THE REAL URBAN EMISSIONS INITIATIVE

CASE STUDY

OCTOBER 2020

Emissions distributions by vehicle age and policy implications

TRUE Initiative U.S. remote sensing database case study

INTRODUCTION

Emissions from motor vehicles and their fuels contribute to ambient levels of ozone, fine particulate matter, nitrogen dioxide (NO_2), sulfur dioxide, and carbon monoxide (CO). These pollutants are linked with adverse health impacts, and 127 million people in the United States live in areas designated nonattainment for one or more of the National Ambient Air Quality Standards established by the United States Environmental Protection Agency (EPA).[1] Pollutants from cars and light- and heavy-trucks are a particular problem for the more than 50 million people who live, work, or go to school in close proximity to high-traffic roadways.[2]

Compared to 1970 vehicle models, new cars, sport utility vehicles (SUVs), pickup trucks, heavy-duty trucks, and buses are roughly 99 percent cleaner for common pollutants (hydrocarbons, carbon monoxide, nitrogen oxides and particle emissions).[3] However, these emission reductions are only achieved by new, properly operating vehicles over a defined test cycle. As discussed in more detail in ICCT's report describing development of the TRUE U.S. remote sensing database, there are many causes of increased emissions in the real-world, and a relatively small number of vehicles with defective or deteriorated systems can have a large impact on overall emissions.[4]

1 U.S. Environmental Protection Agency, "Summary Nonattainment Area Population Exposure Report," (April 30, 2020), https://www3.epa.gov/airquality/greenbook/popexp.html.

2 U.S. Census Bureau, "American Housing Survey for the United States: 2009," (report H150/09, March 2011), https://www.census.gov/prod/2011pubs/h150-09.pdf.

3 U.S. Environmental Protection Agency, "History of Reducing Air Pollution from Transportation in the United States," (September 10, 2015), https://www.epa.gov/transportation-air-pollution-and-climate-change/accomplishments-and-success-air-pollution-transportation.

4 Yoann Bernard, Tim Dallmann, Uwe Tietge, Huzeifa Badshah, and John German, *Development and application of a United States real-world vehicle emissions database,* (ICCT: Washington, DC, 2020), https://theicct.org/publications/true-us-database-development-oct2020.

One of the major causes of increased real-world emissions is vehicle emission control system deterioration. Policymakers in the United States have added a range of regulatory measures over time to help ensure that emissions remain low as vehicles age, including useful life durability requirements, emissions in-use verification and confirmatory testing, and requirements for on-board diagnostics of emissions control systems.

These regulatory measures have helped to keep in-use emissions low as vehicles age, but they are subject to significant limitations. The durability requirements only apply to properly used and maintained vehicles, and manufacturers are not responsible for emission control system malfunctions. The useful life requirements are also limited. For example, the latest Tier 3 light-duty useful life requirements cover 15 years or 150,000 miles (whichever is sooner), up from 10 years or 120,000 miles for the light-duty Tier 2 standards. For heavy-duty diesel engines, the useful life is 10 years or 435,000 miles. However, most vehicles are driven for longer periods of time, and although the oldest contribute a relatively small share of the miles driven, their emissions can continue to deteriorate as they age. Also, malfunctions increase as vehicles age and are less likely to be repaired. Consequently, while the oldest vehicles constitute a relatively small share of the in-use vehicle fleet, they contribute disproportionally to total fleet emissions.

Understanding the emissions distribution with vehicle age is needed to inform policy discussions. This is recognized by the U.S. EPA, which has been estimating the impacts of aging on emissions and the disproportionate contribution of older vehicles as part of their emission inventory work.[5] However, historical estimates have been based on limited, expensive laboratory testing of in-use vehicles or data

5 EPA Motor Vehicle Emission Simulator (MOVES), https://www.epa.gov/moves/moves-onroad-technical-reports

from inspection and maintenance programs. The TRUE U.S. database is ideal for evaluating the impacts of older vehicles on overall emissions because of its vast size and geographical and temporal coverage.

DATA

This case study uses remote-sensing measurements from the Colorado Department of Public Health & Environment and the Virginia Department of Environmental Quality to assess the impact of the oldest fraction of the fleet on total light-duty and heavy-duty emissions. The data is drawn from the TRUE U.S. database, which was constructed by ICCT from remote sensing measurements collected by Colorado, Virginia, and the University of Denver.[6] These data sources include approximately 60 million records and cover an impressive range of geography, ambient conditions, and driving conditions, which makes the data ideal to investigate many causes of real-world emissions.

For light-duty vehicles (LDV) and light-duty trucks (LDT), this case study uses the Colorado and Virginia datasets. The Colorado data spans from 2010 to the first half of 2018 and includes more than 41 million valid measurements, while the Virginia data spans from 2015 to the first half of 2018 and includes over 4 million valid measurements.[7] For heavy-duty vehicles (HDV), only the Colorado dataset was used as Virginia did not measure HDVs. A total of 9,408 unique HDVs with 73,313 measurements spanning model years 1981 through 2019 were measured as part of the Colorado program. The University of Denver dataset was not used due to the much lower number of measurements.

