Sensitivity of MOVES-estimated vehicle emissions to inputs when comparing to real-world measurements

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BACKGROUND

- MOVES, the vehicle emissions model developed by the US EPA, requires the use of local inputs for developing emission inventories required for the Clean Air Act and the NEI. Local information can be provided at the county or (more specific) project level. MOVES also contains national default inputs which can be useful for evaluating trends in nationwide emissions without providing local data.
- Comparing MOVES emission rates to real-world measurements is a key component of evaluating MOVES emission inventories. One challenge to properly compare MOVES estimates to real-world measurements is developing MOVES inputs which accurately capture the conditions of the study-location. Understanding the sensitivity of MOVES inputs is important in interpreting comparisons that use local data vs. national default inputs.
- Previous researchers have evaluated the sensitivity of MOVES emissions estimates to inputs in county-scale and level analyses.[1] However, these results may not extend to remote sensing studies conducted at the road-side or in roadway tunnels, which derive fuel-based emission rates (g/kg-fuel) rather than total emissions.
- In this study, we compare fuel-based emission rates (g/kg) from light-duty vehicles from MOVES2014 to emission rates derived by Dallmann et al. (2012)[2] from emission concentrations measured in the Caldecott tunnel near Oakland, CA in the summer of 2010**.**

OBJECTIVES

1. **Compare fuel-based emission rates estimated from MOVES2014 to emission rates derived from the Caldecott Tunnel in the summer of 2010.**
2. **Demonstrate the sensitivity of MOVES emission rates to model inputs by running MOVES in project-mode to estimate emissions in the tunnel with local inputs and contrasting them with MOVES runs using national default inputs.**

METHODOLOGY

MOVES is run at project-level, with inputs to reflect the conditions of the tunnel shown in Table 1. Due to uncertainties regarding three inputs: vehicle age distribution, vehicle drive cycles, and gasoline fuel sulfur level, we conducted three project-level runs:

1. High End (9 ppm sulfur gasoline, most aggressive drive cycle, older vehicle age distribution)
2. Midpoint (5 ppm sulfur gasoline, average drive cycles, middle range age distribution)
3. Low End (5 ppm sulfur gasoline, least aggressive drive cycle, newer age distribution)

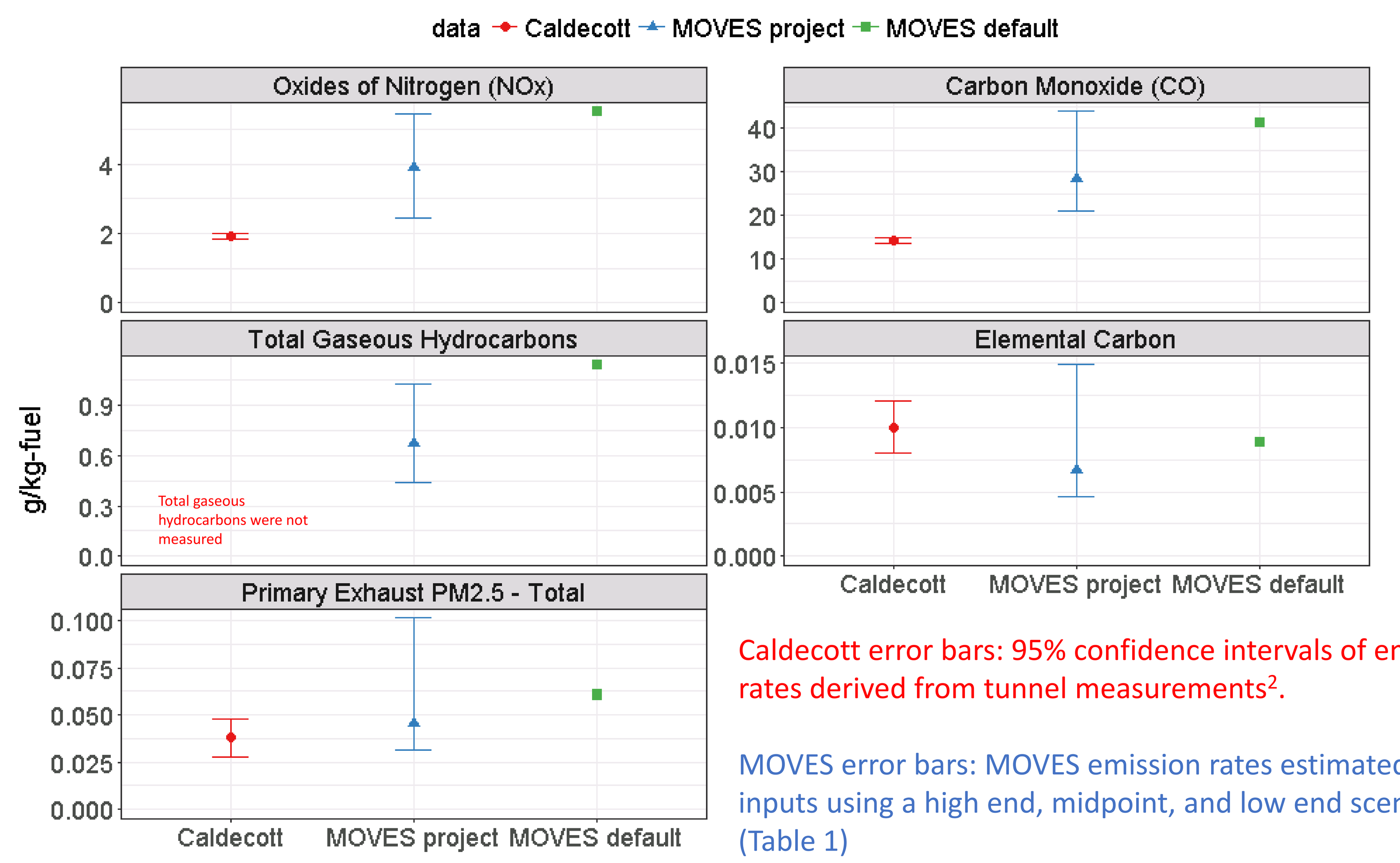
We also ran MOVES2014a at national scale for Contra Costa County, CA, for July 2010 at 5 pm on a weekday for Urban Restricted Access roadways.

