HEI
Health Effects Institute

NUMBER 221
OCTOBER 2024

COMMENTARY BY THE
HEI REVIEW COMMITTEE

Assessing the National Health, Education, and Air Quality Benefits of the United States Environmental Protection Agency's School Bus Rebate Program: A Randomized Controlled Trial Design

Adar et al.

healtheffects.org

Assessing the National Health, Education, and Air Quality Benefits of the United States Environmental Protection Agency's School Bus Rebate Program: A Randomized Controlled Trial Design

Sara D. Adar, Meredith Pedde, Richard Hirth, and Adam Szpiro

---

with a Commentary by the HEI Review Committee

Research Report 221

Health Effects Institute

Boston, Massachusetts

Trusted Science · Cleaner Air · Better Health

CONTENTS

ABOUT HEI

The Health Effects Institute is a nonprofit corporation chartered in 1980 as an independent research organization to provide high-quality, impartial, and relevant science on the effects of air pollution on health. To accomplish its mission, the Institute

- identifies the highest-priority areas for health effects research
- competitively funds and oversees research projects
- provides an intensive independent review of HEI-supported studies and related research
- integrates HEI's research results with those of other institutions into broader evaluations
- communicates the results of HEI's research and analyses to public and private decision-makers.

HEI typically receives balanced funding from the US Environmental Protection Agency and the worldwide motor vehicle industry. Frequently, other public and private organizations in the United States and around the world also support major projects or research programs. HEI has funded more than 380 research projects in North America, Europe, Asia, and Latin America, the results of which have informed decisions regarding carbon monoxide, air toxics, nitrogen oxides, diesel exhaust, ozone, particulate matter, and other pollutants. These results have appeared in more than 260 comprehensive reports published by HEI, as well as in more than 2,500 articles in the peer-reviewed literature.

HEI's independent Board of Directors consists of leaders in science and policy who are committed to fostering the public–private partnership that is central to the organization. The Research Committee solicits input from HEI sponsors and other stakeholders and works with scientific staff to develop a Five-Year Strategic Plan, select research projects for funding, and oversee their conduct. The Review Committee, which has no role in selecting or overseeing studies, works with staff to evaluate and interpret the results of funded studies and related research.

All project results and accompanying comments by the Review Committee are widely disseminated through HEI's website (*www.healtheffects.org*), reports, newsletters, annual conferences, and presentations to legislative bodies and public agencies.

CONTRIBUTORS

RESEARCH COMMITTEE

David A. Savitz, Chair *Professor of Epidemiology, School of Public Health, and Professor of Obstetrics and Gynecology and Pediatrics, Alpert Medical School, Brown University, USA*

Benjamin Barratt *Professor, Environmental Research Group, School of Public Health, Imperial College London, United Kingdom*

David C. Dorman *Professor, Department of Molecular Biomedical Sciences, College of Veterinary Medicine, North Carolina State University, USA*

Christina H. Fuller *Associate Professor, School of Environmental, Civil, Agricultural and Mechanical Engineering, University of Georgia College of Engineering, USA*

Marianne Hatzopoulou *Professor, Civil and Mineral Engineering, University of Toronto, Research Chair in Transport Decarbonization and Air Quality, Canada*

Amy H. Herring* *Sara & Charles Ayres Distinguished Professor of Statistical Science, Global Health, and Biostatistics and Bioinformatics, Duke University, USA*

Heather A. Holmes *Associate Professor, Department of Chemical Engineering, University of Utah, USA*

Neil Pearce *Professor of Epidemiology and Biostatistics, London School of Hygiene and Tropical Medicine, United Kingdom*

Evangelia (Evi) Samoli *Professor of Epidemiology and Medical Statistics, Department of Hygiene, Epidemiology and Medical Statistics, School of Medicine, National and Kapodistrian University of Athens, Greece*

Alexandra M. Schmidt *Professor of Biostatistics, School of Population and Global Health, McGill University, Canada*

Neeta Thakur *Associate Professor of Medicine, University of California San Francisco, USA*

Gregory Wellenius *Professor, Department of Environmental Health, Boston University School of Public Health and Director, BUSPH Center for Climate and Health, USA *

REVIEW COMMITTEE

Melissa J. Perry, Chair *Dean, College of Public Health, George Mason University, USA*

Sara D. Adar† *Associate Professor and Associate Chair, Department of Epidemiology, University of Michigan School of Public Health, USA*

Kiros T. Berhane *Cynthia and Robert Citrone-Roslyn and Leslie Goldstein Professor and Chair, Department of Biostatistics, Mailman School of Public Health, Columbia University, USA*

Ulrike Gehring *Associate Professor, Institute for Risk Assessment Sciences, Utrecht University, Netherlands*

Michael Jerrett *Professor, Department of Environmental Health Sciences, Fielding School of Public Health, University of California Los Angeles, USA*

Frank Kelly *Humphrey Battcock Chair in Community Health and Policy and Director of the Environmental Research Group, Imperial College London School of Public Health, United Kingdom*

Jana B. Milford *Professor Emerita, Department of Mechanical Engineering and Environmental Engineering Program, University of Colorado Boulder, USA*

Jennifer L. Peel *Professor of Epidemiology, Department of Environmental and Radiological Health Sciences, Colorado State University, and the Colorado School of Public Health, USA*

Eric J. Tchetgen Tchetgen *University Professor and Professor of Biostatistics and Epidemiology, Perelman School of Medicine, and Professor of Statistics and Data Science, The Wharton School, University of Pennsylvania, USA*

John Volckens *Professor, Department of Mechanical Engineering, Walter Scott Jr. College of Engineering, Colorado State University, USA*

HEI PROJECT STAFF

Dan Crouse *Senior Scientist (Study Oversight)*

Allison Patton *Senior Scientist (Report Review)*

Kristin C. Eckles *Senior Editorial Manager*

Hope Green *Editorial Project Manager*

Carol Moyer and Tom Zaczkiewicz *Consulting Editors*

*Dr. Herring rotated off the Research Committee before this report's publication.

†Dr. Adar is a member of the HEI Review Committee and has been recused from all discussions of the report.

Research Report 221, *Assessing the National Health, Education, and Air Quality Benefits of the United States Environmental Protection Agency's School Bus Rebate Program: A Randomized Controlled Trial Design*, S.D. Adar et al.

INTRODUCTION

Governmental regulation is essential for protecting environmental quality and human health, but also typically incurs an economic cost. It is therefore essential to understand whether environmental policies result in the intended improvements. The area of study known as environmental accountability research evaluates the extent to which environmental regulations have yielded improved air quality and public health. A major challenge in this research field is isolating changes that can be attributed to the policy in question from improvements that might be due to other unrelated regulations or long-term trends. This challenge is a particular concern when policies target numerous pollutant sources, affect large geographic regions, and take several years to fully implement.

Over the past two decades, HEI has emerged as a leader in air pollution accountability research, contributing to research design, funding, study oversight, and evaluation of such research (see *Preface*). Through a series of Requests for Applications (RFAs*), HEI has now funded more than 20 studies that assessed a wide variety of regulations targeting both point and mobile sources of air pollution. For practical reasons, earlier studies tended to focus on local-level actions that were implemented over a relatively short time frame. HEI later solicited research that evaluated actions with a larger geographical scope or that were implemented over longer timeframes.

In its 2018 research solicitation, RFA 18-1, "Assessing Improved Air Quality and Health from National, Regional, and Local Air Quality Actions," HEI aimed to fund empirical studies to assess the health effects of air quality actions (regulatory and other air quality interventions and natural experiments) or to develop methods required for, and specifically suited to, conducting such research and make them accessible and available to other researchers. Areas of interest included national- or regional-scale regulatory actions implemented over multiple years, local actions targeted at improving air quality in urban areas with well-documented air quality problems, and regulatory programs to improve air quality around major ports and transportation hubs and corridors.