METHOD

For each given measurement year, the share of overall pollutant emissions for light-duty and heavy-duty vehicles was calculated as a function of vehicle age. The remote sensing equipment used by Colorado and Virginia did not measure NO_2 emissions, so only NO emissions are analyzed.

Remote sensing reports pollutant emissions as a ratio to CO_2 or fuel consumption, commonly referred to as CO_2-specific emissions (gram emissions per kg CO_2) or fuel-specific emissions (gram emissions per kg fuel consumed).[8] To obtain a more accurate approximation of the share of emissions by vehicle age, remote-sensing measurements

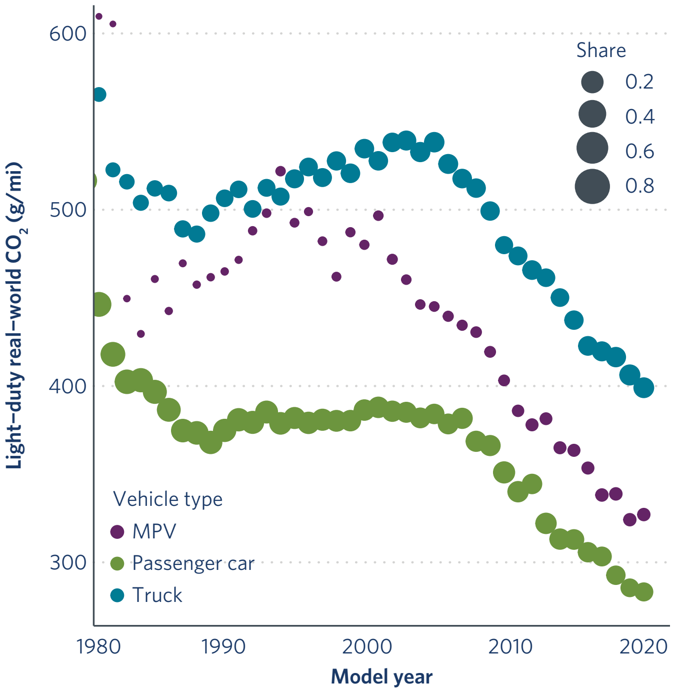

Figure 1. Distance-specific CO_2 values (g/mi) for the average U.S. passenger car, medium-duty passenger vehicle (MPV), and light-duty truck by model year.

are converted into units of mass pollutant emitted per mile driven (g/mi). This is done by multiplying the CO_2-specific vehicle emissions by an estimate of the vehicle CO_2 emissions per mile. Gram per mile emission rates are combined with a proxy of vehicles activity to calculate the mass fraction of total emissions by vehicle age (referred in the figures as share of mass emissions).

For light-duty vehicles, EPA publishes gCO_2/mi values for the average U.S. passenger car, medium-duty passenger vehicle (MPV), and light-duty truck for each model year (Figure 1).[9] These average vehicle CO_2 emissions were used to convert the remote sensing CO_2-specific emissions to mass emissions. For heavy-duty vehicles, this analysis assumes real-world CO_2 have remained unchanged over time for model year (MY) 1990 to MY 2018.[10]

This method implicitly assumes that:

- The actual vehicle activity and use is proportional to the number of remote-sensing measurements. Given the large number of remote sensing measurements and measurement sites, this should be an accurate assumption.

6 Yoann Bernard, Tim Dallmann, Uwe Tietge, Huzeifa Badshah, and John German, *Development and application of a United States real-world vehicle emissions database*, https://theicct.org/publications/true-us-database-development-oct2020.

7 Total number of valid measurements were 41,488,545 for Colorado and 4,298,309 for Virginia.

8 Fuel consumption is proportional to CO_2 emissions for any given fuel, so g/kgCO_2 is functionally identical to g/kg fuel consumed.

9 U.S. EPA Automotive Trends Report, accessed June 15, 2020, https://www.epa.gov/automotive-trends/explore-automotive-trends-data

10 Tim Dallmann and Lingzhi Jin, *Fuel efficiency and climate impacts of soot-free heavy-duty diesel engines,* (ICCT: Washington, DC, 2020), https://theicct.org/publications/soot-free-hd-diesel-engines-jun2020.

