chronic bronchitis, asthma attacks, respiratory ED visits	- Replacing 37% of ICEVs with EVs in 2030 will prevent 15,534 (95% CI: 14,474, 16,602) premature deaths, 2,229 respiratory hospitalizations, 1,309 cardiovascular hospitalizations, 3,673 cases of chronic bronchitis, 3,909 asthma attacks, and 376 respiratory ED visits. - Reductions in mortality, and subsequent cost savings, estimated for every province; magnitudes varied. - Reductions in mortality also estimated when modeling homogeneous EV adoption across provinces, replacing 74% of ICEVs with EVs, and when projecting for cleaner energy generation.
Jacobson (2009)	United States	2020	EV	Light- and heavy- duty gasoline on- road vehicles (100%)	*lifecycle emissions, CO ₂ and other greenhouse gases, electricity generation	Premature death	- Replacing 100% of on-road gasoline vehicles with EVs would prevent an estimated 14,980–8,100 premature deaths if electricity is generated by wind, solar photovoltaics, concentrated solar power, geothermal, hydroelectric, tidal, wave, nuclear or coal with carbon capture and storage. - Electricity generation from wind and concentrated solar power estimated to prevent the greatest number of premature deaths.
Jazcilevich et al. (2011)	Mexico City, Mexico	2026	HEV	Private car fleet (20%)	O ₃ , secondary PM _{2.5} aerosols	Monetary health benefits, mortality (all, lung cancer, cardiopulmonary,	- Hybridization of 20% of private car fleet saves \$55 million USD per year in health benefits. - Decrease in O₃ estimated to prevent 46 (95% CI: 23, 69) deaths, 177 (95% CI: 59, 136) respiratory hospitalizations,

Study ([†] =received funding from industry)	Location	Estimation Year	Vehicle Type	Replacing (percentage replacing or fleet percentage)	Emissions and other pollutants considered (* =lifecycle assessment)	Health Outcome	Main findings
						infant respiratory, SIDS), respiratory hospitalizations, asthma ED visits, chronic bronchitis, minor restricted activity days, lost days (work, school)	58 (95% CI: 36, 80) asthma ED visits, 177,888 (95% CI: 72,773, 283,004) minor restricted activity days, and 728,059 (95% CI: 230,094, 1,133,299) lost school days. • Decrease in PM _{2.5} estimated to prevent 57 (95% CI: 20, 97) cardiopulmonary deaths, 7 (95% CI: 2, 13) lung cancer deaths, 0 infant respiratory deaths, 0 SIDS cases, 155 (95% CI: 0, 1,926) cases of chronic bronchitis, 197,892 (95% CI: 159,334, 236,443) minor restricted activity days, and 21,022 (95% CI: 17,891, 24,152) lost workdays.
Ji et al. (2012)	34 cities, China	—	EV	Conventional vehicles	Primary PM _{2.5} , electricity generation	Excess death	- In the majority of cities, EVs were estimated to lead to more excess deaths than gasoline cars (due to larger emissions factors based on China's use of coal) and fewer excess deaths than diesel cars. - For example, in Shanghai EVs were estimated to cause an excess of 26 (11–38) deaths per 10¹⁰ person-km traveled, compared to 90 (70–111) deaths for diesel cars and 9 (8–10) deaths for gasoline cars (ranges represent 5th and 95th simulation result percentages).
Kouridis et al. (2022)	Athens, Thessaloniki, and Patra, Greece	2030	EV	Passenger cars (40% by 2030, 100% by 2050), small trucks (30% by 2030, 80% by 2050) (also included motorcycles and mopeds)	PM ₁₀ , CO ₂ , NO _x	Years of life lost, respiratory and cardiac hospital admissions, chronic bronchitis cases, restricted activity days, monetized health and productivity	Combining all 3 cities, for the years 2020–2030, it was estimated that vehicle electrification would prevent 10,210 years of life lost, 625 respiratory and cardiac hospital admissions, 497 chronic bronchitis cases, and 1.5 million restricted activity days. The monetized social benefit was estimated to be €733 million.
Kwan et al. (2023)	Malaysia	2040	EV	Passenger cars, two-wheel vehicles, buses	*Lifecycle factors, electricity generation, CO, NO _x , PM _{2.5} , SO ₂	Mortality (respiratory, CVD, lung cancer), monetized mortality, DALYs	Depending on adoption uptake and electricity generation, annually: - Decreases in NO_x would prevent 5,138–10,234 respiratory deaths (88,467–176,208 DALYs) and save an estimated RM 6–7.5 billion in respiratory disease costs. - Decreases in SO₂ would prevent 340–2,639 respiratory deaths (6,783–45,443 DALYs). - Increases in PM_{2.5} would lead to an additional 80–719 respiratory deaths (1,378–9,910 DALYs), 33–239 lung cancer deaths (638–4,563 DALYs), and 745–5,339 cardiovascular deaths (13,179–94,441 DALYs). It would also increase the cost of cardiovascular disease and lung cancer by an estimated RM 4.2 billion. - Increases in CO would lead to an additional 155–329 respiratory deaths (2,671–5,659 DALYs)
Liang et al. (2019) [†]	China	2030	EV	Private passenger vehicles (15% to 52%), higher percentages of	Annual PM _{2.5} , summer O ₃ , electricity generation	Premature death	Electrification of 15%, 27%, or 52% of private passenger vehicles estimated to prevent 10,214 (95% CI: 6,285, 12,962) premature deaths, 17,456 (95% CI: 10,656, 22,160) premature deaths, or 25,459 (95% CI: 15,664, 32,210)