In response, Adar and colleagues proposed to assess the effects of school bus retrofit and replacement funding opportunities as part of the United States Environmental Protection Agency's (US EPA's) National Clean Diesel Rebate Program on student health and educational performance. To facilitate the transition of school districts to lower-emitting school buses, the US EPA funded fleet owners to replace or retrofit old, higher-emission, diesel-powered school buses. The program started with a pilot in 2012, and school bus replacement programs have continued in various forms to date. A random lottery approach is used to allocate the funds. Dr. Adar and colleagues planned to take advantage of the randomized allocation of funding to evaluate the effect of the program on school attendance and educational performance. They later added aims on emergency department visits for respiratory causes and community air pollution levels at the request of HEI's Research Committee.

The HEI Research Committee recommended the proposal by Adar and colleagues for funding due to its strong study design with testable hypotheses. The Committee liked that the study would evaluate a national program with policy relevance using a clearly defined and randomized intervention and well-defined outcomes. They also appreciated the approach of using an intention-to-treat analysis (explained below) that leveraged randomized selection of school districts for funding, which was a unique opportunity in environmental epidemiology. The Research Committee also liked the inclusion of student absenteeism as a potential mediator of educational performance and the sensitivity analyses proposed by the investigators to evaluate some underlying assumptions of the study.

This Commentary provides the HEI Review Committee's evaluation of the study. It is intended to aid the sponsors of HEI and the public by highlighting both the strengths and limitations of the study and by placing the Investigators' Report into scientific and regulatory context.

Dr. Sara D. Adar's 3-year study, "Assessing the National Health and Education Benefits of the EPA's School Bus Retrofit and Replacement Program: A Randomized Controlled Trial Design," began in January 2020. Total expenditures were $545,277. The draft Investigators' Report from Adar and colleagues was received for review in April 2023. A revised report, received in September 2023, was accepted for publication in October 2023. During the review process, the HEI Review Committee and the investigators had the opportunity to exchange comments and clarify issues in both the Investigators' Report and the Review Committee's Commentary. Dr. Adar is a member of the HEI Review Committee and has been recused from all discussions of the report.

* A list of abbreviations and other terms appears at the end of this volume.

SCIENTIFIC AND REGULATORY BACKGROUND

SCHOOL BUS EXPERIENCES OF STUDENTS IN THE UNITED STATES

Every day, school buses transport 20 to 25 million children, including 50% of all pre-high school students and 60% of low-income students, to and from primary and secondary schools in the United States.[1–3] Nationwide, in 2019 and 2020, students attending traditional public schools who rode school buses rode about 25 minutes each way to school, with 75% of students riding school buses for less than 30 minutes.[4] However, the experience of riding the school bus varies geographically, by race, and by family income, with rural and minority children typically experiencing longer bus rides. A survey of 1,194 elementary school principals in five states (Arkansas, Georgia, New Mexico, Pennsylvania, and Washington) reported that students who attended rural elementary schools were more likely to be eligible to ride school buses than were students attending urban schools.[5] Compared with students who attended suburban schools, those attending rural schools also had longer bus rides — lasting 30 minutes or more each way with rougher ride conditions — than suburban school students. One of the most studied cities for student transportation is New York City, where typical lengths of school bus rides were in line with national averages.[6] In New York City, public school students who rode school buses were more likely to be Black or Hispanic and to attend choice or charter schools (thus traveling farther to school). They had disproportionately longer travel times to school compared with students who used public transportation or arranged private transportation.[6,7] With many children spending at least an hour per day on school buses, their exposure to emissions from the school buses, particularly those with old, highly emitting diesel engines, and to traffic emissions generally, is of concern.

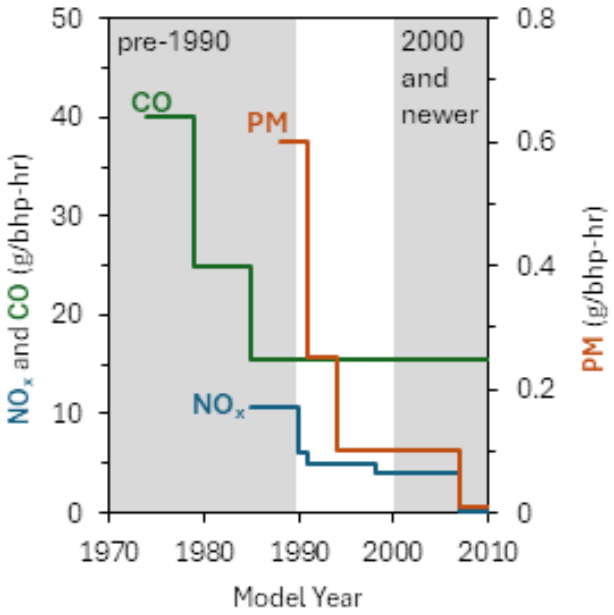
DIESEL EMISSIONS FROM SCHOOL BUSES

About 89% of the half million school buses currently in use are powered by diesel fuel.[8,9] Increased concentrations of air pollutants — including fine particulate matter ≤2.5 µm in aerodynamic diameter ($PM_{2.5}$), black carbon, ultrafine particles, and carbon monoxide (CO) — from diesel exhaust have been reported near idling school buses during student pickup and drop-off and inside the buses themselves, including in previous research funded by HEI.[10,11] Diesel exhaust has been classified by the International Agency for Research on Cancer as a known human carcinogen,[12] and exposure has been associated with increased risks of adverse respiratory symptoms, hospitalizations related to heart and lung illnesses, and premature death.[13]

To reduce these emissions, the US EPA implemented substantially more stringent emissions certification standards for school bus and other engines starting with model year 1985 for CO and starting with model year 1990 for PM and nitrogen oxides (NO_x) (**Commentary Figure 1**). Following on earlier reductions, the most recent emissions requirements of 2007 and 2010 have substantially improved emissions of PM and NO_x and alleviated some of the associated health concerns.[14–17] These latest improvements were possible because of a combination of new technologies and fuel standards. For example, diesel particulate filters and selective catalytic converters became standard in new diesel engines in 2007 and 2010, respectively. Supporting the effectiveness of these technologies and also reducing PM formation on its own, the US EPA implemented fuel requirements to reduce PM emissions and to protect catalytic converters, including the phase in of ultra-low sulfur diesel starting in 2006.[18] Most states have also implemented rules to address air quality issues associated with idling of school buses and other vehicles.[19]

As a result of the decreases in allowable emissions from new diesel engines over time, newer model year diesel engines used in school buses and other vehicles have substantially lower emissions of air pollutants such as CO, PM, and NO_x than do older diesel engines. However, many old school buses remain on the road. School buses are currently retired at an age of about 15 years, and in 2023, the average age of school bus fleets was just under 9 years with 67% of diesel school buses having the newest model year 2010 or newer technologies.[9,20,21] Overall, about 1% of the school bus fleet in the early 2020s were pre-1990 model years.[22] As of 2022, about 3% of buses were 1999 and older model years, and at least 8% of buses were of unknown age.[23]

Several studies have demonstrated decreased air pollutant emissions from school buses with new technologies. Tests of new school buses that use lower-emitting diesel



Commentary Figure 1. Changes in US emissions standards for CO, PM, and NO_x from heavy-duty highway compression ignition engines (as used in school buses) over time. (Data from US EPA 2016.)

technologies (e.g., diesel particulate filters and selective catalytic conversion), alternative fuels (e.g., condensed natural gas and liquefied petroleum gas), and electric power have shown reduced emissions of NO_x compared with older diesel buses.[24] Additionally, retrofitting older buses with newer emissions control technologies such as diesel oxidation catalysts or crankcase filter systems can reduce exhaust (i.e., tailpipe and engine) emissions in some cases.[10,25] Calibrating the emissions control technology and testing the same bus before and after the retrofit were both important to see these effects. Although exhaust emissions have decreased with new technologies and power sources, in-use real-world emissions continue to be higher than laboratory-based emissions certification standards.[24]