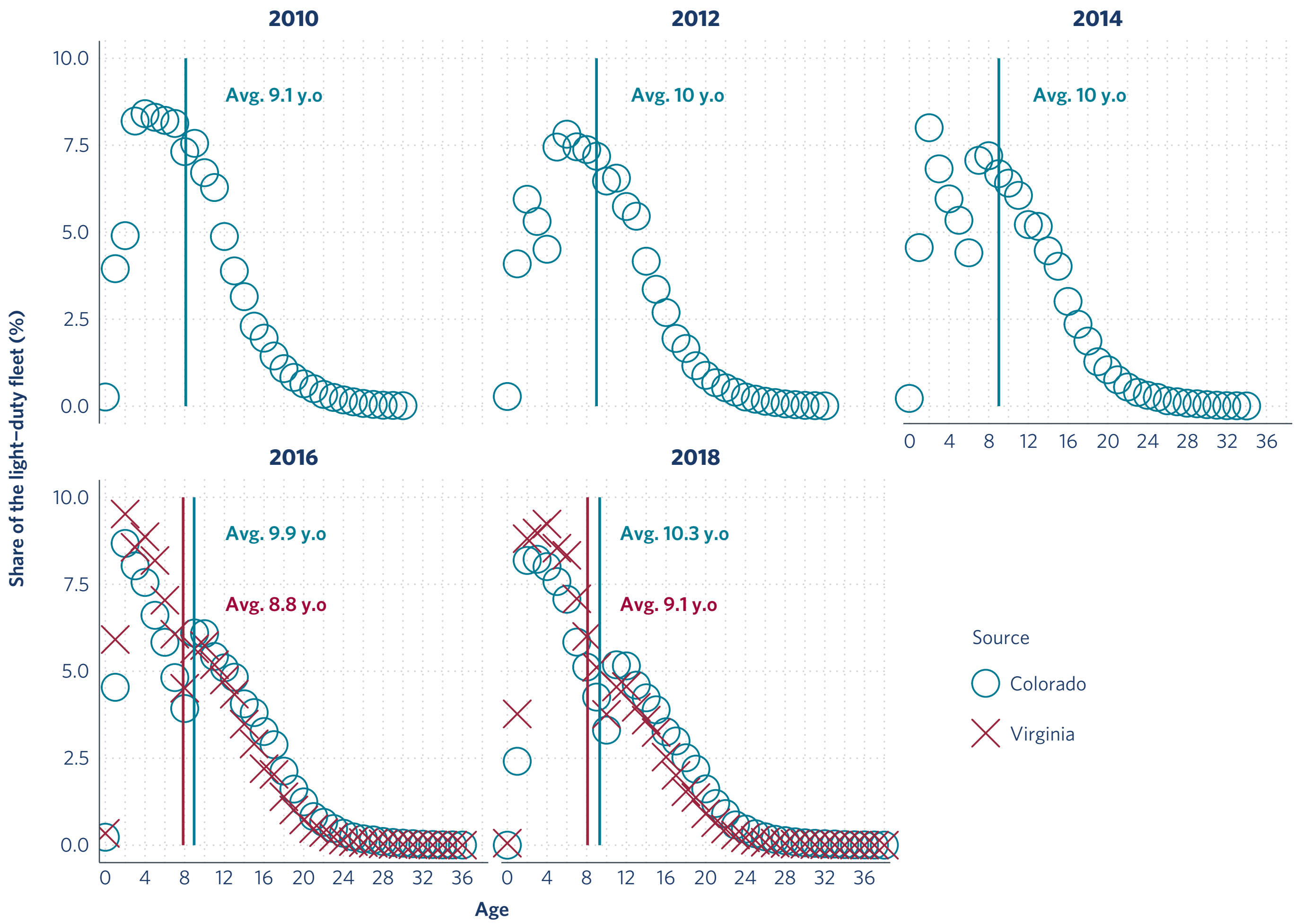

Figure 2. Share of the light-duty fleet by vehicle age.

- Colorado's and Virginia's average light-duty vehicle follows the same improvement trend for CO_2 as reported by the EPA.
- The relative contribution of each pollutant by vehicle age is proportional to the number of measurements and the average CO_2-specific pollutant emissions measured by remote-sensing multiplied by the average real-world CO_2 emissions for the corresponding vehicle type and model year.

RESULTS FOR LIGHT-DUTY VEHICLES AND TRUCKS

This section evaluates light-duty mass emissions by age from the Colorado and Virginia datasets. Trends are presented from every other measurement year for brevity. As a first step, differences in age distribution between the two datasets are evaluated. The following sub-sections calculate the cumulative share of pollutant mass emissions by vehicle age for nitrogen monoxide (NO), carbon monoxide (CO), and hydrocarbon (HC).

COMPARISON OF FLEET AGE ACROSS DATA SETS

Figure 2 compares the vehicle age distribution of the Colorado and Virginia datasets. The share for each age is calculated based on the number of remote-sensing measurements.

The comparison shows that Colorado's average light-duty vehicle age was 9.1 years old in 2010 and roughly 10 years old from 2012 to 2018. Virginia's average vehicle age was about 9 years old in 2016 and 2018, about 1 year younger than the average age in Colorado for the years that overlap.[11]

11 The lower and variable share for newer vehicles, seen most obviously in 2014, is due to the 2007-2009 recession, which caused vehicle sales to drop as much as 40% from 2008 through 2012. Bill Dupor, "Auto Sales and the 2007–09 recession," *Federal Reserve Bank of St. Lois Economic Synopses,* Number 16 (July 5, 2019), https://doi.org/10.20955/es.2019.16.