Study ([†] =received funding from industry)	Location	Estimation Year	Vehicle Type	Replacing (percentage replacing or fleet percentage)	Emissions and other pollutants considered (* =lifecycle assessment)	Health Outcome	Main findings
				some commercial fleets			premature deaths, respectively. - Health benefits are unevenly distributed, with most occurring in urban areas. - Avoided premature deaths estimated to decrease with electricity generation from coal-fired power plants and increase with electricity generation from non-fossil power plants.
Lin et al. (2019)	Taiwan	2013	EV	Conventional vehicles (100%)	PM _{2.5} , electricity generation	Death, respiratory and CVD hospitalizations, monetization of prevented events	Replacing conventional vehicles with EVs (with air pollutants from transportation reduced to zero, power for EVs generated from non-thermal power plants, and no emissions by non-thermal energy) prevented:• 11,545 (95% CI: 4,336, 25,715) deaths, valued at 44.15 billion (95% CI: 16.58 billion, 98.34 billion) USD2013 3,926 (95% CI: 0, 10,300) respiratory hospitalizations, valued at 10.79 million (95% CI: 0, 28.41 million) USD2013 2,421 (95% CI: 720, 4,101) CVD hospitalizations, valued at 7.77 million (95% CI: 2.31, 13.17 million) USD2013 The location used to generate additional electricity power impacts projected results.
Liou et al. (2021)	Taiwan	—	EV, HEV, PHEV	ICEVs	*lifecycle emissions, PM _{2.5} and precursors (PM _{2.5} , NO _x , SO _x)	Monetized mortality	Cost savings associated with prevented deaths of changing from ICEV to: - EV: \$15.37 USD per 1,000 km driven, \$1.4 billion USD/year - HEV: \$38.24 USD per 1,000 km driven, \$3.5 billion USD/year - PHEV: \$15.82 USD per 1,000 km driven, \$1.4 billion USD/year
Lu et al. (2022)	Beijing, China	2050	EV	Passenger cars (40.5%)	PM _{2.5}	Mortality (including cause-specific), monetized mortality	- Electrification of 40.5% of passenger cars estimated to prevent 117 (95% CI: 53, 229) deaths corresponding to a cost savings of \$13.7 million (95% CI: \$2.8 million, \$52.4 million) USD. - Overall, men and population aged >50 years had the greatest mortality benefit. - Provide estimates for years between 2020 and 2050, and stratified by sex, cause of death, and age
Luk et al. (2015) [†]	United States	—	EV	Light-duty gasoline passenger vehicle	*lifecycle emissions, PM _{2.5} , VOC, NO _x , SO _x , electricity generation	Health impact costs	Health impacts per vehicle lifetime are estimated to be lower for EVs powered by electricity derived from natural gas than for gasoline vehicles (approximately \$600 vs. \$700 USD, respectively).
Ma et al. (2021)	Beijing-Tianjin-Hebei region, China	2030	EV, PHEV	Passenger cars (21%), trucks (5%), buses (20%)	PM _{2.5} , electricity generation	Premature death, monetized premature death, morbidity, lost workdays	Electric vehicle policies are estimated to prevent: 23.5 million (95% CI: 20.29 million, 39.03 million) morbidities (estimated to be 99% respiratory symptoms) including approximately 19,530 (95% CI: 8,310, 28,450) hospitalizations - Approximately 4,600 (95% CI: 1,500, 9,300) premature

