

Modeling Impacts of Cold Climates on Vehicle Emissions



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This project relates to the research thrust area of 'environmental impact assessment,' specifically the impact of cold climates on vehicle exhaust emissions. Motor vehicles emit pollutants that are harmful to human. Emissions are thought to be elevated during engine cold starts. During winter, low-lying temperature inversion can trap vehicle emissions near the surface, leading to significantly elevated pollutant concentrations. Despite the importance, vehicle emissions data for cold climates are sparse and the accuracy of vehicle emissions model parameterizations for cold climates is not known. The goal of this project is to improve ability of EPA's Motor Vehicle Emission Simulator (MOVES) model to simulate cold start emissions in cold climates

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ON VEHICLE EMISSIONS**

FINAL REPORT

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in Cold Climates**

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lb	Pounds (avdp)	0.454	kilograms	kg	kg	kilograms	2.205	Pounds (avdp)	lb
T	Short tons (2000 lb)	0.907	megagrams	mg	mg	megagrams (1000 kg)	1.103	short tons	T
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fl oz	fluid ounces (US)	29.57	milliliters	mL	mL	milliliters	0.034	fluid ounces (US)	fl oz
gal	Gallons (liq)	3.785	liters	liters	liters	liters	0.264	Gallons (liq)	gal
ft ³	cubic feet	0.0283	meters cubed	m ³	m ³	meters cubed	35.315	cubic feet	ft ³
yd ³	cubic yards	0.765	meters cubed	m ³	m ³	meters cubed	1.308	cubic yards	yd ³
Note: Volumes greater than 1000 L shall be shown in m ³									
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(exact)					(exact)				
°F	Fahrenheit temperature	5/9 (°F-32)	Celsius temperature	°C	°C	Celsius temperature	9/5 °C+32	Fahrenheit temperature	°F
<u>ILLUMINATION</u>					<u>ILLUMINATION</u>				
fc	Foot-candles	10.76	lux	lx	lx	lux	0.0929	foot-candles	fc
fl	foot-lamberts	3.426	candela/m ²	cd/cm ²	cd/cm ²	candela/m ²	0.2919	foot-lamberts	fl
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TABLE OF CONTENTS

LIST OF FIGURES	ii
LIST OF TABLES	iii
EXECUTIVE SUMMARY	1
CHAPTER 1. INTRODUCTION	2
1.1 Problem Statement	2
1.2 Background	3
1.3 Objectives	4
CHAPTER 2. PROCEDURE.....	1
2.1 MOVES2010b Model	1
2.2 Input for MOVES2010b	2
2.2.1 Meteorological Conditions.....	2
2.2.2 Vehicle Fleet and Activity Data.....	2
2.3 Pollutants and Vehicle Types	7
CHAPTER 3. RESULTS	8
3.1 County Total Emissions.....	8
3.2 Temperature-Dependence of Start Emissions.....	12
CHAPTER 4. CONCLUSIONS	17
REFERENCES	19

LIST OF FIGURES

Figure 1.1 Locations of the three counties modeled in this study	5
Figure 2.1 Diurnal profiles of ambient temperature (left) and relative humidity (right) used as input to MOVE2010b to simulate county-total emissions.....	2
Figure 2.2 Vehicle population data by source type (vehicle type; <i>x</i> -axis) and Highway Performance Monitoring System (HPMS) vehicle class (color coded) for each of the three counties for 2012	3
Figure 2.3 Age distribution of vehicle fleet for 2012 in each of the three counties.	4
Figure 2.4 Annual vehicle miles traveled (VMT) by HPMS vehicle class for each of the three counties for 2012	5
Figure 2.5 VMT fraction by source type (vehicle type; <i>x</i> -axis) and road type (color coded) for each of the three counties for 2012	6
Figure 3.1 MOVES201b estimates of county-total CO emission rates (tons/week) by process (color coded) from passenger cars, passenger trucks, light commercial trucks, combination short-haul trucks, and combination long-haul trucks for Yakima County, Washington (left), Canyon County, Idaho (middle), and Ada County, Idaho (right).	8
Figure 3.2 MOVES201b estimates of county-total NO _x emission rates (tons/week) by process (color coded) from passenger cars, passenger trucks, light commercial trucks, combination short-haul trucks, and combination long-haul trucks for Yakima County, Washington (left), Canyon County, Idaho (middle), and Ada County, Idaho (right).	9
Figure 3.3 MOVES201b estimates of county-total VOC emission rates (tons/week) by process (color coded) from passenger cars, passenger trucks, light commercial trucks, combination short-haul trucks, and combination long-haul trucks for Yakima County, Washington (left), Canyon County, Idaho (middle), and Ada County, Idaho (right).	10
Figure 3.4 MOVES201b estimates of county-total benzene emission rates (tons/week) by process (color coded) from passenger cars, passenger trucks, light commercial trucks, combination short-haul trucks, and combination long-haul trucks for Yakima County, Washington (left), Canyon County, Idaho (middle), and Ada County, Idaho (right).	11
Figure 3.5 Temperature-dependence curve for start emissions of CO for the year 2012 assuming relative humidity of 80%	13
Figure 3.6 Temperature-dependence curve for start emissions of NO _x for the year 2012 assuming relative humidity of 80%	15
Figure 3.7 Temperature-dependence curve for start emissions of VOCs for the year 2012 assuming relative humidity of 80%	16