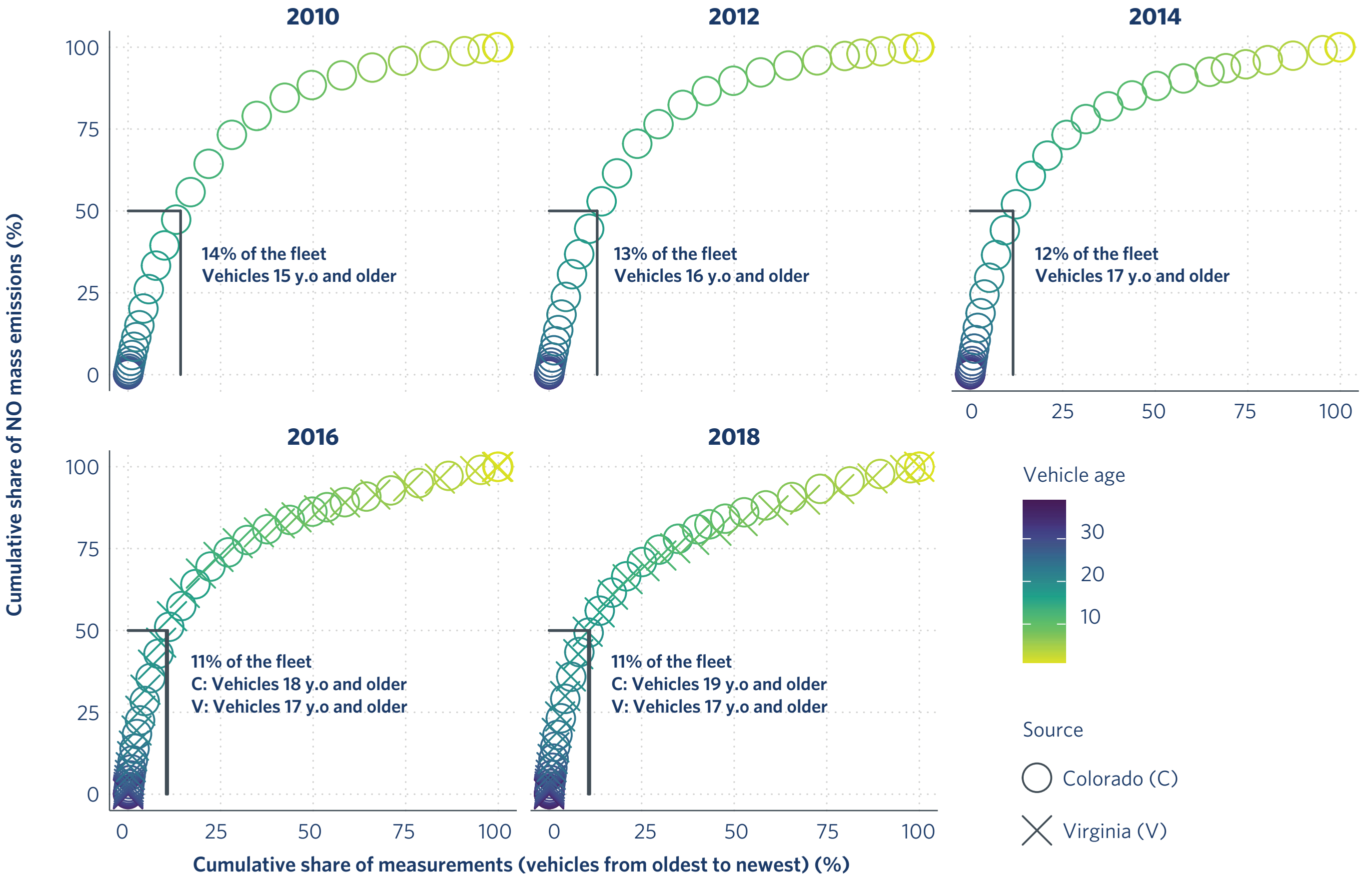

Figure 3. Cumulative share of light-duty NO mass emissions by vehicle age.

CUMULATIVE SHARE OF NO MASS EMISSIONS BY VEHICLE AGE FOR DIFFERENT MEASUREMENT YEARS

Figure 3 presents the cumulated share of fleet NO mass emissions by vehicle age, from oldest to newest light-duty vehicles.

The cumulative share of NO mass emissions by vehicle age is remarkably similar in Colorado and Virginia, especially considering the difference in the age distribution between the Colorado and Virginia measurements (Figure 2).