EFFECT OF REDUCING SCHOOL BUS EMISSIONS ON CHILDREN

The relationship between reduced emissions and changes in children's exposures has been less clear. A study in Washington (by the authors of the current study) found lower fine and ultrafine particles on school buses after diesel oxidation catalysts, closed crankcase ventilation systems, and ultra-low sulfur diesel fuel were adopted.[26] However, in a separate study of a small sample of diesel-powered school buses in the United States, retrofitting buses with a diesel oxidation catalyst, a crankcase filtration system, or both resulted in substantially reduced exhaust concentrations of ultrafine particles, black carbon, and $PM_{2.5}$ during idling but did not reduce in-cabin concentrations of the measured pollutants.[10]

Studies of student health and educational performance are starting to provide evidence that school bus rides affect students' educational experience and that reducing school bus emissions can improve the educational performance and school attendance rates of students. In a study of school bus ridership in New York City, bus rides longer than 45 minutes were associated with decreased school attendance and higher probability of chronic absenteeism relative to shorter bus rides.[6] School bus emissions decreased, and English and math test scores improved after school bus retrofits in studies in Georgia.[27,28] Studies in Washington state (including by the investigators of the current study) reported improvements in student respiratory health following the implementation of lower-emitting school bus technologies and fuels, especially among patients with persistent asthma.[26,29] A recent nationwide study in the United States projected that replacing diesel model year 2005 school buses with diesel model year 2010 school buses could result in reduced attributable mortality and new childhood asthma cases and that an estimated $84,200 of health and climate benefits would be achieved for each diesel school bus replaced with an electric school bus.[30] Those benefits would be mainly realized in large cities, although there would also be some benefits in other areas.

REGULATORY PROGRAMS FOR LOWER-EMITTING SCHOOL BUSES

To reduce the potential effects of diesel exhaust on children, the US EPA provides funds to support the replacement or retrofit of older, higher-emission diesel school buses by owners of school bus fleets through various rebate and grant programs. The school bus retrofit and replacement funding opportunities evaluated in the current study were part of the National Clean Diesel Rebate Program, which was authorized by the Diesel Emissions Reduction Act (DERA) of 2010, and provided rebates for the replacement of 2006 and older model year school buses with new models of diesel, gasoline, propane, condensed natural gas, or electric school buses. Between 2012 and 2017, the US EPA awarded over $27 million to replace or retrofit school buses, and since then, the program has continued for a total of more than $66 million either disbursed or committed to school bus replacement as of April 2024.[31]

In recent years, the US EPA has run other clean school bus programs concurrently with the DERA School Bus Rebates. Those programs include the American Rescue Plan (ARP) Electric School Bus Rebates for electric school buses for underserved school districts and the Bipartisan Infrastructure Law (BIL) rebate and grant programs to replace old, higher-emitting diesel buses, with priority to fleets that serve disadvantaged communities. In most cases, the US EPA's school bus replacement programs require proof of new school bus purchases and scrappage of the old school buses, although school buses from model years 2011 that are fueled by diesel, gasoline, propane, or condensed natural gas can alternatively be sold or donated when using BIL funding to purchase new battery-electric school buses if a fleet has no diesel school buses of 2010 or older model years.

Selection of applicants for funding in the National Clean Diesel Rebate Program is determined via various lottery methods, with funding priority set by random selection. Starting in 2014, some US EPA regions (each of which includes several states and territories) contributed additional funding to the rebate program to allow the selection of additional applicants from those regions after the US EPA headquarter funds were allocated. About one third of applicants selected for funding in lottery years 2012 and 2014–2017 (there was no lottery in 2013) were allocated US EPA regional funds. The ARP and BIL lotteries have more complex procedures to target the allocation of funding, but, at the time of funding the current study, only the DERA program was in place.

The current study by Adar and colleagues took advantage of the randomized allocation of DERA funds to evaluate whether this program to replace old diesel school buses improved student health (based on school attendance and respiratory emergency department visits for school-aged children) and educational performance (based on standardized test scores), and community air quality levels, all at the school district level. Their findings inform the implementation of programs to replace the most highly polluting old school buses.

SUMMARY OF THE STUDY

STUDY OBJECTIVES

Adar and colleagues studied the effects of being selected for the US EPA's school bus retrofit and replacement funding on school attendance; standardized test scores for reading, writing, and related skills (i.e., reading/language arts, hereafter referred to as *reading*) and math; emergency department visits for respiratory causes; and community air pollution levels. They evaluated whether these outcomes had improved more in school districts that were selected for funding in the rebate funding lottery compared with those that had also applied for funding but were not selected. Specific aims of the study were as follows:

1. To quantify the effects of the rebate program funding to replace old, higher emission diesel school buses with lower-emitting, upgraded buses on (a) school attendance rates for all students and (b) emergency department visit rates for respiratory causes in school-aged Medicaid beneficiaries
2. To quantify the effects of the program on standardized test scores
3. To quantify the effects of the program on community-level, outdoor air quality represented by $PM_{2.5}$

The investigators used a randomized controlled design that took advantage of the randomized allocation of funding for school bus replacements and retrofits. They compared the outcomes before and after each lottery between school districts that were selected to receive the funding and other school districts that were not, regardless of which (if any) school districts replaced their buses with new models (see **Sidebar** description of intention-to-treat analysis). They used data at the school district level starting in the 2012–2013 school year — before the first randomized allocation of funding in the 2012 pilot — and ending in the 2018–2019 school year after funding from the 2017 lottery had been awarded.

STUDY DESIGN AND METHODS

Design and Approach

This study implemented a quasi-experimental design across school districts that applied for funding to replace their old diesel school buses. They used a regression modeling approach to compare outcomes in the school year during which applicants applied for funding to outcomes in the year after the funding was awarded via lottery. Applicants that were selected for funding were notified of their selection at the end of the school year and were expected to replace or retrofit their buses in the following summer. For example, 2012 lottery applicants were notified of the results at the end of the 2012–2013 school year and should have replaced their buses in the summer of 2013. Thus, the years that were analyzed for school districts that entered the 2012 lottery were the 2012–2013 school year (*before*) and the 2013–2014 school year (*after*). Replacement buses were required to be current models for that year (e.g., model year 2012 or later for the lottery that took place in 2012). Proof of school bus purchase and scrappage of the old school bus were required to receive the allocated funds. (See **Commentary Figure 2**.)

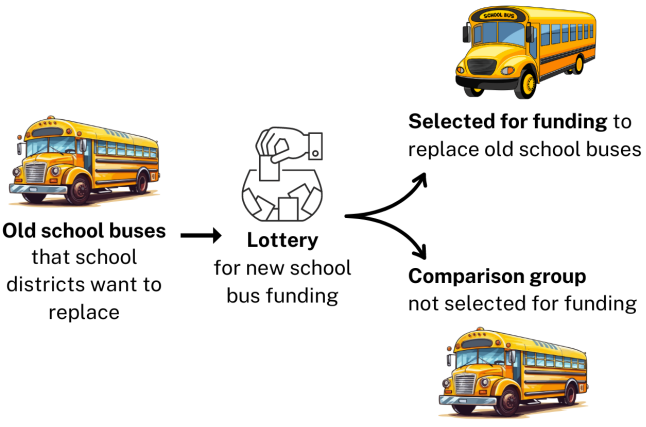
Study Population

The study population was assembled based on the dataset of individual school districts that had reporting requirements for school attendance and standardized test scores and applied for funding in 2012 and 2014–2017; there was no lottery in 2013. Therefore, applications were excluded from analyses if they (1) represented more than one school district; (2) represented private, nontraditional, or tribal schools; (3) were located outside of the continental United States; or (4) had incomplete information related to the school district that the applicant represented.

The investigators obtained the following information on the school districts represented by the lottery applicants via a Freedom of Information Act request to the US EPA: what school districts were served by applicants, how many school buses the applicants intended to replace, and whether the applicant was selected for funding through the program. For those applicants that were selected for funding, they also obtained information on characteristics of original buses, whether those were replaced or retrofitted, and confirmation of the replacements or retrofits.