LIST OF TABLES

Table 1.1 Average low and high temperatures for January for the most populous city in each of the three counties. Data are from http://www.usclimatedata.com	5
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EXECUTIVE SUMMARY

Vehicle emissions include carbon monoxide (CO), nitrogen oxides ($\text{NO}_x = \text{NO} + \text{NO}_2$), volatile organic compounds (VOCs), and air toxics such as benzene. Each of these pollutants is linked to adverse human health effects. To evaluate the contributions of start emissions to total vehicle emissions of these pollutants in the U.S. Pacific Northwest, the MOVES2010b emission model was applied to Ada and Canyon counties in Idaho and Yakima County in Washington using county-specific vehicle fleet and activity data for 2012 and January meteorological conditions. MOVES2010b indicates that start emissions dominate total vehicle emission for CO, VOCs, and benzene, and include a significant portion of total vehicle NO_x emissions. Depending on the county, vehicle start emissions contribute 68–70%, 22–26%, 65–67%, and 82–83% to total vehicle emissions of CO, NO_x , VOC, and benzene, respectively. The MOVES2010b model was also run to generate temperature response curves for vehicle start emissions of CO, NO_x , and VOCs. Start emissions of CO, NO_x , and VOCs all show a strong dependence on temperature, though the sensitivities differ for different pollutants, vehicle types, vehicle model years, and fuel types. MOVES2010b estimates that when the temperature increases from -10°F to 70°F , start emissions decrease by 9–96%. This study highlights the importance of start emissions in contributing to air pollution due to motor vehicles during winter and the sensitivity of start emissions to temperature. For regions with colder winter climates, such as Montana and Alaska, contributions from start emissions would be even greater. Accurate estimates of vehicle start emissions require accurate models. Experimental measurements of vehicle emissions at a full range of wintertime temperatures should be carried out and compared with the results of this study to systematically evaluate the accuracy of MOVES predictions.

CHAPTER 1. INTRODUCTION

1.1 Problem Statement

This project relates to the research area of “environmental impact assessment,” specifically the impact of cold temperatures on vehicle exhaust emissions. Vehicle emissions include carbon monoxide (CO), volatile organic compounds (VOCs), and nitrogen oxides ($\text{NO}_x = \text{NO} + \text{NO}_2$). Volatile organic compounds and NO_x contribute to the formation of ozone and secondary particulate matter (PM) pollutants. In addition, air toxics, such as formaldehyde, benzene, and polycyclic aromatic compounds (PAHs), are directly emitted from vehicles. Carbon monoxide, ozone, PM, and air toxics are all harmful to human health. Exposure to traffic-related pollution has been linked to adverse health effects, such as exacerbation of asthma symptoms, impaired lung function, total and cardiovascular mortality, and cardiovascular morbidity (HEI, 2010).

Emissions are thought to be elevated during engine cold starts due to condensation of fuel on cold surfaces and colder, less efficient catalytic conversion. Vehicle emissions models such as the U.S. Environmental Protection Agency’s MOtor Vehicle Emissions Simulator (MOVES) suggest that in cold climates, the largest pollutant mass emitted by vehicles occurs during engine cold starts and idling, rather than during the time when vehicles are moving along the road. Pollution from high emissions during cold weather can be worsened by a low-lying temperature inversion that traps the air along with the pollutants near the ground, leading to significantly elevated pollutant concentrations. Despite the expected high level of vehicle emissions during cold conditions, vehicle emissions data at low temperatures are sparse, and the accuracy of vehicle emissions model parameterizations at low temperatures has not been systematically

evaluated. The overarching goal of this project is to improve the ability of the MOVES model to simulate cold-start emissions in cold climates.