Table 1. MOVES Project-scale and National Default Inputs used to represent the Caldecott Tunnel July 2010 measurement conditions, including high, midpoint, and low-end MOVES scenarios for Project-Level.

MOVES Input [caption in Figure 2]	Project-Level	MOVES defaults (National-Scale)
Day Type/Month/Year	Weekday, July 2010	Weekday, July 2010
Vehicle Type Fractions	Default MOVES2014 Source Types splits within fuel types for Contra Costa County (Passenger Cars, Passenger Trucks, Light Commercial Trucks only)	Default MOVES2014 Source Types splits within fuel types for Contra Costa County.
Light-duty Gasoline Age Distribution (Average age in years) [age.dist]	**High End:** Van Nuys CA 2010 (8.5 years)[3] **Midpoint:** ARB's estimate for Contra Costa County in 2010 (7.4 years)[4] **Low End:** Caldecott Tunnel 2006 (5.7 years)[5]	Default MOVES2014 (7.9 years)
CA vehicle standards [CA.stds]	LEV/Section 177 Inputs for 1994+ model years	No LEV/Section 177 Inputs
Link Grade[2] [grade]	+4%	0%
Average Speed[2] [speed]	37 mph	45.8 mph (National default for Urban Restricted Access weekday at 5 pm)
Drive Cycle [drive.cycle]	**High End:** Most Aggressive ARB speed trace (1 of 16 speed traces measured in Caldecott Tunnel[6] in 1996) **Midpoint:** Average operating mode distribution derived from 16 ARB speed traces **Low End:** Least aggressive ARB speed trace (1 of 16 speed traces)	Default MOVES highway driving cycles based on 37 mph
Fuels	Default MOVES2014 fuel properties for July 2010 Contra Costa (California E10 gasoline)	Default MOVES2014 fuel properties for July 2010 Contra Costa
Gasoline Fuel Sulfur Level [gas.sulfur]	**High End: 9 ppm** (Default MOVES2014 for Contra Costa County) **Midpoint & Low End: 5 ppm** sulfur in gasoline (AAM 2010 July San Francisco[7])	**9 ppm** (Default MOVES2014 for Contra Costa County)
I/M Program	MOVES default for Contra Costa County	MOVES default for Contra Costa
Meteorology	10-year average July Contra Costa County at 5 pm	10-year average July Contra Costa County at 5 pm