The cumulative emissions share by measurement year is similar, although the accumulated share of the oldest vehicles is rising faster as newer vehicles are added to the fleet. For measurements taken in 2010, vehicles 15 years old and older, which make up approximatively 14% of the fleet, were responsible of 50% of total mass of NO emissions. The percentage of the fleet responsible for 50% of the total mass of NO emissions decreased in each measurement year through 2016, when 11% of the fleet (18 years old and older in Colorado, 17 years old and older in Virginia) were responsible for 50% of NO mass emissions.

It is clear that as newer vehicles with low emissions are added to the fleet over time, the emissions contribution of the oldest vehicles is increasing. This means that policy actions to mitigate the emissions of the small fraction of the oldest vehicles is increasingly important and relevant.

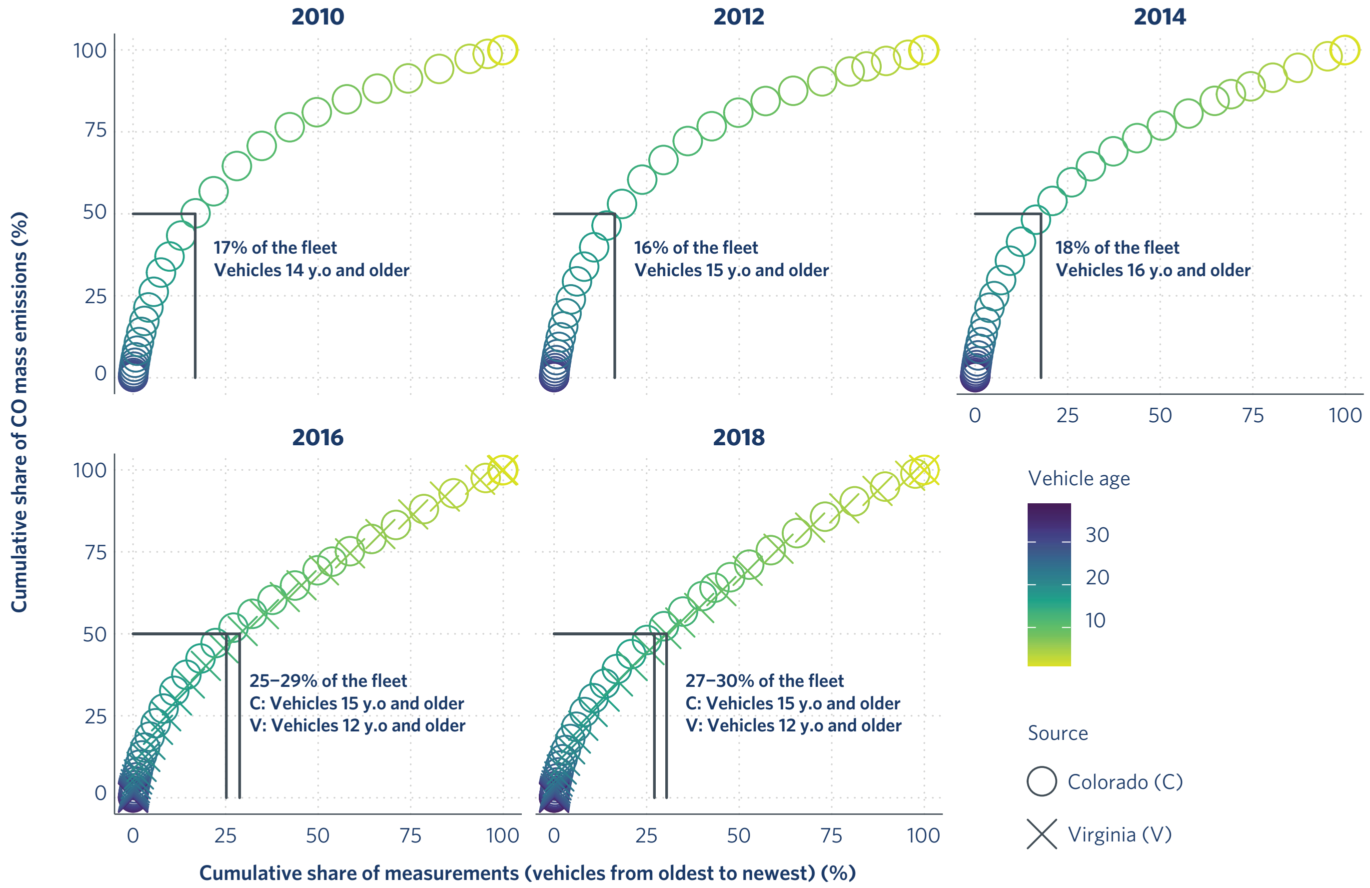

Figure 4. Cumulative share of light-duty CO mass emissions by vehicle age.

CUMULATIVE SHARE OF CO MASS EMISSIONS BY VEHICLE AGE FOR DIFFERENT MEASUREMENT YEARS

Figure 4 presents the cumulated share of light-duty fleet CO emissions by vehicle age, from oldest to newest light-duty vehicles.