Outcomes

District-level absenteeism data were obtained from the state-level departments of education, and data on school characteristics were obtained from the US Department of Education. Information on the numbers of respiratory-caused emergency department visits (i.e., asthma, upper respiratory



Commentary Figure 2. Conceptual framework of the study to assess a policy that provided funding to replace old school buses via a lottery mechanism. (Adapted from Investigators' Report Figure 1.)

Sidebar: Principles of the Intention-to-Treat Approach

The study by Adar and colleagues mimics a randomized controlled trial using intention-to-treat analysis to assess the effects of a school bus replacement and retrofit program. Intention-to-treat analysis is a method used in the medical setting to evaluate whether individual participants or groups of participants experienced a treatment effect in a placebo-controlled randomized clinical trial based on the randomly assigned treatment (e.g., a new medication, therapy, or intervention) assignment, ignoring whether or not the assigned treatment was followed and completed.[32,33] Analysts compare outcomes in the *treatment* group who were assigned to receive the treatment versus the *placebo* or *control* group who were assigned to *not* receive the treatment, regardless of the degree of noncompliance among participants in the trial. Intention-to-treat generally includes all participants that were randomized in the final analysis, even if their inclusion were later found to violate the study protocol, because excluding participants after randomization for any reason could potentially distort the randomization mechanism and bias the results, depending on the amount of exclusion and whether there were any systematic differences between the participants that were and were not excluded.[34] Intention-to-treat analysis has the benefit of retaining randomization, so it will not be subject to bias due to confounding. However, if the treatment assignments are not followed, the treated and control groups can be too similar to one another. Although the intention-to-treat approach will incorporate error if individuals or groups did not follow their random treatment assignment, the results of this misclassification will bias the results toward no association, and thus, the result will be a conservative estimate of the true effects of the treatment on the outcomes under study. As a result, intention-to-treat analysis might underestimate the effect of a treatment and can also limit the statistical power.

Some alternative approaches to intention-to-treat are to set the treatment groups based on the actual – instead of assigned – treatment of participants or to restrict the study population to only those who follow their randomized assignments.[32] In clinical trials, not all participants who are randomized to the treatment group actually follow and complete the intended treatment protocol due to side effects or other factors. At the same time, participants in the control group might make changes that affect their health or even adopt aspects of the treatment protocol (e.g., in a dietary intervention). Under perfect compliance, intention-to-treat and these alternative approaches will be the same, but if there is noncompliance the alternative approaches might differ due to confounding or selection bias.

infections, or pneumonia) among children aged 5–18 who received health coverage through the low-income Medicaid program were obtained for all zip codes intersecting applicant school districts. Standardized test score data for math and reading for children in grades 3–8 were acquired from a harmonized national dataset of student educational performance (the Stanford Education Data Archive) in December 2023. At the time of the study, standardized test scores were only available for school years spanning 2012–2017, so the final lottery year was not included in standardized test score analyses. $PM_{2.5}$ data were obtained from publicly available concentration surfaces that were modeled by combining chemical transport model predictions, ground measurements, and satellite observations on a 0.01-degree grid (roughly 1 × 1 km) and assigned to each school district for September 1 to May 31 of each school year that was analyzed.

Intention-to-Treat Analysis

The investigators took advantage of the randomized allocation of funding to conduct a study similar to a randomized controlled study (see Sidebar), where the *treatment* group was school districts with applications that were randomly selected for funding to reimburse the purchase of one or more new, lower-emission school buses and the *control* group was school districts with applications that were not randomly selected for funding.

Of the school districts that entered the funding lottery, some school districts that were selected for funding did not receive the funding and some school districts that were not selected for funding might have purchased new school buses using other funding sources. Therefore, an alternative strategy for analysis could have been to test the observed differences between districts based on whether they did replace their older, more highly emitting school buses with new school buses (see Sidebar description of intention-to-treat and alternative analyses). However, the investigators decided to use a modified intention-to-treat analysis (with some school districts excluded as indicated below) instead of an alternative approach to maintain randomization and to analyze the data in the least biased way possible.

Statistical Analyses

The main models were a modified intention-to-treat analysis where the investigators restricted their population to only those school districts with complete data on the outcomes of interest. The investigators produced multivariate regression models of student educational performance and health outcomes as a function of whether the applicant was selected for funding and other factors. Educational performance, school attendance, and air quality outcomes were modeled using linear models. Emergency department visits were modeled as a Poisson function and adjusted for population size. Each

primary model was adjusted for the outcome values for the school year of the lottery (the *before* year), which year's lottery was entered, whether the applicant entered the lottery multiple times in the same year (allowed for some school districts with large fleets), and the US EPA region (because supplemental funding from some regions increased the chance of being selected for funding). Because school districts were not limited to entering the lottery in only 1 year, the investigators used general estimating equations with robust standard errors clustered at the state level to account for any potential correlation in the data.

Supplemental and Sensitivity Analyses

The investigators noted that the analyses at the school district level assumed that all children in the school district are affected by the intervention, but not all children in a district attend the affected schools, not all children ride school buses, and not all school buses in the district were replaced or retrofitted. They also noted that modeling all school districts together will estimate a common effect for replacing any old school buses, yet not all old school buses are equivalent. To address some of these differences in the treatment, they conducted analyses that were stratified by quartiles of the fraction of children who were likely to ride the buses requested for replacement and by the model year of replaced buses (pre-1990, 1990–1999, and 2000 or newer).

The investigators conducted many sensitivity analyses of such factors as properties of the school districts, accounting for prelottery levels of the outcome measures, and inclusion of observations that had been excluded due to missingness estimated using a multiple imputation approach.[35] They also conducted mediation analyses to assess whether respiratory emergency department visits mediated (i.e., were an intermediate causal step between) the effect of selection for funding to replace school buses on school attendance and educational performance.

Finally, they estimated the overall contribution of the program by multiplying the total number of students in selected school districts in the school year of the lottery by the observed primary effect estimate, and by 180 days in the school year, and extrapolated the findings to the nationwide population of school children and old school buses.

SUMMARY OF KEY RESULTS

Characteristics of the School Districts

The US EPA received 3,153 applications for funding to replace or retrofit school buses in the years 2012 and 2014–2017. Interest in new school buses substantially exceeded the available funding; therefore, only 14% of school districts that applied were selected for funding. Of the full set of applications, the analyses in the current study included 406 applications that were selected for funding and 2,613 that were not. The remaining 4% of applications were excluded based on the predetermined exclusion criteria. Standardized test score data were unavailable for about 20% of school districts in the study because of low student participation in standardized tests in some school districts and differences in test administration. Lottery status was not predictive of missingness for any of the outcomes considered.

Of those school districts that applied for the funding lottery, the proportion of each school district characteristic (e.g., size, demographics, urbanicity, and free and reduced-price lunch eligibility [a proxy for family income]), number of buses requested, school attendance rates, and standardized test scores in the years they entered the funding lottery were similar regardless of whether they were selected for funding. However, prelottery emergency department visits and $PM_{2.5}$ concentrations were slightly lower in school districts that were allocated funding than in those that were not. Compared with all 18,893 school districts in the United States, school districts that applied for the lottery funding were larger, had a higher proportion of students that were white, had a lower proportion of low-income families, and were less urban. These comparisons suggest that the results of the analyses have internal validity (i.e., the selected and not selected districts were similar) but that they cannot be easily generalized to all school districts.

Buses Replaced Following the School Bus Rebate Lotteries

Compliance with the intervention was high, with 371 of the included districts that were selected for funding (91%) providing proof of purchase of a new school bus and scrappage of the old school bus to receive the funding. Information on the type of school bus that was purchased was available for 380 of all school districts selected for funding through the program. Almost all of those school districts replaced old diesel buses with new, lower-emitting diesel buses (93.2%), with a minority choosing buses powered by other fossil fuels (6.6%). Only one school district (0.3%) installed retrofit diesel oxidation catalyst and closed crankcase ventilation technology. No school district purchased electric buses; electric school buses were largely unavailable during the study period. Information on school bus purchasing behaviors was not available for the school districts that were selected for funding but did not receive the funding or for the school districts that were not selected for funding.