RESULTS

1. Comparison of Caldecott Tunnel Measurements with MOVES estimates

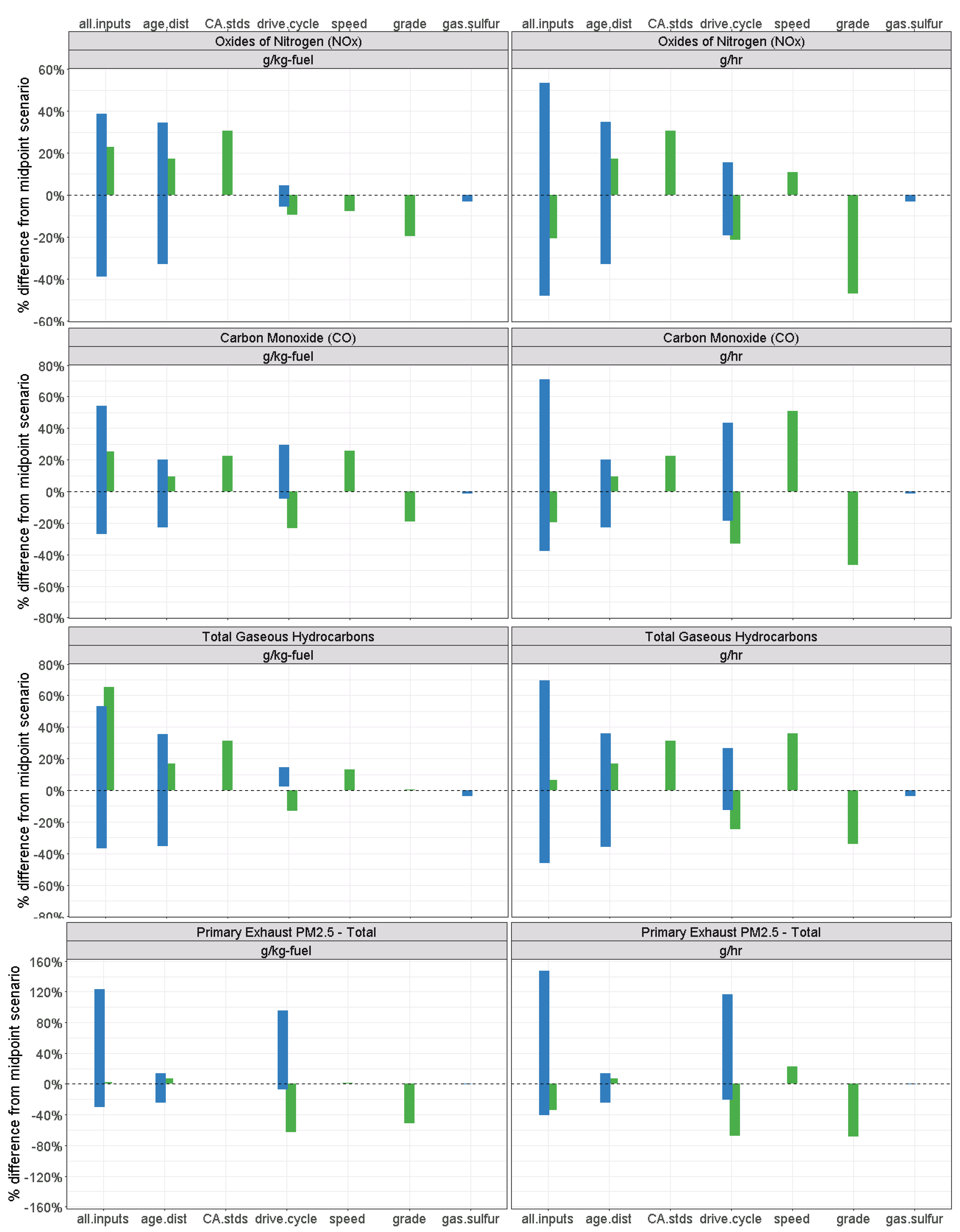


Caldecott error bars: 95% confidence intervals of emission rates derived from tunnel measurements[2].

MOVES error bars: MOVES emission rates estimated from inputs using a high end, midpoint, and low end scenario (Table 1)

Figure 1. Comparison of emission rates from light-duty gasoline-fueled vehicles estimated from the Caldecott Tunnel Measurements (RED), the MOVES Project-Level Runs (BLUE), and using MOVES defaults using a national-scale run (GREEN).