1.2 Background

Emissions inventories are critical for understanding regional air quality concerns and for developing plans to attain and maintain the National Ambient Air Quality Standards (NAAQS) for criteria pollutants such as ozone, NO_x, and PM. The U.S. Environmental Protection Agency (U.S. EPA), as mandated by the Clean Air Act, sets the NAAQS, which are based on scientific evidence of human health effects. Every third year, states are required by the Air Emissions Reporting Requirements to report emissions from large and small point sources, nonroad and on-road mobile sources, and biogenic sources. In 2012, the MOVES model became an official tool recommended by the EPA to model pollutant emissions from vehicles. MOVES is being used by agencies to develop state emissions inventories that are used in the National Emissions Inventory (NEI) and for State Implementation Plans (SIPs) and Transportation Conformity.

Regional air quality models, in combination with emissions inventories, are powerful tools for understanding the temporal and spatial distributions of ambient pollutant concentrations. For example, in the Laboratory for Atmospheric Research (LAR) at Washington State University (WSU), emissions inventories are used as input for a regional air quality forecasting system of the Pacific Northwest called AIRPACT (<http://www.lar.wsu.edu/airpact>; Chen et al., 2008; Herron-Thorpe et al., 2012). The development and operation of AIRPACT have been funded by the NW-AIRQUEST Consortium, a group of air quality agencies, federal agencies with air quality concerns, and universities in the Pacific Northwest. Members of NW-AIRQUEST include Idaho Department of Environmental Quality (IDEQ), Oregon DEQ, Washington Department of Ecology, Southwest Clean Air Agency, EPA Region 10, Nez Perce

Tribe, Lane Regional Air Pollution Authority, University of Washington, Puget Sound Clean Air Agency, U.S. Forest Service – Pacific Northwest Research Station, National Park Service – Pacific West Region, and Olympic Region Clean Air Agency. AIRPACT supports the mission of NW-AIRQUEST to develop, maintain, and enhance a sound scientific basis for air quality management decision-making and to foster collaboration among all of the partners to make effective use of measurement and modeling expertise and resources. As vehicle emissions contribute to a significant portion of VOC, NO_x, PM, and air toxics emissions, MOVES is an essential component and the accuracy of AIRPACT predictions, and other similar regional air quality modeling systems used around the U.S. depend strongly on the accuracy of MOVES.

During December 2008 to January 2009, WSU's LAR took ambient measurements of pollutant concentrations near Boise, Idaho, for the Treasure Valley PM_{2.5} Wintertime Study (PM_{2.5} = PM with an aerodynamic diameter less than or equal to 2.5 μm) (Mwaniki et al., 2014). Measurements indicated that CO-to-NO_x ratios predicted by MOVES were in better agreement with observed ambient ratios than those of MOBILE6.2, which is an older-generation vehicle emission model, although both models significantly overpredicted the observed ratios (Wallace et al., 2012). No study has systematically evaluated how well the MOVES model predicts emissions in wintertime conditions. Evaluating and improving the ability of MOVES to estimate cold-start emissions with local information pertinent to the location of study are critical to improving the emissions inventory and assessing the impact of vehicle emissions on regional air quality in cold climates.

1.3 Objectives

As an initial step in the objective of assessing the importance of cold-start emissions in the Pacific Northwest and the accuracy of the MOVES model, this project evaluated the

contribution of start emissions to total vehicle emissions for January 2012 for three counties in the Pacific Northwest using MOVES and investigated the temperature-dependence parameterization of start emissions used in MOVES.

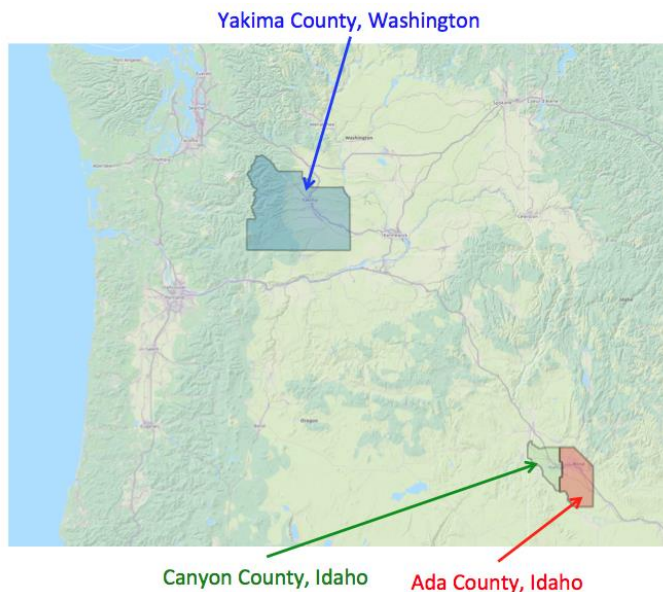


Figure 1.1 Locations of the three counties modeled in this study

The three counties of interest were Ada County and Canyon County in Idaho and Yakima County in Washington. These three counties were selected because their winters are often characterized by cold temperatures, which increase cold-start emissions, and because they often experience temperature inversions that, combined with valley topography, trap air pollution near the ground, leading to increased human exposure. Locations of the three counties are shown in Figure 1.1. Average low and high temperatures for January for the most populous city in each of the three counties are listed in Table 1.1.