Study ([†] =received funding from industry)	Location	Estimation Year	Vehicle Type	Replacing (percentage replacing or fleet percentage)	Emissions and other pollutants considered (* =lifecycle assessment)	Health Outcome	Main findings
Maesano et al. (2020)	14th district, Paris, France	2013	EV, HEV	Passenger cars on Avenue du Général Leclerc (100%)	PM ₁₀ , non- exhaust emissions	Mortality	deaths corresponding to a savings of CNY 20.15 billion (95% CI: 6.7 billion, 40.3 billion) 15 million (95% CI: 12.7 million, 17.3 million) lost workdays Under average meteorological conditions, replacing 100% of passenger cars with: - EVs estimated to prevent 21 (95% CI: 14, 27) deaths due to short-term PM₁₀ reductions, and 137 (95% CI: 86, 188) deaths per year due to long-term PM₁₀ reductions. - HEVs estimated to prevent 12 (95% CI: 8, 17) deaths due to short-term PM₁₀ reductions and 84 (95% CI: 52, 117) deaths per year due to long-term PM₁₀ reductions. Under meteorological conditions that favor air pollution, replacing 100% of passenger cars with: - EVs estimated to prevent 34 (95% CI: 23, 45) deaths due to short-term PM₁₀ reductions - HEVs estimated to prevent 21 (95% CI: 14, 27) deaths due to short-term PM₁₀ reductions
Maizlish et al. (2022)	United States	2050	EV	Light duty passenger vehicles (50%, 100%)	PM _{2.5} , non- exhaust emissions	Mortality, monetized mortality, DALYs	100% electrification of light duty passenger vehicles avoided 1,400 deaths, corresponding to an annual savings of \$13 billion USD, and 16,400 DALYs. 50% electrification of light duty passenger vehicles avoided 700 deaths, corresponding to an annual savings of \$7 billion USD, and 8,200 DALYs.
Mehlig et al. (2021)	United Kingdom	2030, 2040	EV, HEV, PHEV	Percentages of vehicle km driven: 2030: Cars (16% HEV, 13% PHEV, 34% EV), light goods vehicles (13% PHEV, 16% EV), heavy goods vehicles (16% EV), buses (6% HEV, 40% EV) 2040: Cars (2% HEV, 6% PHEV, 90% EV), light goods vehicles (11% PHEV, 79% EV), heavy goods vehicles (85% EV), buses (6% HEV, 88% EV)	PM _{2.5} , NO _x	Monetized health benefit	Electrification of the vehicle fleet is estimated to result in a total annual benefit of: £10.8 billion (range £2.4 billion–£33.5 billion) in 2030 £11.6 billion (range £2.5 billion–£36.1 billion) in 2040