Effects of the Intervention on School Attendance and Standardized Test Scores

When analyses were restricted to school districts that intended to replace the oldest, pre-1990 school buses, selection of an application for funding was associated with improved district-level school attendance and standardized test scores for both reading and math (**Commentary Figure 3**). Results for all school buses and for slightly newer buses (1990–1999 model year) showed the same trends, although these were not statistically significant. Results for the newest school buses that were intended to be replaced (model year

2000 or newer) did not show any effects on school attendance or standardized test scores.

The investigators reported that the effects on test scores were comparable to those of typical interventions to reduce class size. Additionally, they estimated that the overall magnitude of the effects was equivalent to about 350,000 additional student-days of school attendance, presumed to be because of improved health, in the school districts that were selected for funding, which they extrapolated to 1.3 million additional student-days if all pre-2000 model year school buses in the United States were replaced.

In secondary analyses, increased fractions of students riding buses did not appear to influence the association between being selected for funding and standardized test scores, although it might have influenced the association between being selected for funding and school attendance. Also, school attendance did not appear to mediate the overall relationship between being selected for funding and educational performance. In general, the sensitivity analyses with different adjustments to the epidemiological models and assumptions around the treatment of missing data corroborated the main results.

Effects of the Intervention on PM Concentrations and Emergency Department Visits

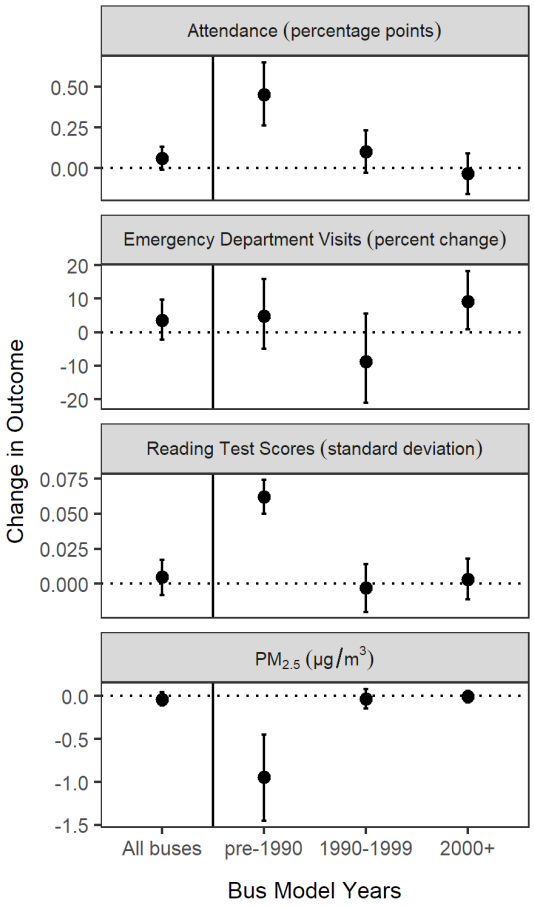
The investigators did not find an effect of being selected for funding on numbers of emergency department visits for respiratory causes in children, but these analyses were highly sensitive to model assumptions. They did find a sizable effect on community-level, outdoor air pollution — a 1-μg/m^3 reduction in $PM_{2.5}$ concentrations — in the year after the lottery in those districts that were selected for funding to replace the oldest (pre-1990) school buses. The $PM_{2.5}$ results were robust across many different specifications of the model (e.g., using the change in $PM_{2.5}$ concentration as the dependent variable instead of the $PM_{2.5}$ concentration itself) and under numerous sensitivity analyses (see above), and no alternative explanation for the unexpectedly large magnitude of the result was found.

HEI REVIEW COMMITTEE EVALUATION

In its independent evaluation of the study, the Review Committee appreciated that Dr. Adar and colleagues brought together disparate datasets to conduct a novel and useful accountability study of a program to allocate funding for replacement of old diesel school buses and presented the results in a clearly written report. They agreed with the investigators that being selected for funding appeared to improve student educational performance and school attendance, especially for pre-1990 school buses, and that the results for emergency department visits were less clear. Additionally, the Committee and investigators were not able to explain the large observed reductions in community-level, outdoor air pollution that were robust to many sensitivity analyses, because it was not clear how changing out a relatively small number of school buses could affect air quality in a school district by so much. The Committee thought that the main results for school attendance and standardized test scores were well supported by the evidence.

INTENTION-TO-TREAT AT SCHOOL DISTRICT LEVEL

The Review Committee appreciated the strong study design to test hypotheses diligently and the extensive supplemental analyses, all at the level of school districts. Leveraging a randomized funding lottery to mimic a randomized control trial and using a modified intention-to-treat approach (see Sidebar) to analyze the data are novel in this context. Specifically, the Committee liked the approach to compare school districts based on whether they were randomly selected for funding, regardless of whether it was known how (or whether) they chose to replace or retrofit school buses, similar to how patients are assigned treatments and analyzed in clinical studies. This approach provides an unbiased estimate of the effect



Commentary Figure 3. Effects of selection for funding to replace or retrofit school buses, stratified by school bus model year, on school attendance, emergency department visits, standardized test scores for reading, and $PM_{2.5}$ concentrations. Changes in standardized test scores for math (not shown) were similar to those for reading, but with a slightly smaller magnitude of effect.

of the program and does not rely on additional information (mostly unavailable) on the school buses purchased in individual school districts and school bus ridership of individual students. Additionally, detailed supplemental analyses (e.g., related to how many children potentially rode the affected school buses) and sensitivity analyses were consistent with the main results, indicating that the overall conclusions were robust.

The Committee agreed with the investigators that conducting analyses at the school district level introduces some limitations of an ecological analysis, which typically is conducted on data aggregated to groups of people (e.g., all students living within a zip code or school district or town). For example, not all children in a school district will ride buses (or more specifically, buses that have been replaced or retrofitted), and not all children will attend the schools that received new buses (because most districts have multiple schools and not all of them will receive new buses). However, the Committee emphasized that this does not invalidate the approach for measuring the effectiveness of the intervention on a population level and that the investigators have rightly recognized these limitations and attempted to address them where possible.

DEVIATIONS FROM RANDOMIZATION AND MISSING DATA

Post-Randomization Exclusion

The Review Committee and investigators noted that some exclusions of applications in the modified intention-to-treat analysis were made after the lottery randomization process. For example, some applications were excluded from the analyses because the school districts were not located in the continental United States or because there was incomplete information available on the school districts. Although the post-randomization exclusions were small (only 4% of school districts) and not related to whether the school districts were selected for funding, this modification of the intention-to-treat analysis might introduce selection bias if the exclusions were related to any of the outcomes.[34] The Committee appreciated that the investigators conducted sensitivity analyses to partially address whether post-randomization exclusions might have affected the results.

In particular, the investigators adjusted each model for prelottery levels of other outcomes considered in the study. They also replaced all excluded data with extreme values to confirm the stability of their findings to their exclusions due to missing data. They reported that the results were robust to post-randomization exclusion for school attendance, standardized test scores, and community air pollution level. However, the results for respiratory emergency department visits were not robust to the sensitivity analyses, suggesting that the findings related to emergency department visits might have been affected by changes in demographics over time, post-randomization exclusion due to missingness of data, or insufficient power to detect small effects with the available data. The Committee overall thought that the sensitivity analyses strengthened the main conclusions of the study.

Nonuniform Allocation of Funding

There were also some deviations from uniform random selection in the lottery itself, where some applicants had a higher likelihood of being selected for funding. Those deviations included the availability of extra funding in some US EPA regions and the option for applicants with large fleets to submit multiple applications. The investigators used fixed effects in their regression models to account for these differences among regions and applicants, and they also used general estimating equations with robust standard errors clustered at the state level to account for any potential correlation in the data. The Review Committee agreed that the analyses were sufficient to account for differences in probability of selection because of nonuniform allocation of funding.