Table 1.1 Average low and high temperatures for January for the most populous city in each of the three counties. Data are from <http://www.usclimatedata.com>.

Location City (County), State	Average Low °C (°F)	Average High °C (°F)
Yakima (Yakima), WA	-4.8 (23)	3.7 (39)
Nampa (Canyon), ID	-6.2 (21)	2.8 (37)
Boise (Ada), ID	-4.1 (25)	3.2 (38)

CHAPTER 2. PROCEDURE

2.1 MOVES2010b Model

The MOtor Vehicle Emission Simulator (MOVES), which is provided by the U.S. Environmental Protection Agency (EPA) Office of Transportation and Air Quality (OTAQ), is considered a state-of-the-art tool for estimating emissions from highway vehicles. As stated in EPA's documentation, the model is based on analyses of millions of emission test results and considerable knowledge about vehicle emissions (U.S. EPA, 2009). MOVES replaced MOBILE6.2, the previous model recommended for estimating on-road mobile emissions, and NONROAD, the previous model recommended for off-road emissions. MOVES estimates air pollution emissions from cars, trucks, motorcycles, and buses; pollutants modeled by MOVES include greenhouse gases, nitrogen oxides, total and speciated volatile organic compounds (VOCs), air toxics, and particulate matter (PM). Links to technical reports for MOVES are provided at <https://www.epa.gov/moves/moves-technical-reports>.

The version utilized in this study is MOVES2010b, and county-level MOVES simulations were performed. To estimate county total emissions, county-specific vehicle fleet and activity data from 2012 and MOVES' default January diurnal temperature and relative humidity profiles were used as input. To generate temperature-dependence emission data, 17 MOVES2010b simulations were performed. All 17 simulations used 2012 vehicle fleet and activity data for Yakima County and relative humidity of 80%. For each simulation, temperature was held fixed. Temperature was varied from -10°F to 70°F in 5°F increments over 17 simulations

2.2 Input for MOVES2010b

The MOVES model requires various inputs. Specifically, it requires data on vehicle population and activity and data on meteorological conditions. This section presents the input for MOVE2010b used in this study.

2.2.1 Meteorological Conditions

Meteorological conditions that affect emission rates include temperature and relative humidity. At low ambient temperatures, a catalyst takes longer to warm up to optimum operating temperature. At higher ambient temperatures, VOCs volatilize to the gas phase more easily. Relative humidity (RH) has an effect on NO_x emissions. Figure 2.1 shows the diurnal profiles of ambient temperatures and RH used as input to MOVE2010b to simulate county-total emissions.

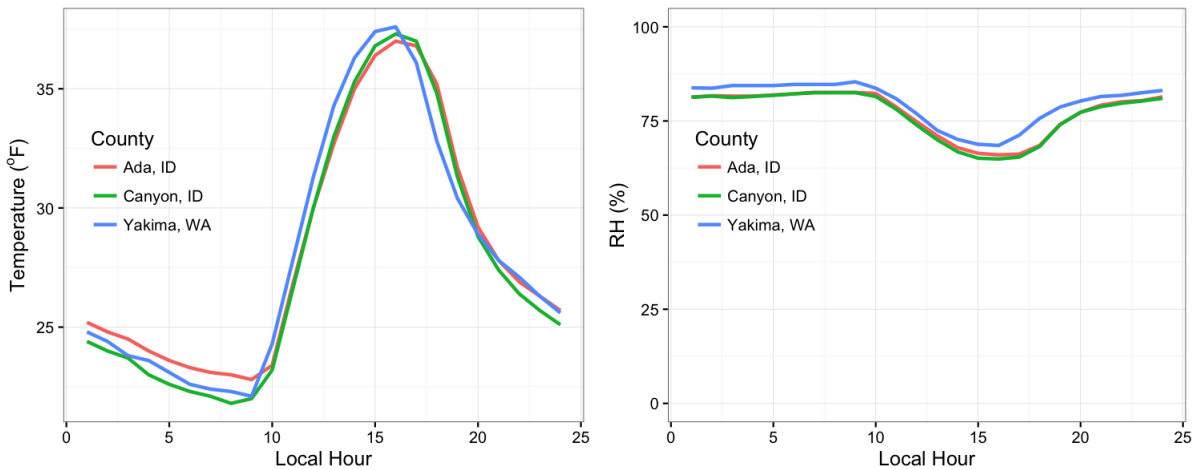


Figure 2.1 Diurnal profiles of ambient temperature (left) and relative humidity (right) used as input to MOVE2010b to simulate county-total emissions

2.2.2 Vehicle Fleet and Activity Data

County-specific data for 2012 for Ada County, Idaho and Canyon County, Idaho are available from the Idaho Department of Environmental Quality (IDEQ). County-level data for Yakima County, Washington are available from the Washington Department of Ecology. These data were provided in MOVES-ready format by IDEQ and summarized in this section.