Study (†=received funding from industry)	Location	Estimation Year	Vehicle Type	Replacing (percentage replacing or fleet percentage)	Emissions and other pollutants considered (* =lifecycle assessment)	Health Outcome	Main findings
Minet et al. (2021)	Greater Toronto and Hamilton area, Canada	—	EV	Private passenger vehicles (20%, 50%, 100%), transit buses (100%)	NO ₂ , O ₃ , PM _{2.5} , BC, electricity generation, non- exhaust emissions	Premature death, monetized premature death, years life lost	100% electrification of private passenger vehicles could prevent 325 premature deaths per year (a savings of \$2.5 billion [2016\$CAD]) and save 5,855 years of life lost 20% electrification of private passenger vehicles could prevent 65 premature deaths and save 1,205 years of life lost 50% electrification of private passenger vehicles could prevent 165 premature deaths and save 2,935 years of life lost 100% electrification of transit buses could prevent 145 premature deaths (a savings of \$1.1 billion [2016\$CAD]) and save 2,670 years of life lost
Moglia et al. (2022)	Australia	2042	EV	ICEVs (5%– 100%)	MeCO _{2e}	Mortality, monetized mortality	Depending on the rate of EV adoption, vehicle transitions were estimated to save between 2,520 (±504) and 23,270 (±4,654) lives. Depending on the modeling assumptions used, this translated to a value of AUD \$4.7 billion (±0.9 billion) to \$154.6 billion (±30.9 billion). When accounting for changes in PM_{2.5} and O₃, depending on fleet electrification percentages, the impact ranged by city and scenario from 57 (95% CI –13, 125) additional deaths to 769 (95% CI 506, 1,021) fewer deaths, per month. The corresponding monetary benefits also ranged by city and scenario from a cost of \$0.6 billion to a benefit of \$7.7 billion, per month.
Mousavinezhad et al. (2024)	New York, Los Angeles, Chicago, and Houston, United States	2035	EV	Light-duty vehicles (18%, 29%, 100%), all vehicles (<100%)	PM _{2.5} , O ₃ , non-exhaust emissions, electricity generation	Respiratory mortality, monetized mortality	≤46% reduction of DALYs using existing power infrastructure and the vehicle types considered ≤52% reduction of DALYs using solar electricity generation and the vehicle types considered ≤35% reduction of DALYs for EVs - PHEV with a 10-mile electric range showed the greatest potential to decrease DALYs
Onat et al. (2014)	United States	—	EV, HEVs, PHEVs with all-electric ranges of 10, 20, 30, and 40 miles	ICEVs	*Lifecycle factors, PM, photochemical oxidants, electricity generation	DALY	- When not accounting for variability and uncertainty, EVs, HEVs, and PHEVs showed an approximately 15% to 30% reduction in DALYs by 2050 compared to a business-as-usual scenario. - When accounting for variability and uncertainty, DALY estimates in 2050 compared to 2015 are 23% higher for the business-as-usual scenario, 4% higher for HEVs, 12% lower for PHEVs, 14% lower for EVs.
Onat et al. (2016)	United States	2030, 2050	EV, HEVs, PHEVs	ICEVs (100%)	*Lifecycle factors, CO ₂ , PM, photochemical oxidants, electricity generation	DALY	- Due to projected changes in PM_{2.5}, 35% fleet electrification estimated to prevent 109 premature deaths; 70% fleet electrification estimated to prevent 177 premature deaths - Due to projected changes in O₃, 35% fleet electrification estimated to prevent 5 premature deaths, 7,534 asthma exacerbations, 20 asthma ED visits, 5,518 lost school days, and 4 respiratory hospital admissions; 70% fleet
Pan et al. (2019)	Greater Houston area, United States	2040	EV	Gasoline and diesel vehicles (35%, 70%)	O ₃ , PM _{2.5} , electricity generation	Premature death, asthma exacerbations, asthma ED visits, lost school days, respiratory hospital admissions, monetized benefits	