While the CO emissions results from Colorado and Virginia are reasonably similar, they differ more than they did for NO. Also, while measurements from 2010, 2012, and 2014 are quite similar, with 16%-18% of the oldest vehicles accounting for 50% of the total mass of emissions, there is a major shift from 2014 to 2016. For Colorado, vehicles 16 years old and older, which made up 18% of the fleet, accounted for 50% of the CO emissions in 2014, but this jumped to 25% of the fleet in 2016. In 2018, vehicles 15 years old and old, which made up 27% of the fleet, accounted for 50% of CO emissions. Virginia was even higher, with vehicles 12 years old and older, making up 29% of the fleet in 2016 and 30% of the fleet in 2018, accounting for 50% of total CO mass emissions.

This is the opposite of the situation for light-duty NO and suggests that CO from older vehicles is a much smaller problem than NO from older vehicles.

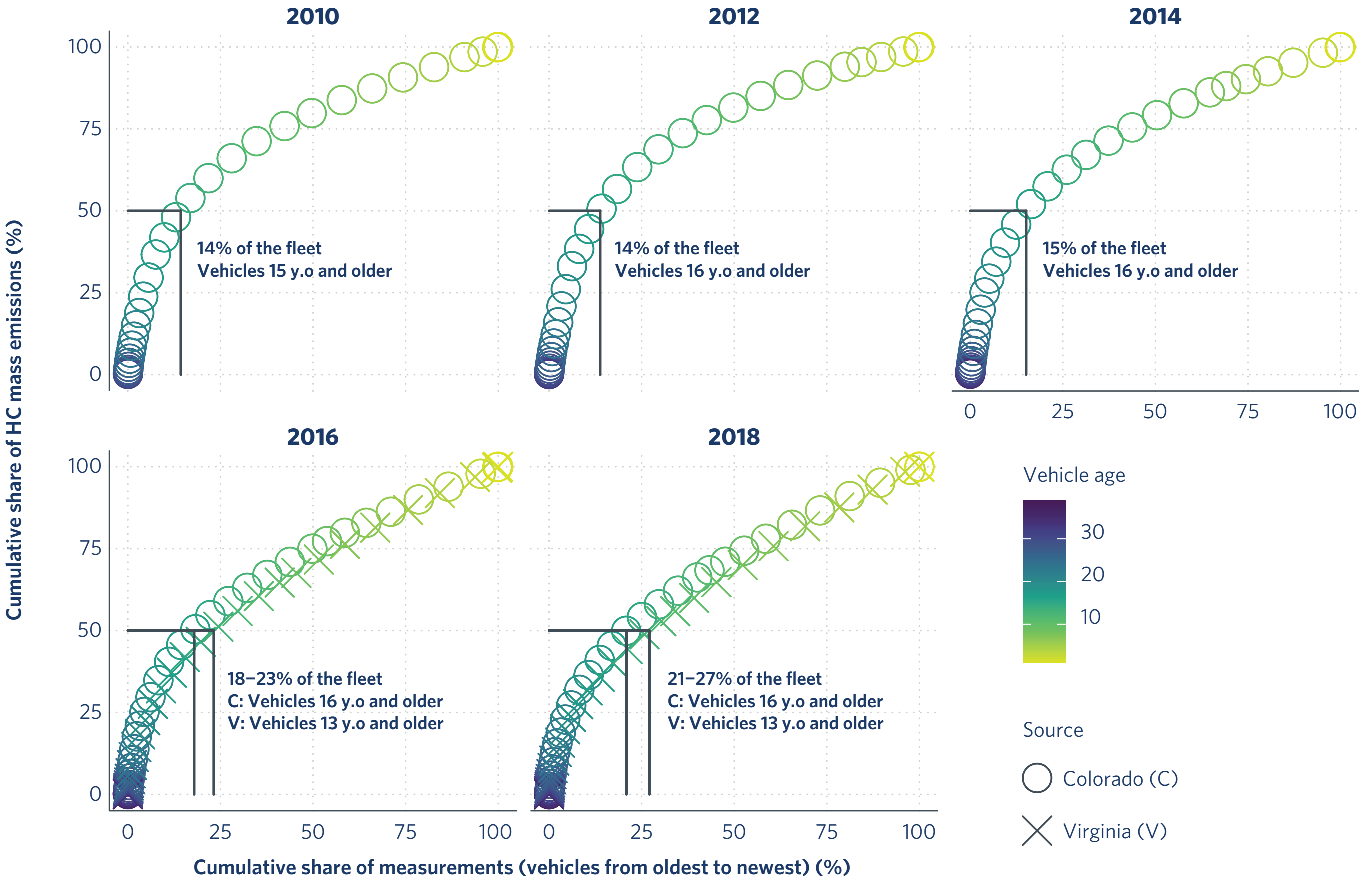

Figure 5. Cumulative share of light-duty HC mass emissions by vehicle age

CUMULATIVE SHARE OF HC EMISSIONS BY VEHICLE AGE FOR DIFFERENT MEASUREMENT YEARS

Figure 5 presents the cumulated share of fleet HC emissions by vehicle age, from oldest to newest light-duty vehicles.