Treatment of Missing Data

Separately from randomization of the allocation of funding, missing data on any variable in the models could theoretically have affected the results because the main models were based on complete-case data. The Review Committee noted that there were some baseline differences between the selected and unselected lottery applicants that might still be important. They appreciated that the investigators had confirmed that there was no association of missingness for any of the outcomes with lottery status and that the investigators reran all models after using multiple imputation together with Rubin's rule for missing outcome variables.[35] All findings except for emergency department visits were robust to accounting for missingness using multiple imputation. The Committee appreciated the analyses with imputation because these results would likely continue to be valid if the missing data were random, even if the complete-case analysis were biased.

Although the Committee would have preferred that missing data due to incomplete information on the randomized school districts and other causes could have been avoided, it appreciated the investigators' efforts to evaluate the potential impact of deviations from randomization and missing data.

FINDINGS AND INTERPRETATION

The investigators presented interesting and useful findings, including that the greatest improvements in school attendance and standardized test scores were associated with the replacement of the oldest (pre-1990) diesel school buses. Based on these findings, the Review Committee concurred with the investigators that the program had positive effects on students' school attendance and standardized test scores. The Review Committee was puzzled by some of the results, especially for emergency department visits, where the effect was opposite (but not statistically significant) of the hypothesized direction and for community-level, outdoor $PM_{2.5}$ concentrations, where the 1-μg/m^3 reduction was much larger than

expected and it was not clear how changing out a relatively small number of school buses could affect air quality in a school district by that much, given that typical $PM_{2.5}$ concentrations in the United States today are only about 8 $\mu g/m^3$. However, it is possible that students experienced lower pollution exposures while traveling on the buses, thereby affecting their school attendance and standardized test scores. The Committee thought that the interpretation of those results could benefit from further exploration.

The investigators also presented an interesting extrapolation of the potential benefits of replacing all school buses in the entire continental United States. Although the Review Committee thought this analysis was useful and agreed with the investigators that it does not account for sustained benefit over time, they thought it perhaps overestimated the potential annual benefits. First, school districts that did not enter the lottery might be less likely to replace their current school buses, even if funding becomes more widely available. Second, other differences between school districts that applied and those that did not apply for the lottery might mean that the results for the study population are not representative of most school districts, especially those that experience environmental and social justice issues and were underrepresented in the lottery applications.

The US EPA continues to fund rebate and grant programs for the purchase of lower-emitting school buses and motivates those programs in part with the benefits reported in other publications resulting from the current study.[36,37] Recently, electric buses have become more readily available and have been prioritized in the US EPA's programs to fund purchases of new school buses. At the same time, the US EPA has started to give preference to applicants in underserved districts when allocating funding.[38,39] Additionally, after the end of the study period, the COVID-19 pandemic disrupted healthcare and education, with reduced student school attendance and educational performance compared with before the pandemic.[40,41] As a result of those changes, the incremental benefits of programs to replace old school buses might change in the future. It would be valuable to update the analysis of clean school bus programs in 5 to 10 years to evaluate the benefits of replacing diminishing numbers of the oldest school buses. Additional future benefits are expected when school buses in today's fleet are replaced with the newest generation of diesel school buses, with school buses operating on other fuels, or with electric school buses.

SUMMARY AND CONCLUSIONS

Dr. Adar and colleagues conducted a thorough accountability study of the US EPA's School Bus Retrofit and Replacement Program under DERA that was administered via a lottery mechanism over the period of 2012 and 2014–2017. They linked data on school attendance, reading and math standardized test scores, emergency department visits, and community-level, outdoor $PM_{2.5}$ concentrations to compare student outcomes in school districts that were selected for funding to school districts that were not selected for funding. They reported that student educational performance and school attendance increased more in districts that were selected for funding than in districts that applied for funding but were not selected, with the highest improvements in student educational performance observed for the school districts that were selected for funding to replace pre-1990 school buses with new school buses. Improvements in community air quality were found, although the magnitude of the effect suggests the need for further research to understand their implications. Results for effects on student emergency department visits were inconsistent and need further research.

Key strengths of the study were the novel imitation of a randomized controlled trial through the application of a modified intention-to-treat approach to analyze the effect of funding being made available for new school buses, the clearly stated hypotheses, the combination of disparate datasets, and the many sensitivity analyses to evaluate factors that might have affected the statistical analyses or the effectiveness of the intervention (e.g., replacing buses versus retrofitting diesel engines and the fraction of students who rode school buses in different school districts). The Committee noted some limitations, in particular some post-randomization exclusions. However, the investigators demonstrated that the results were reasonably robust. Thus, the Committee concurred with the investigators that remaining uncertainties were unlikely to change the overall results substantially regarding the effectiveness of the program to replace old diesel school buses with lower-emitting school buses from model years that were new at the time of the lotteries.

Results of the current study provide evidence of benefits of funding for school bus replacement programs by federal and state agencies.[36,37,38] Additional focus on disadvantaged school districts and the adoption of new technologies (e.g., electric buses) is expected to reduce emissions from the oldest school buses with the highest emissions. Therefore, it would be valuable to update the analyses in 5–10 years to evaluate the effects of programs to replace more of the older diesel school buses with newer models and newer technologies, including those powered by lower-emitting diesel, other fossil fuels, and electricity. This work will be important to support the health and educational performance of schoolchildren and communities.

ACKNOWLEDGMENTS

The HEI Review Committee thanks the ad hoc reviewers for their help in evaluating the scientific merit of the Investigators' Report. The Committee is also grateful to Dan Crouse for oversight of the study, to Allison Patton and Samantha Miller for assistance with review of the report and in preparing its Commentary, to Carol Moyer and Tom Zaczkiewicz for the editing of this Report and its Commentary, and to Kristin Eckles and Hope Green for their roles in preparing this Research Report for publication.

REFERENCES

National Center for Education Statistics. 2022. Table 236.90. Students Transported at Public Expense and Current Expenditures for Transportation: Selected Years, 1929–30 through 2018–19 [data table]. In: Digest of Education Statistics, US Department of Education, Institute of Education Sciences. *https://nces.ed.gov/programs/digest/d21/tables/dt21_236.90.asp* [accessed 18 June 2024].

School Bus Fleet Magazine. 2022. US State-by-State School Transportation Statistics 2022–2023. *https://www.schoolbusfleet.com/download?id=10211604&dl=1* [accessed 18 June 2024].

Bureau of Transportation Statistics. 2021. The Longer Route to School. *https://www.bts.gov/topics/passenger-travel/back-school-2019* [accessed 18 June 2024].

Catt AD. 2020. Commuting Concerns: A Survey of US Parents on K–12 Transportation before and during the COVID-19 Pandemic; EdChoice. *https://eric.ed.gov/?id=ED609382* [accessed 18 June 2024].

Howley CB, Howley AA, Shamblen S. 2021. Riding the school bus: A comparison of the rural and suburban experience in five states. J Res Rural Educ 17:41–63.

Cordes SA, Rick C, Schwartz AE. 2022. Do long bus rides drive down academic outcomes? Educ Eval Policy Anal 44:689–716, *https://doi.org/10.3102/01623737221092450*.

Weinstein M, Cordes SA, Rick C, Schwartz AE. 2022. Riding the yellow school bus: Equity in bus transportation across districts, schools, and students. Urban Education 0(0), *https://doi.org/10.1177/00420859221114084*.

Electrification Coalition. 2024. Electric School Buses: Program Overview. *https://electrificationcoalition.org/schoolbus/* [accessed 18 June 2024].

Engine Technology Forum. 2024. America's Truck and Bus Fleets Continue Turnover to Advanced Generation of Near-zero Emission Internal Combustion Engines [press release and infographic based on S&P mobility]. *https://enginetechforum.org/press-releases/posts/truck-and-bus-fleets-continue-turnover-to-advanced-gen-of-near-zero-emission-ice* [accessed 25 June 2024].

Zhu Y, Zhang Q. 2014. Characterizing Ultrafine Particles and Other Air Pollutants In and Around School Buses. Research Report 180. Boston, MA: Health Effects Institute.