Study ([†] =received funding from industry)	Location	Estimation Year	Vehicle Type	Replacing (percentage replacing or fleet percentage)	Emissions and other pollutants considered (* =lifecycle assessment)	Health Outcome	Main findings
Pan et al. (2023)	30 metropolitan areas, United States	2050	EV	Passenger vehicles (passenger cars, trucks, transit buses, school buses) (almost 100%) (also included motorcycles)	PM _{2.5}	Mortality, monetized mortality	electrification estimated to prevent 11 premature deaths, 16,119 asthma exacerbations, 43 asthma ED visits, 11,844 lost school days, and 8 respiratory hospital admissions - Monetized benefits calculated for each outcome: the largest benefit estimated as a \$1.5 billion savings [2015\$USD] due to prevented deaths from reductions in PM_{2.5} for 70% fleet electrification The magnitude of impacts from vehicle electrification varied by metropolitan area: - In the 5 areas with the largest impacts, 186–1,163 deaths were prevented, per year, corresponding to \$2.02 billion–\$12.61 billion in savings. - In the 5 areas with the smallest impacts, 12–33 deaths were prevented, per year, corresponding to \$0.13 billion–\$0.36 billion in savings.
Perez et al. (2015)	Basel, Switzerland	2020	EV	Private car fleet (50%)	PM _{2.5} , elemental carbon, noise, CO ₂	Premature death at age ≥30 years (all-cause natural, lung cancer, cardiovascular), DALYs, high annoyance, high sleep disturbance	- Projected changes in PM_{2.5} estimated to prevent 3% of natural deaths (n=66), 6% of cardiovascular deaths (n=40), 5% of lung cancer deaths (n=4), and 2% of restricted activity days (n=57,271) - Projected changes in elemental carbon estimated to prevent 6% of natural deaths (n=118) - Projected changes in noise estimated to prevent 1% of cardiovascular deaths (n=7), 3% of high annoyance (n=269), and 1% of high sleep disturbances (n=90) - Projected changes in CO₂ estimated to prevent 3.9 DALYs per 1,000 people
Peters et al. (2020)	United States	—	EV	Light-duty passenger vehicles (25%, 75%)	PM _{2.5} , O ₃ , electricity generation	Premature mortality, monetized death	- Using 2014 electricity generation, 25% fleet electrification is estimated to prevent 437 (95% CI: 295, 578) premature deaths per year due to PM_{2.5} reductions and 98 (95% CI: 33, 162) premature deaths per year due to O₃ formation reductions - When increasing emission-free sources of electricity generation, 25% fleet electrification is estimated to prevent 922 (95% CI: 623, 1,219) premature deaths per year due to PM_{2.5} reductions and 113 (95% CI: 38, 188) premature deaths per year due to O₃ formation reductions - Using 2014 electricity generation, 75% fleet electrification is estimated to prevent 1,576 (95% CI: 1,065, 2,086) premature deaths due to PM_{2.5} reductions and 420 (95% CI: 139, 698) premature deaths due to O₃ formation reductions - When increasing emission-free sources of electricity generation, 75% fleet electrification is estimated to prevent 2,939 (95% CI: 1,985, 3,888) premature deaths per year due to PM_{2.5} reductions and 366 (95% CI: 121, 608) premature

Study ([†] =received funding from industry)	Location	Estimation Year	Vehicle Type	Replacing (percentage replacing or fleet percentage)	Emissions and other pollutants considered (* =lifecycle assessment)	Health Outcome	Main findings
Petrauskienė et al. (2020)	Lithuania	2050	EV	ICEVs	* Lifecycle factors, electricity generation	DALYs	deaths per year due to O ₃ formation reductions The estimated reductions in premature death correspond to a cost savings of \$5.1 billion to \$31.7 billion USD, depending on the scenario. Using a projected electricity mix for 2050, EVs are estimated to result in an approximately 90% reduction in DALYs compared to ICEVs fueled with petrol or diesel.
Requia et al. (2018a)	Greater Toronto and Hamilton Area, Canada	—	EV	Light-duty passenger vehicles (10%, 100%)	PM _{2.5} , non-exhaust emissions	All-cause mortality	10% electrification is estimated to prevent 6 (37%) of 16 excess deaths per year due to traffic 100% electrification is estimated to prevent 14 (87%) of 16 excess deaths per year due to traffic
Rizza et al. (2021)	Turin, Italy	2025, 2030	EV, HEV	In 2030, passenger cars (20% EVs, 50% HEVs) and light duty vehicles (15%, 25% HEVs)	PM ₁₀ , PM _{2.5} , NO ₂ , non-exhaust emissions	All-cause mortality for ages 0–99 years, respiratory hospitalizations for ages 0–99 years, cardiovascular hospitalization for ages 0–99 years, economic cost of illness, monetized mortality	In 2030, estimated reductions in illness due to short-term impact of changes in air pollution: - PM₁₀: 40 (CI: 40, 41) deaths (valued at €153 million), 58 (CI: 57, 58) respiratory hospitalizations, and 46 (CI: 45, 46) cardiovascular hospitalizations - PM_{2.5}: 46 (CI: 16, 75) deaths (valued at €174 million), 55 (CI: –5, 114) respiratory hospitalizations, and 39 (CI: 5, 73) cardiovascular hospitalizations - NO₂: 22 (CI: 11, 32) deaths (valued at €82 million), 21 (CI: 2, 40) respiratory hospitalizations, and 23 (CI: 10, 37) cardiovascular hospitalizations In 2030, estimated reductions in illness due to long-term impact of changes in air pollution: - PM₁₀: 71 (CI: 68, 74) deaths (valued at €269 million), 61 (CI: 61, 61) respiratory hospitalizations, and 76 (CI: 76, 76) cardiovascular hospitalizations - PM_{2.5}: 149 (CI: 113, 186) deaths (valued at €566 million), 85 (CI: –71, 237) respiratory hospitalizations, and 250 (CI: 170, 330) cardiovascular hospitalizations - NO₂: 107 (CI: 89, 124) deaths (valued at €405 million), 81 (CI: 54, 107) respiratory hospitalizations, and 457 (CI: –10, 903) cardiovascular hospitalizations In 2030, estimated economic cost savings due to changes in health outcomes: - Due to short-term pollutant reductions, €1.12 for respiratory hospitalizations and €1.4 for cardiovascular hospitalizations - Due to long-term pollutant reductions, €3.25 for respiratory hospitalizations and €18.89 for cardiovascular hospitalizations