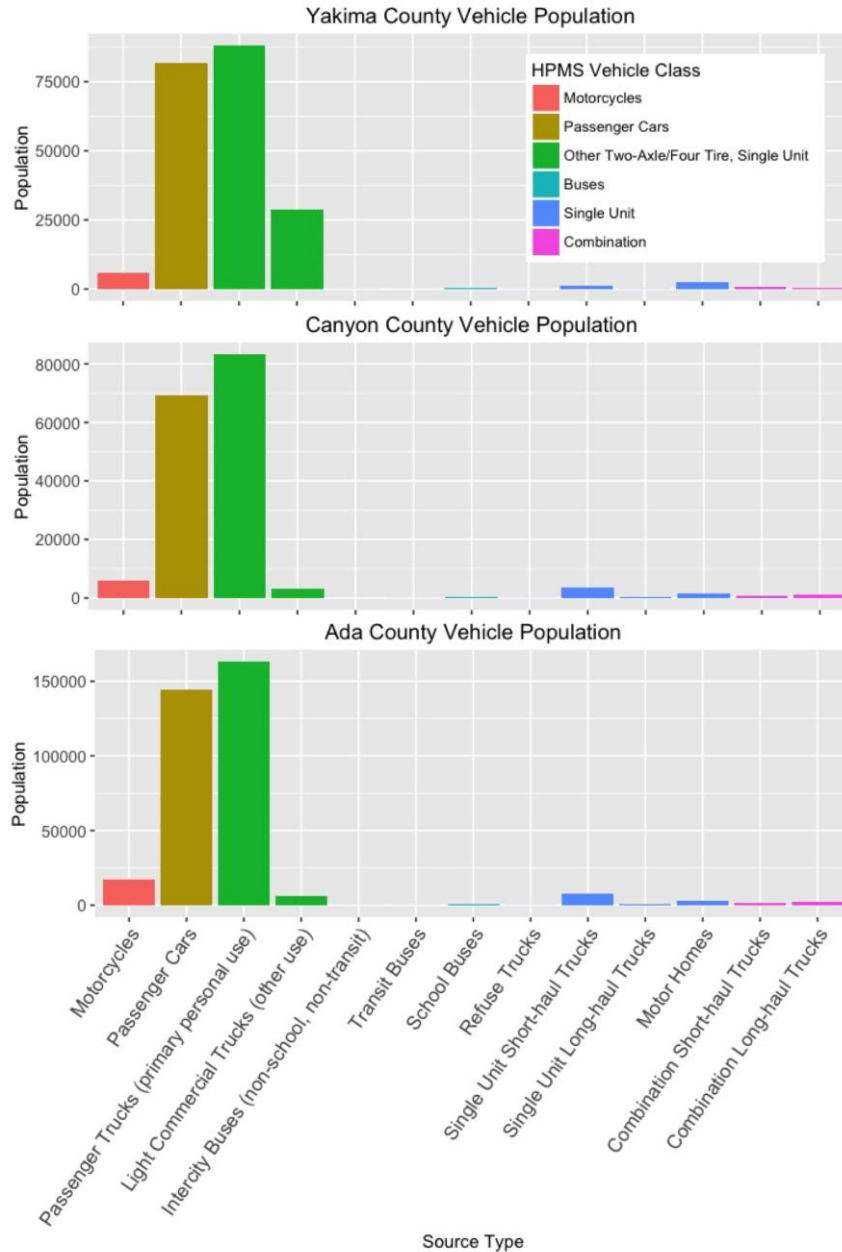


Figure 2.2 Vehicle population data by source type (vehicle type; x-axis) and Highway Performance Monitoring System (HPMS) vehicle class (color coded) for each of the three counties for 2012

Figure 2.2 shows the 2012 vehicle population data by vehicle type (also referred to as source type) and Highway Performance Monitoring System (HPMS) vehicle class for each of the three counties. The total vehicle population in Ada County, Idaho was about twice that of Yakima County, Washington and about twice that of Canyon County, Idaho. In all three

counties, passenger cars and passenger trucks dominated the vehicle population, though light commercial trucks made a significant contribution in Yakima County, Washington as well. The age distribution of the three dominant vehicle types plus the combination long-haul and short-haul trucks is shown in Figure 2.3. Overall, vehicles are newer in Ada County, Idaho and older in Yakima County, Washington, but the differences are small. In MOVES, vehicle age is related to vehicle deterioration, technology improvements (e.g., changing fuel consumption), and trends in vehicle weights; all these factors affect emission rates.