Richmond-Bryant J, Bukiewicz L, Kalin R, Galarraga C, Mirer F. 2011. A multi-site analysis of the association between black carbon concentrations and vehicular idling, traffic, background pollution, and meteorology during school dismissals. Sci Total Enviro 409:2085–2093, *https://doi.org/10.1016/j.scitotenv.2011.02.024*.

Benbrahim-Tallaa L, Baan RA, Grosse Y, Lauby-Secretan B, El Ghissassi F, Bouvard V, et al.; International Agency for Research on Cancer Monograph Working Group. 2012. Carcinogenicity of diesel-engine and gasoline-engine exhausts and some nitroarenes. Lancet Oncol 13:663–664, *https://doi.org/10.1016/s1470-2045(12)70280-2*.

US EPA. Final Rule and Related Materials for Control of Air Pollution from New Motor Vehicles: Heavy-Duty Engine and Vehicle Standards. *https://www.epa.gov/regulations-emissions-vehicles-and-engines/final-rule-and-related-materials-control-air-pollution* [accessed 13 November 2023].

Health Effects Institute (HEI). 2015. Executive Summary. The Advanced Collaborative Emissions Study (ACES). Boston, MA: Health Effects Institute. *https://www.healtheffects.org/publication/executive-summary-advanced-collaborative-emissions-study-aces*.

McDonald JD, Bemis JC, Hallberg LM, Conklin DJ. 2015. Advanced Collaborative Emissions Study (ACES): Lifetime Cancer and Non-Cancer Assessment in Rats Exposed to New-Technology Diesel Exhaust. Research Report 184. Boston, MA: Health Effects Institute. *https://www.healtheffects.org/publication/advanced-collaborative-emissions-study-aces-lifetime-cancer-and-non-cancer-assessment*

Mauderly J, McDonald J. 2012. Advanced Collaborative Emissions Study (ACES) Phase 3A: Characterization of US 2007-Compliant Diesel Engine and Exposure System Operation. Communication 17. Boston, MA: Health Effects Institute. *https://www.healtheffects.org/publication/advanced-collaborative-emissions-study-aces-phase-3a-characterization-us-2007-compliant*.

Khalek I, Bougher T, Merritt P. Phase 1 of the Advanced Collaborative Emissions Study. 2009. CRC Report: ACES Phase 1. Alpharetta, GA: Coordinating Research Council. *https://crcao.org/wp-content/uploads/2019/05/ACES-Phase1-Final-Report-15JUN2009.pdf* [accessed 27 June 2024].

US EPA. 2016. Heavy-Duty Highway Compression-Ignition Engines and Urban Buses: Exhaust Emission Standards; EPA-420-B-16-018.

US DOE. 2020. IdleBase. *https://cleancities.energy.gov/files/docs/idlebox_idlebase_database.xlsx* [accessed 27 June 2024].

Schlosser N. 2021. Maintenance Survey 2021. School Bus Fleet Magazine.

Platt W. 2023. 2023 School Bus Fleet Maintenance Survey. *https://www.schoolbusfleet.com/10192096/2023-sbf-maintenance-survey-wages-increase-along-with-expenses-for-parts* [accessed 18 June 2024].

Adar SD, Pedde M, Hirth R, Szpiro A. 2024. Assessing the National Health, Education, and Air Quality Benefits of the United States Environmental Protection Agency's School

Bus Rebate Program: A Randomized Controlled Trial Design. Research Report 221. Boston, MA: Health Effects Institute.

Lazer L, Freehafer L, Wang J. 2024. Dataset of US School Bus Fleets Version 3. Washington, DC: World Resources Institute. *https://datasets.wri.org/dataset/school_bus_fleets* [accessed 18 June 2024].

McCaffery C, Zhu H, Tang T, Li C, Karavalakis G, Cao S, et al. 2021. Real-world NO_x emissions from heavy-duty diesel, natural gas, and diesel hybrid electric vehicles of different vocations on California roadways. Sci Total Environ 784:147224, *https://doi.org/10.1016/j.scitotenv.2021.147224*.

Smit R, Keramydas C, Ntziachristos L, Lo T, Ng K, Wong HA, et al. 2019. Evaluation of real-world gaseous emissions performance of selective catalytic reduction and diesel particulate filter bus retrofits. Environ Sci Technol 53: 4440–4449. *https://doi.org/10.1021/acs.est.8b07223*.

Adar SD, D'Souza J, Sheppard L, Kaufman JD, Hallstrand TS, Davey ME, et al. 2015. Adopting clean fuels and technologies on school buses: Pollution and health impacts in children. Am J Respir Crit Care Med 191:1413–1421, *https://doi.org/10.1164/rccm.201410-1924OC*.

Austin W, Heutel G, Kreisman D. 2019. School bus emissions, student health and academic performance. Econ Educ Rev 70:109–126, *https://doi.org/10.1016/j.econedurev.2019.03.002*.

Austin W. 2019. School bus diesel retrofits, air quality, and academic performance: National evidence using satellite data. NBER Working Paper Series. Working Paper 25641. *https://www.nber.org/papers/w25641* [accessed 19 June 2024].

Beatty TKM, Shimshack JP. 2011. School buses, diesel emissions, and respiratory health. J Health Econ 30:987–999, *https://doi.org/10.1016/j.jhealeco.2011.05.017*.

Choma EF, Robinson LA, Nadeau KC. 2024. Adopting electric school buses in the United States: Health and climate benefits. Proc Natl Acad Sci USA 121:e2320338121, *https://doi.org/10.1073/pnas.2320338121*.

US EPA. 2024. Awarded DERA Rebates. *https://www.epa.gov/dera/awarded-dera-rebates*, last updated June 20, 2024 [accessed 26 August 2024].

McCoy CE. 2017. Understanding the intention-to-treat principle in randomized controlled trials. West J Emerg Med 18:1075–1078, *https://doi.org/10.5811/westjem.2017.8.35985*.

Gupta SK. 2011. Intention-to-treat concept: A review. Perspect Clin Res 2:109–112, *https://doi.org/10.4103/2229-3485.83221*.

Fergusson D, Aaron SD, Guyatt G, Hébert P. 2002. Post-randomisation exclusions: The intention to treat principle and excluding patients from analysis. BMJ 325:652–654. *https://doi.org/10.1136/bmj.325.7365.652*.

Rubin DB. 1987. Multiple Imputation for Nonresponse in Surveys (1st ed.). New York, NY: John Wiley & Sons, Inc., *https://doi.org/10.1002/9780470316696*.

US EPA. 2024. EPA Clean School Bus Program Third Report to Congress Fiscal Year 2023; EPA-420-R-24-001, *https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P1019JFZ.pdf* [accessed 7 June 2024].

US EPA. 2024. Benefits of Clean School Buses. *https://www.epa.gov/cleanschoolbus/benefits-clean-school-buses* [accessed 21 June 2024].

Electric School Bus Initiative. 2024. Clearinghouse: Electric School Bus Funding and Financing Opportunities | Electric School Bus Initiative. *https://electricschoolbusinitiative.org/clearinghouse-electric-school-bus-funding-and-financing-opportunities* [accessed 7 June 2024].

US EPA. Clean Heavy-Duty Vehicles Grant Program. 2024. *https://www.epa.gov/clean-heavy-duty-vehicles-program/clean-heavy-duty-vehicles-grant-program* [accessed 25 April 2024].

Polikof M, Clay I, Silver D. 2023. Beyond Test Scores: Broader Academic Consequences of the COVID-19 Pandemic on American Students. Report from a Consensus Panel; Center on Reinventing Public Education. *https://eric.ed.gov/?id=ED640412* [accessed 24 June 2024].

Gigli KH, Graaf G. 2023. Changes in use and access to care for children and youth with special health care needs during the COVID-19 pandemic. J Pediatr Health Care 37:185–192, *https://doi.org/10.1016/j.pedhc.2022.09.008*.