Results also presented for 2025.

Study ([†] =received funding from industry)	Location	Estimation Year	Vehicle Type	Replacing (percentage replacing or fleet percentage)	Emissions and other pollutants considered (* =lifecycle assessment)	Health Outcome	Main findings
Sariigiannis et al. (2017)	Thessaloniki, Greece	2020	EV, HEV	Gasoline-fueled cars (50% EVs, 4% HEVs)	PM ₁₀ , PM _{2.5} , NO ₂ , benzene	Mortality, morbidity, leukemia cases, DALYs, monetized estimates due to prevented mortality or leukemia incidence	- Estimated 4% reduction in mortality and morbidity in Thessaloniki municipality due to reductions in PM₁₀ and PM_{2.5}. - Reduction in DALYs and leukemia cases presented separately for 25 municipalities in the greater Thessaloniki area. Across municipalities, DALY estimates range from 0 to 13,077 overall and 0 to 1.39 per capita. Leukemia incidence estimated as <1 case for the 5th percentile and <1 to 1.46 cases for the 95th percentile. - Reductions in air pollution estimated to save €162 million annually (€66 million for PM₁₀, €54 million for PM_{2.5}, €41 million for NO₂, and €1 million for benzene).
Schnell et al. (2021)	China	2013, 2014	EV	Heavy-duty vehicles (40%), light-duty vehicles (40%)	PM _{2.5} , NO ₂ , CO ₂ , electricity generation, non- exhaust emissions	Premature death, monetized health impact	During the January 2013 extreme air quality event: 40% adoption of electric heavy-duty vehicles would have prevented 562 (95% CI: 410, 723) premature deaths and saved \$87 million USD net economic and health impact in one month. 40% adoption of electric light-duty vehicles would have prevented 145 (95% CI: 38, 333) premature deaths and saved \$156 million USD net economic and health impact in one month. For January 2014, a month without extreme meteorology: 40% adoption of electric heavy-duty vehicles would have prevented 485 premature deaths and saved \$54 million USD net economic and health impact in one month. 40% adoption of electric light-duty vehicles would have prevented 108 premature deaths and saved \$137 million USD net economic and health impact in one month.
Segersson et al. (2021)	Gothenburg and Stockholm, Sweden	2011	EV	Light vehicles (50%)	PM _{2.5} , PM ₁₀ , BC, non-exhaust emissions	Premature death	- Estimated decreases in number of premature deaths ranged from 4 to 10 in Gothenburg and 4 to 19 in Stockholm, depending on the health impact analysis approach used. - While premature deaths were estimated to decrease overall, using some approaches, premature deaths due to traffic wear were estimated to increase.
Shamsi et al. (2021)	Highway 401, Toronto, Canada	—	EV	Passenger vehicles (10%, 50%, 100%)	NO _x	Deaths, monetized death	10% electrification of passenger vehicles would prevent 3 (95% CI: 2, 4) deaths, valued at CAD 24 million, per year. 50% electrification of passenger vehicles would prevent 12 (95% CI: 6, 18) deaths, valued at CAD 96 million, per year. 100% electrification of passenger vehicles would prevent 24 (95% CI: 12, 36) deaths, valued at CAD 192 million, per year.
Sonawane et al. (2012)	Mumbai, India	2012, 2017	EV, HEV	2012: electric vehicles: 2-wheel (5%), 3-wheel	PM ₁₀ , NO ₂	Monetized health benefit	- In 2012, health benefits per year are estimated to be: - From EVs, 9.9 million Rs per year when using a purchasing power parity valuation method, and 1.1 million