2. Sensitivity of MOVES emissions to inputs



Legend

MOVES project MOVES default

MOVES project: Differences in emissions from the midpoint project-level scenario for the range of inputs deemed feasible for representing the Caldecott July 2010 measurement (Table 1)

MOVES default: Differences between the MOVES National default run and the midpoint project-level run, due to each input

Left column (g/kg-fuel): Differences between fuel-based emission rates

Right column (g/hr) Differences between total emission rates

Figure 2. Percent differences in emissions from the baseline MOVES project-level case (midpoint) compared to using the range of feasible values for the Caldecott Tunnel (BLUE), and using the MOVES National-scale defaults (GREEN).

DISCUSSION

1. Measurement Comparisons

- The project-level MOVES runs estimated a wide range of g/kg emissions, based on three plausible input scenarios.
- The range of NOx and CO fuel-based emission rates estimated from MOVES project-level runs are higher than tunnel measurements .
- The range of Elemental Carbon and $PM_{2.5}$ fuel-based emission rates are within the variability of the tunnel measurements.
- The project-level MOVES fuel-based emission rates estimates are generally closer to the tunnel measurements (NOx, CO, $PM_{2.5}$) than the national default MOVES runs (with the exception of Elemental Carbon).

2. Sensitivity of MOVES emissions to inputs

- The unmeasured MOVES inputs that lead to the largest uncertainty in modeling the Caldecott Tunnel measurements include: **vehicle age distribution** (NOx, THC, and CO) and **driving cycle** ($PM_{2.5}$), with a smaller uncertainty due to gasoline fuel sulfur.
- The following MOVES national default inputs **increased** emission rates, compared to the midpoint project-level inputs:
  - **CA vehicle emission standards** (absence in national default)
  - **Vehicle age distribution** (older age distribution in defaults)
- While the following MOVES national-level defaults **decreased** emission rates compared to the midpoint project-level inputs:
  - **Driving cycle** (default cycles less aggressive than the local driving cycles)
  - **Grade** (0% default compared to the 4% Caldecott Tunnel grade)
- Using the higher average speed in the MOVES national default average speed had a mixed effect:
  - For CO and THC, the higher speed increased fuel-based emission rates
  - For NOx, higher speed decreased fuel-based emission rates, with nominal changes to $PM_{2.5}$
  - For total emissions, higher average speed consistently increased all emissions
- Overall, the MOVES national default inputs led to **higher fuel-based emission rates** (NOx, CO, THC, and $PM_{2.5}$) compared to the midpoint project-level runs.
- Conversely, the MOVES national default inputs led to **lower total emission rates** (NOx, CO, and $PM_{2.5}$) compared to the midpoint project-level runs due to less aggressive driving cycles and 0% grade in the national default inputs.
- The sensitivity of MOVES total emissions (g/hr) were similar to the sensitivity of fuel-based emissions (g/kg) for the following inputs: vehicle age distribution, CA vehicle standards, and gasoline sulfur level, but much more sensitive to inputs which have also have a large impact on fuel consumption: driving cycle, grade, and average speed.
- **When comparing MOVES emissions to remote sensing data, it is important to:**
  1. **Use local data rather than national defaults**
  2. **Acknowledge that conclusions derived from analysis of fuel-based emission rates may not directly apply to total emissions (g/hr).**

LIMITATIONS

- MOVES is not designed to model California emissions. MOVES2014 runs for the Caldecott tunnel included inputs for the California LEV standards, but do not account for the California pre-1994 vehicle NOx standards, which are much tighter than the Federal standards. The pre-1994 vehicle emissions contributed 41% of NOx emissions in the midpoint Project-level case.
- The sensitivity of the emissions to MOVES inputs were evaluated based on the Caldecott Tunnel as a baseline. Thus, they are a function of what was unknown about the inputs to represent the Caldecott conditions, and of the specific baseline conditions (high road grade, low speed freeway). The MOVES emissions sensitivities to inputs will vary for other baseline study conditions, and varying uncertainty of inputs.
- This case study presented gasoline emissions rates only. Heavy-duty diesel emissions had considerably different sensitivities to MOVES inputs.

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