ABBREVIATIONS AND OTHER TERMS

CI	confidence interval
CHIP	Children's Health Insurance Program
ED	emergency department
ICD	International Classification of Diseases
ITT	intention-to-treat
PM	particulate matter
$PM_{2.5}$	particulate matter ≤2.5 μm in aerodynamic diameter
pp	percentage point
QA	quality assurance
RFA	Request for Applications
RLA	reading and language arts
SD	standard deviation
SEDA	Stanford Education Data Archive
US EPA	United States Environmental Protection Agency

HEI BOARD, COMMITTEES, and STAFF

BOARD OF DIRECTORS

Richard A. Meserve, Chair *Senior of Counsel, Covington & Burling LLP; President Emeritus, Carnegie Institution for Science; former Chair, US Nuclear Regulatory Commission, USA*

Jo Ivey Boufford *Clinical Professor of Global Health and Pediatrics, New York University, USA*

Homer A. Boushey *Emeritus Professor of Medicine, University of California San Francisco, USA*

Jared L. Cohon *President Emeritus and Professor, Civil and Environmental Engineering and Engineering and Public Policy, Carnegie Mellon University, USA, In Memoriam 1947–2024*

Stephen Corman *President, Corman Enterprises, USA*

Martha J. Crawford *Operating Partner, Macquarie Asset Management, USA*

Ana V. Diez Roux *Dana and David Dornsife Dean and Distinguished University Professor of Epidemiology, Dornsife School of Public Health, Drexel University; Director, Drexel Urban Health Collaborative, USA*

Michael J. Klag *Dean Emeritus and Second Century Distinguished Professor, Johns Hopkins Bloomberg School of Public Health, USA*

Alan I. Leshner *CEO Emeritus, American Association for the Advancement of Science, USA*

Catherine L. Ross *Regents' Professor Emerita, City and Regional Planning and Civil and Environmental Engineering, Georgia Institute of Technology; Chairman of the Board of Directors of the Auto Club Group, American Automobile Association, USA*

Martha E. Rudolph *Environmental Attorney, Former Director of Environmental Programs, Colorado Department of Public Health and Environment, USA*

Karen C. Seto *Frederick Hixon Professor of Geography and Urbanization Science, Yale School of the Environment, USA*

RESEARCH COMMITTEE

David A. Savitz, Chair *Professor of Epidemiology, School of Public Health, and Professor of Obstetrics and Gynecology and Pediatrics, Alpert Medical School, Brown University, USA*

Benjamin Barratt *Professor, Environmental Research Group, School of Public Health, Imperial College London, United Kingdom*

David C. Dorman *Professor, Department of Molecular Biomedical Sciences, College of Veterinary Medicine, North Carolina State University, USA*

Christina H. Fuller *Associate Professor, School of Environmental, Civil, Agricultural and Mechanical Engineering, University of Georgia College of Engineering, USA*

Marianne Hatzopoulou *Professor, Civil and Mineral Engineering, University of Toronto, Research Chair in Transport Decarbonization and Air Quality, Canada*

Heather A. Holmes *Associate Professor, Department of Chemical Engineering, University of Utah, USA*

Neil Pearce *Professor of Epidemiology and Biostatistics, London School of Hygiene and Tropical Medicine, United Kingdom*

Evangelia (Evi) Samoli *Professor of Epidemiology and Medical Statistics, Department of Hygiene, Epidemiology and Medical Statistics, School of Medicine, National and Kapodistrian University of Athens, Greece*

Alexandra M. Schmidt *Professor of Biostatistics, School of Population and Global Health, McGill University, Canada*

Neeta Thakur *Associate Professor of Medicine, University of California San Francisco, USA*

Gregory Wellenius *Professor, Department of Environmental Health, Boston University School of Public Health and Director, BUSPH Center for Climate and Health, USA*

Continues next page

HEI BOARD, COMMITTEES, and STAFF

REVIEW COMMITTEE

Melissa J. Perry, Chair *Dean, College of Public Health, George Mason University, USA*

Sara D. Adar* *Associate Professor and Associate Chair, Department of Epidemiology, University of Michigan School of Public Health, USA*

Kiros T. Berhane *Cynthia and Robert Citrone-Roslyn and Leslie Goldstein Professor and Chair, Department of Biostatistics, Mailman School of Public Health, Columbia University, USA*

Ulrike Gehring *Associate Professor, Institute for Risk Assessment Sciences, Utrecht University, Netherlands*

Michael Jerrett *Professor, Department of Environmental Health Sciences, Fielding School of Public Health, University of California Los Angeles, USA*

Frank Kelly *Humphrey Battcock Chair in Community Health and Policy and Director of the Environmental Research Group, Imperial College London School of Public Health, United Kingdom*

Jana B. Milford *Professor Emerita, Department of Mechanical Engineering and Environmental Engineering Program, University of Colorado Boulder, USA*

Jennifer L. Peel *Professor of Epidemiology, Department of Environmental and Radiological Health Sciences, Colorado State University, and the Colorado School of Public Health, USA*

Eric J. Tchetgen Tchetgen *University Professor and Professor of Biostatistics and Epidemiology, Perelman School of Medicine, and Professor of Statistics and Data Science, The Wharton School, University of Pennsylvania, USA*

John Volckens *Professor, Department of Mechanical Engineering, Walter Scott Jr. College of Engineering, Colorado State University, USA*

STAFF AND CONSULTING SCIENTISTS

Elena Craft *President*

Robert M. O'Keefe *Vice President*

Ellen K. Mantus *Director of Science*

Donna J. Vorhees *HEI Energy CEO and Vice President*

Thomas J. Champoux *Director of Science Communications*

Jacqueline C. Rutledge *Director of Finance and Administration*

Jason Desmond *Deputy Director of Finance and Administration*

Nikola Sobot *Director of Development*

Emily Alden *Corporate Secretary*

Amy Andreini *Science Communications Specialist*

Hanna Boogaard *Consulting Principal Scientist*

Aaron J. Cohen *Consulting Principal Scientist*

Jacki Collins *Senior Staff Accountant*

Dan Crouse *Senior Scientist*

Cloelle Danforth *Senior Scientist*

Gabriela Daza *Research Assistant*

Philip J. DeMarco *Compliance Manager*

*Dr. Adar is a member of the HEI Review Committee and has been recused from all discussions of the report.

Continues next page

HEI BOARD, COMMITTEES, and STAFF

(*Staff and Consulting Scientists, continued*)

Kristin C. Eckles *Senior Editorial Manager*
Elise G. Elliott *Staff Scientist*
Hope Green *Editorial Project Manager*
Lenny Howard *Human Resources Ombudsman*
Lissa McBurney *Senior Science Administrator*
Janet McGovern *Executive Assistant*
Samantha Miller *Research Assistant*
Victor Nthusi *Consulting Research Fellow*
Pallavi Pant *Head of Global Health*
Allison P. Patton *Senior Scientist*
Yasmin Romitti *Staff Scientist*
Anna Rosofsky *Senior Scientist and Environmental Justice Program Lead*
Abinaya Sekar *Consulting Research Fellow*
Robert Shavers *Operations Manager*
Eva Tanner *Staff Scientist*
Alexis Vaskas *Digital Communications Manager*
Ada Wright *Research Assistant*
Daniel S. Greenbaum *President Emeritus, In Memoriam 1952–2024*
Annemoon M. van Erp *Deputy Director of Science Emerita*

NUMBER 221

OCTOBER 2024

COMMENTARY BY THE HEI REVIEW COMMITTEE

Publishing history: This document was posted at *www.healtheffects.org* in October 2024.

Citation for document:

HEI Review Committee. 2024. Commentary. In: Adar SD, Pedde M, Hirth R, Szpiro A. 2024. Assessing the National Health, Education, and Air Quality Benefits of the United States Environmental Protection Agency's School Bus Rebate Program: A Randomized Controlled Trial Design. Research Report 221. Boston, MA: Health Effects Institute.

 Composition: David Wade, Virginia Beach, VA. Library of Congress Catalog Number for the HEI Report Series: WA 754 R432.

HEI

Health Effects Institute

75 Federal Street

Suite 1400

Boston, Massachusetts 02110, USA

+1-617-488-2300

healtheffects.org