The HC results are quite similar to the CO results, although the Colorado and Virginia results diverge to a greater degree than for CO. Like CO, the HC results are relatively stable from 2010 to 2014, with 14%-15% of the oldest part of the fleet responsible for 50% of total mass of HC emissions. Also as with CO, there is a jump after 2014, with Colorado increasing from 15% of the oldest part of the fleet in 2014 to 18% of the fleet in 2016 and 21% of the fleet in 2018 (all vehicles 16 years old and older) being responsible for 50% of total HC mass emissions. Virginia further increased the share of vehicles 13 years old and older to 23% in 2016 and 27% in 2018 being responsible for 50% of total HC mass emissions.

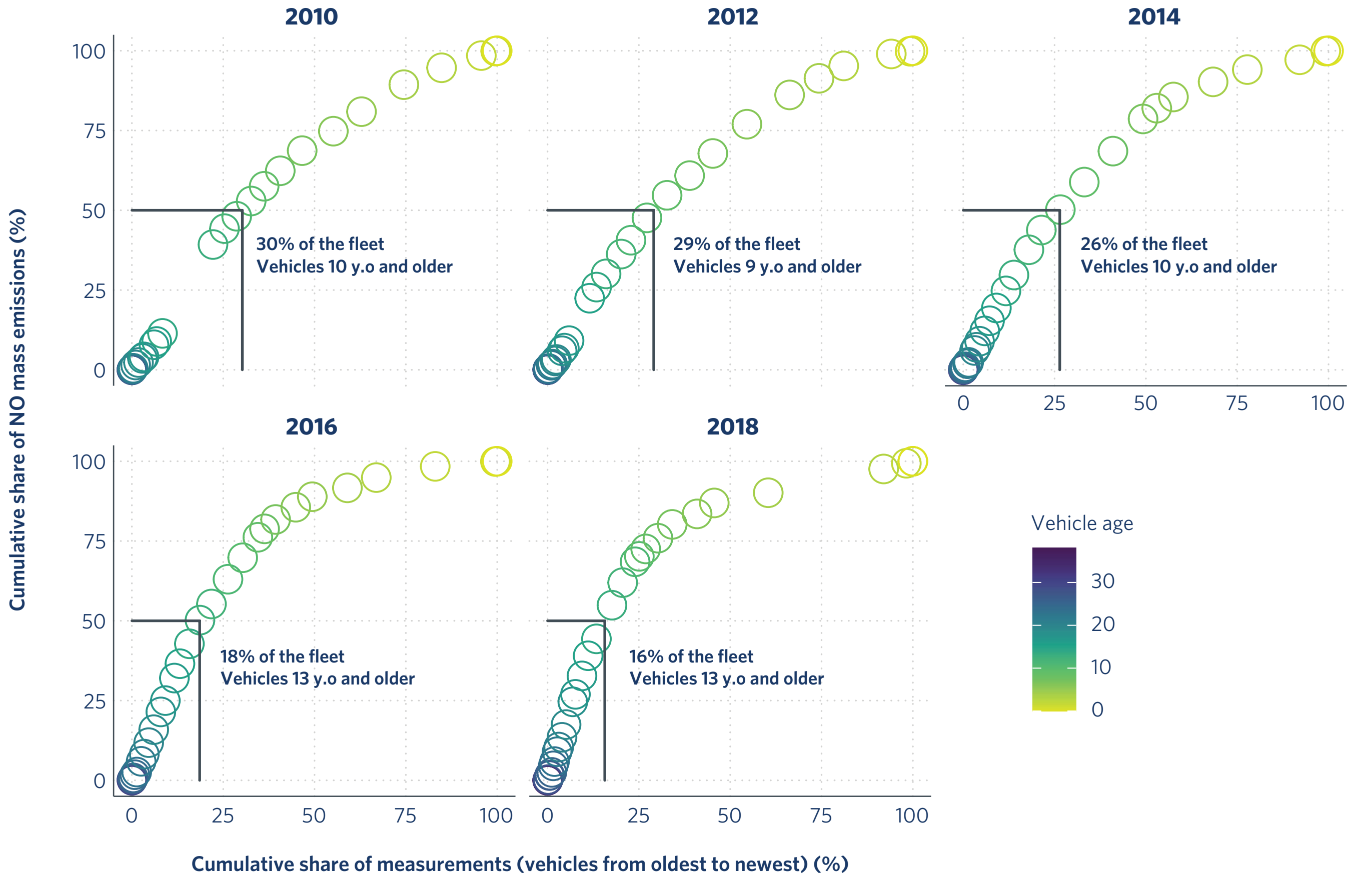

Figure 6. Cumulative share of heavy-duty NO mass emissions by vehicle age.