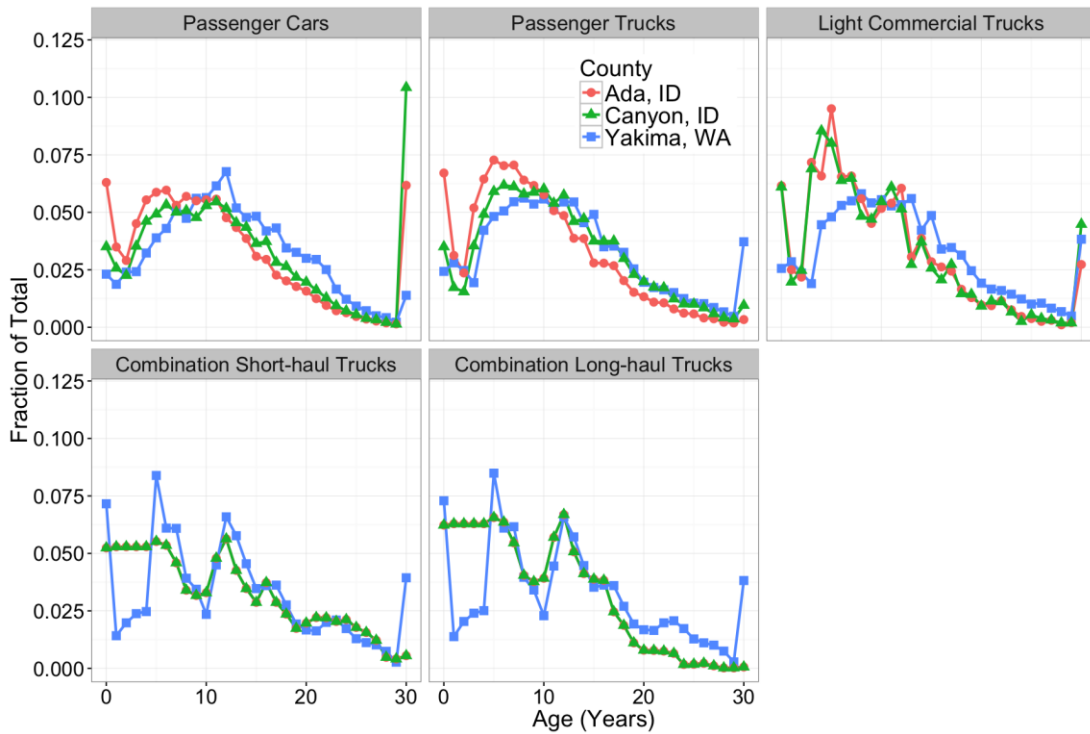


Figure 2.3 Age distribution of vehicle fleet for 2012 in each of the three counties. Note that for combination short-haul and long-haul trucks, the age distributions for Ada County and Canyon County are the same

Running emissions depend on distance traveled. Figure 2.4 shows the annual vehicle miles traveled (VMT) by HPMS vehicle class in each of the three counties. The VMT data were correlated with vehicle population data. In all three counties, VMT were dominated by passenger cars and vehicles in the “Other Two-Axle/Four Tire, Single Unit” class. Other inputs required by

the MOVES model and related to vehicle population include VMT by source type and road type (vehicle type). Figure 2.5 shows the fraction of VMT by source type and road type. For Ada County, where Boise is located, most travel was on urban roads. Canyon County is adjacent to Ada County and had a similar distribution of VMT fractions as Ada County. Yakima County, Washington, in contrast, is in a more rural setting, and the VMT were almost evenly split between urban and rural roads.