Study ([†] =received funding from industry)	Location	Estimation Year	Vehicle Type	Replacing (percentage replacing or fleet percentage)	Emissions and other pollutants considered (* =lifecycle assessment)	Health Outcome	Main findings
				(20%), taxis (20%), public buses (5%); 4- wheel HEV s (1%) 2017: electric vehicles 2-wheel (10%); 3-wheel (30%), taxis (30%), public buses (10%); 4- wheel HEV s (2%)			Rs when using a VSL valuation method - From HEVs, 193,425 Rs when using a purchasing power parity valuation method and 27,470 Rs when using a VSL method In 2017, health benefits per year are estimated to be: - From EVs, 60.0 million Rs when using a purchasing power parity valuation method and 7.6 million Rs when using a VSL method - From HEVs, 23.3 million Rs when using a purchasing power parity valuation method and 2.8 million when using a VSL method
Tessum et al. (2014)	United States	2020	EV, HEV	Passenger vehicle miles traveled (10%)	*lifecycle emissions, electricity generation, PM _{2.5} , O ₃	All-cause mortality attributed to PM _{2.5} , respiratory mortality attributed to O ₃ , monetized mortality	Total impacts range from 230 deaths per year for EVs powered by wind, water, or solar electricity (\$0.14 USD per gallon gasoline-equivalent) to 3,200 deaths per year for EVs powered by electricity from coal (\$1.94 USD per gallon gasoline-equivalent). Compared with gasoline vehicles, air quality-related health impacts were approximately: 30% lower for gasoline HEVs 50% lower for EVs powered by electricity from natural gas 70% lower for EVs powered by electricity from wind, water, or solar power 200% higher for EVs powered by electricity from the projected 2020 U.S. average electricity generation mix 350% higher for EVs powered by electricity from coal
Tobollik et al. (2016)	Rotterdam, Netherlands	2020	EV	Private vehicle kilometers traveled (50%)	PM _{2.5} , EC, noise	Mortality (years of life lost) among adults aged 30+ years due to: all causes excluding accidents, ischemic heart disease, and lung cancer; morbidity (years lived with disability); restricted activity days among adults aged 18–65 years	Compared to 2010, a 50% increase in electrification of private vehicle kilometers traveled would result in: 2,097 (95% CI: 1,403, 2,711) fewer years of life lost due to all causes excluding accidents, 346 (95% CI: 269, 423) fewer years of life lost due to ischemic heart disease, and 282 (95% CI: 138, 410) fewer years of life lost due to lung cancer due to PM_{2.5} 13,962 (95% CI: 11,976, 15,316) fewer restricted activity days due to PM_{2.5} 67 (95% CI: 46, 98) fewer years of life lost due to EC 2 (95% CI: 1, 10) additional years lived with disability due to noise 4 (95% CI: 2, 6) additional years lived with disability due to sleep disturbance

Compared to a business-as-usual scenario in 2020, a 50% increase in electrification of private vehicle kilometers traveled would result in:

- No changes in years of life lost due to PM_{2.5} or EC
- No changes in restricted activity days due to PM_{2.5}