RESULTS FOR HEAVY-DUTY VEHICLES

The measured HDVs virtually all use diesel engines, the emissions from which are significantly different than from gasoline engines. Diesel engines almost always run lean, meaning they have excess oxygen during the combustion process. Relatively small amounts of CO are emitted during lean operation and the excess oxygen in the exhaust makes oxidation of HC in the diesel oxidation catalyst highly efficient. On the other hand, the excess oxygen makes catalyst reduction of NO_x very difficult. Thus, as diesel engines typically exhibit low levels of CO and HC, this analysis focuses on NO emissions.

Figure 6 presents the cumulated share of heavy-duty diesel fleet NO mass emissions by vehicle age, from oldest to newest heavy-duty vehicles.

In the first test year, 2010, it took the oldest 30% of the fleet, consisting of vehicles 10 years old or older, to make up 50% of the total mass of heavy-duty NO emissions. This means that average emissions from the older 30% of heavy-duty vehicles were only about two and one-third times higher than the average emissions of the newer 70% of heavy-duty vehicles. However, the United States introduced new heavy-duty emission standards in 2010. As the oldest trucks were retired and replaced with new trucks meeting the much more stringent NO_x standards introduced in 2010, the proportion of the oldest vehicles contributing to 50% of total mass emissions decreased rapidly. By 2018, 16% of the fleet, consisting of vehicles 13 years old or older, made up 50% of total fleet NO mass emissions. Also note that the curve of cumulative emissions by vehicle age was relatively flat in 2010 and is much more curved for the newer vehicles in 2018. Clearly, the older vehicles still present in 2018 are contributing a much larger share of total NO mass emissions.

DISCUSSION AND POLICY IMPLICATIONS

This analysis of over 45 million real-world emissions measurements from remote sensing confirms that a relatively small number of the oldest fraction of the fleet contributes disproportionally to total emissions.

For light-duty CO and HC emissions, the impact of the oldest vehicles has greatly diminished over time and the curves of cumulative emissions by vehicle age are flattening. In 2010, only 17% (CO) and 14% (HC) of the oldest vehicles contributed to 50% of total fleet mass emissions, but by 2018 this had increased to 27%-30% (CO) and 21%-27% (HC).

However, the impacts and trends of the oldest vehicles are quite different for NO emissions and are particularly striking. For light-duty, in contrast to CO and HC, only 11% of the oldest vehicles (19 years old and older in Colorado, and 17 and older in Virginia) contribute to 50% of total light-duty NO mass emissions in 2018, down from 14% of the oldest vehicles (15 years and older) in 2010. For heavy-duty, 16% of the oldest vehicles (13 years old and older) contribute 50% of total heavy-duty NO mass emissions in 2018, down dramatically from 30% (10 years old and older) in 2010.

One policy implication from this analysis is that the definition of vehicle useful life is unrealistic compared to real-world usage. The Light-duty Tier 3 emission standards being phased in from 2017 to 2025 extend the vehicle useful life requirements to 15 years, but the useful life for previous standards was only 10 to 11 years. Compare this to vehicles 19 years old and older (Colorado) or 17 years old and older (Virginia) contributing 50% of total fleet NO mass emission in 2018. While the extension of useful life to 15 years with Tier 3 was clearly needed, vehicles older than 15 years still contribute well over 50% of total NO mass emissions in 2018.

The situation is similar for heavy-duty NO emissions. The useful life for heavy-duty vehicles is 10 years, while heavy-duty vehicles 13 years old and older contributed 50% of total NO mass emissions in 2018. In the same year, the NO contribution of trucks older than the 10-year useful life requirement is 70% of the total NO mass emissions, despite representing just 25% of the fleet.

As over half of NO mass emissions from both light-duty and heavy-duty are from vehicles that exceed the useful life requirements and are no longer subject to emissions regulation, it is clear that additional policies are needed to lower average NO fleet emissions and achieve ambient air quality goals. Such policies could include some combination of the following:

- Extend useful life requirements.
- Remove the restriction that in-use test vehicles must be properly used and maintained in order to ensure emission control systems are more robust and maintain low emissions under all reasonable use and maintenance.
- Impose higher fees on vehicles beyond the useful life period to encourage owners to scrap older vehicles.
- Implement scrappage programs which pay owners to retire the oldest vehicles. Such programs must be carefully structured to avoid paying for vehicles that would have been scrapped anyway.
- Restrict access of the oldest, high emitting vehicles to urban areas that exceed ambient air quality standards, commonly referred to as Low Emission Zones (LEZs). This minimizes the environmental impacts of older vehicles without requiring them to be scrapped.

THE REAL URBAN EMISSIONS INITIATIVE

FOUNDATION

THE INTERNATIONAL COUNCIL ON CLEAN TRANSPORTATION

This case study is based on an analysis of the TRUE Initiative U.S. remote sensing database.

For more information, please see:
"Development and application of a United States real-world vehicle emissions database"
https://theicct.org/publications/true-us-database-development-oct2020