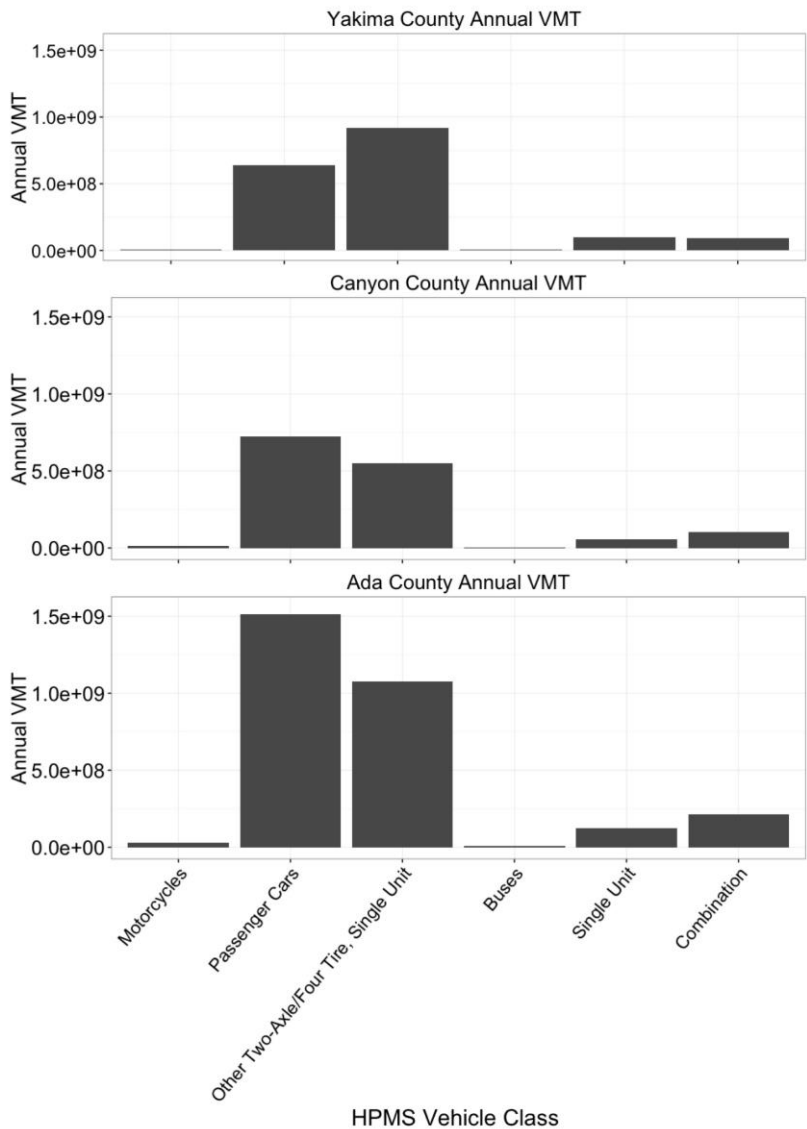


Figure 2.4 Annual vehicle miles traveled (VMT) by HPMS vehicle class for each of the three counties for 2012