Study ([†] =received funding from industry)	Location	Estimation Year	Vehicle Type	Replacing (percentage replacing or fleet percentage)	Emissions and other pollutants considered (* =lifecyle assessment)	Health Outcome	Main findings
Tsoi et al. (2023)	Hong Kong, China	—	EV	Light-duty vehicles (100%), buses (100%)	Traffic noise	Mortality from heart disease and cerebrovascular disease, cases of hypertension, coronary heart disease, stroke, and hearing loss	• 26 (95% CI: 13, 161) fewer years lived with disability due to noise • 41 (95% CI: 24, 60) fewer years lived with disability due to sleep disturbance Electrification of light-duty vehicles would prevent: • 138.27 (95% CI 54.02, 219.64) deaths (94.65 [95% CI 37.65, 150.10] for heart disease and 43.62 [95% CI 16.37, 69.54] for cerebrovascular disease) • 1,817.02 (95% CI 584.86, 2,943.33) morbidities Electrification of buses would prevent: • 244.53 (95% CI 97.16, 382.19) deaths (167.39 [95% CI 67.70, 261.20] for heart disease and 77.14 [95% CI 29.46, 120.99] for cerebrovascular disease) • 7,474.01 (95% CI 2,585.93, 11,233.32) morbidities • To achieve an estimated 90% reduction in health costs attributable to PM_{2.5} emissions for selected bus routes, 13 of 19 bus routes needed to be electrified in the Boston metropolitan area and 11 of 15 bus routes needed to be electrified in the Milan metropolitan area. • In both cities, electrifying 4 routes resulted in an approximately 50% reduction in health costs attributable to PM_{2.5} emissions. • In both cities, health savings increased as the number of bus routes electrified increased.
Vijay et al. (2023)	Greater Boston, USA; Milan metropolitan area, Italy	2020	EV	Diesel buses	PM _{2.5}	Monetized mortality	
Zhu et al. (2023)	Yangtze River Delta, China	2060	EV, PHEV	Light-duty passenger vehicles (50%– 100%), medium- and heavy-duty passenger vehicles (60%– 100%), taxis and buses (80%– 100%), light-duty trucks (40%– 100%), medium- and heavy-duty trucks (20%– 100%)	PM _{2.5} , O ₃ , NO ₂ , electricity generation	Non-communicable disease and lower respiratory infection mortality (PM _{2.5}), COPD mortality (O ₃), all-cause mortality (NO ₂)	Vehicle electrification could prevent: • 17,470–71,460 deaths due to changes in PM_{2.5} and O₃ • 33,440–102,480 deaths due to changes in NO₂ Overall impact varied by city and age. People >65 years old benefited the most from air pollution reductions in some scenarios.

Abbreviations: AUD=Australian dollar, BC=black carbon, CAD=Canadian dollar, CI=confidence interval, CNY=Chinese Yuan, CO=carbon monoxide, CO₂=carbon dioxide, COPD=chronic obstructive pulmonary disease, CVD=cardiovascular disease, DALY=disability-adjusted life years, EC=elemental carbon, ED=emergency department, EV=electric vehicle, GBP=Great British pound, HEV=hybrid electric vehicle, ICEV=internal combustion engine vehicle, km=kilometer, MSA=metropolitan statistical area, MtCO₂e=metric tons of carbon dioxide equivalent, NH₃=ammonia, NO₂=nitrogen dioxide, NO_x=nitrogen oxides, non-exhaust emissions=include brake, tire, and road wear, O₃=ozone, PHEV=plug-in hybrid electric vehicle, PM=particulate matter, PM_{2.5}=fine particulate matter, PM₁₀=coarse

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particulate matter, PM10–2.5=particulate matter 2.5–10 micrometers in diameter, RM=Malaysian ringgit, Rs=Indian rupees, SIDS =sudden infant death syndrome, SO₂=sulfur dioxide, SOX=sulfur oxide, USD=U.S. dollar, VOC=volatile organic compounds, VSL= value of statistical life,

* lifecycle factors (include factors such as extraction of materials, manufacturing, maintenance, operation, charging, and end-of-life recycling and disposal),

[†] received funding from industry

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