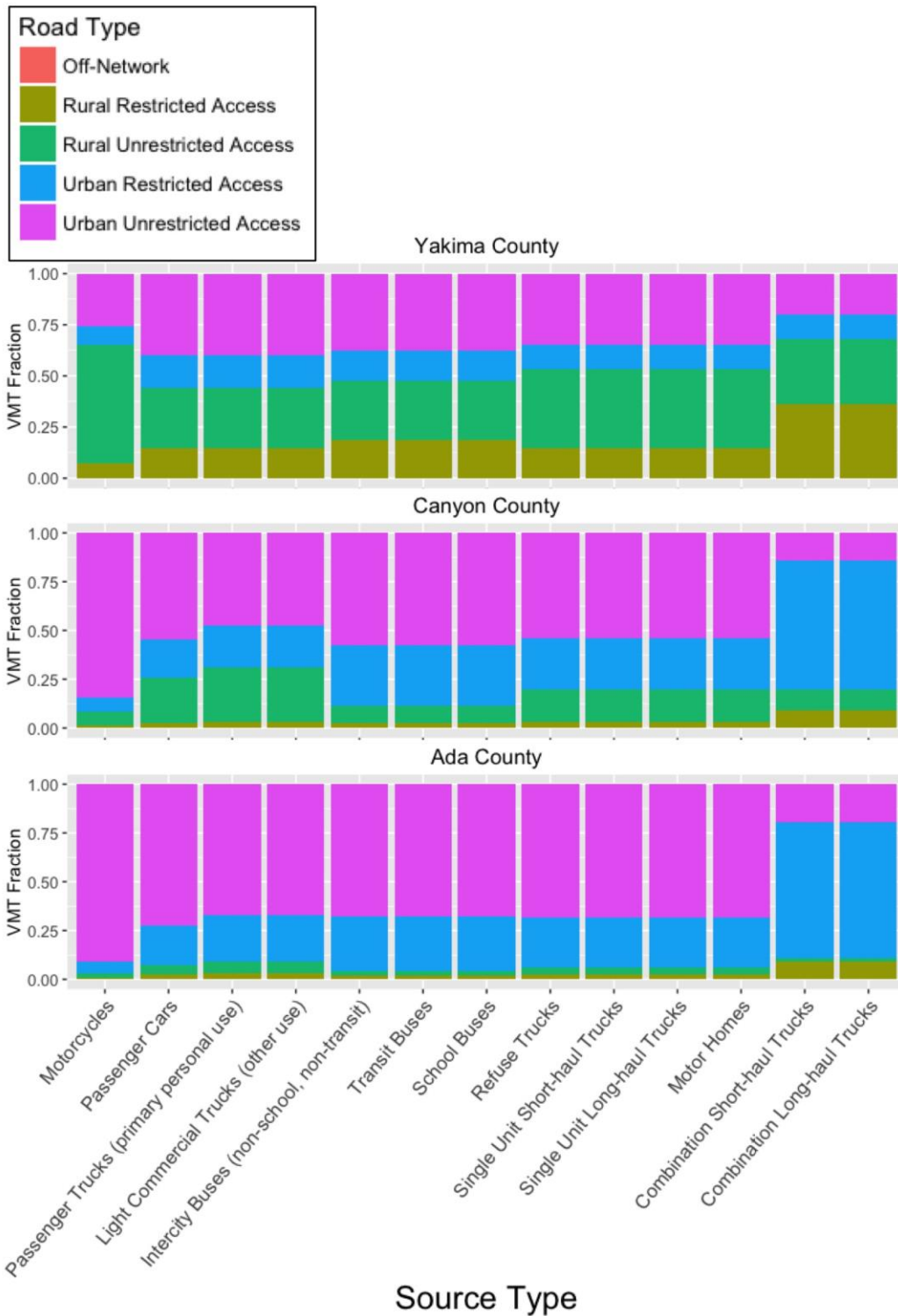


Figure 2.5 VMT fraction by source type (vehicle type; *x*-axis) and road type (color coded) for each of the three counties for 2012

2.3 Pollutants and Vehicle Types

This report presents MOVES2010b predictions of county-total emissions based on vehicle fleet and activity data from 2012 shown in Section 2.2.2 and January climatology of temperature and relative humidity diurnal profiles shown in Figure 2.1. The results from MOVES2010b for the following four pollutants are analyzed: (1) carbon monoxide, (2) nitrogen oxides, (3) volatile organic compounds, and (4) benzene. Carbon monoxide (CO) is a criteria pollutant regulated by the EPA and can be harmful to human health when inhaled in large amounts (U.S. EPA, 2010). Nitrogen oxides (NO_x) contain mostly NO that can be converted to NO₂, which is also a criteria pollutant that can cause respiratory illness (WHO, 2003). Volatile organic compounds (VOCs) contain various chemical species such as formaldehyde, hexane, 3,3-butadiene, and naphthalene. Both NO_x and VOCs contribute to the formation of ozone (O₃) and particulate matter (PM). Ozone is a criteria pollutant that can cause respiratory and other illnesses (WHO, 2003). Particulate matter is another criteria pollutant; it has been linked to lung cancer, cardiovascular and respiratory diseases, and other morbidities as well as premature death (Pope et al., 2002). In addition to containing O₃ and PM precursors, some VOCs are air toxics. Benzene is a VOC and is considered an air toxic; it is a human carcinogen and has been linked to a variety of adverse effects, including leukemia and other disorders of the blood (U.S. Department of Health and Human Services, 2007).

For simplicity, results are shown for only five of the thirteen vehicle types: (1) passenger cars, (2) passenger trucks, (3) light commercial trucks, (4) combination short-haul trucks, and (5) combination long-haul trucks. Not accounting for small contributions from the other eight vehicle types will not change the conclusions presented in this report.

CHAPTER 3. RESULTS

3.1 County Total Emissions

Figure 3.1, Figure 3.2, Figure 3.3, and **Error! Reference source not found.**Figure 3.4 show the county total emissions for CO, NO_x, VOCs, and benzene, respectively. In all four figures, each panel represents a county, each bar represents a vehicle type, and each color represents a process. The percentages of total emissions due to start emissions are highlighted by blue text in all four figures. Results from all eleven processes included in MOVES2010b are shown. As noted earlier, results are shown for only five of the thirteen vehicle types: (1) passenger cars, (2) passenger trucks, (3) light commercial trucks, (4) combination short-haul trucks, and (5) combination long-haul trucks. Depending on the county, MOVES2010b predicts that January county-total emissions from these five vehicle types contribute 93–94%, 87–90%, 93–95%, and 95–97% of total CO, NO_x, VOC, and benzene emissions, respectively.

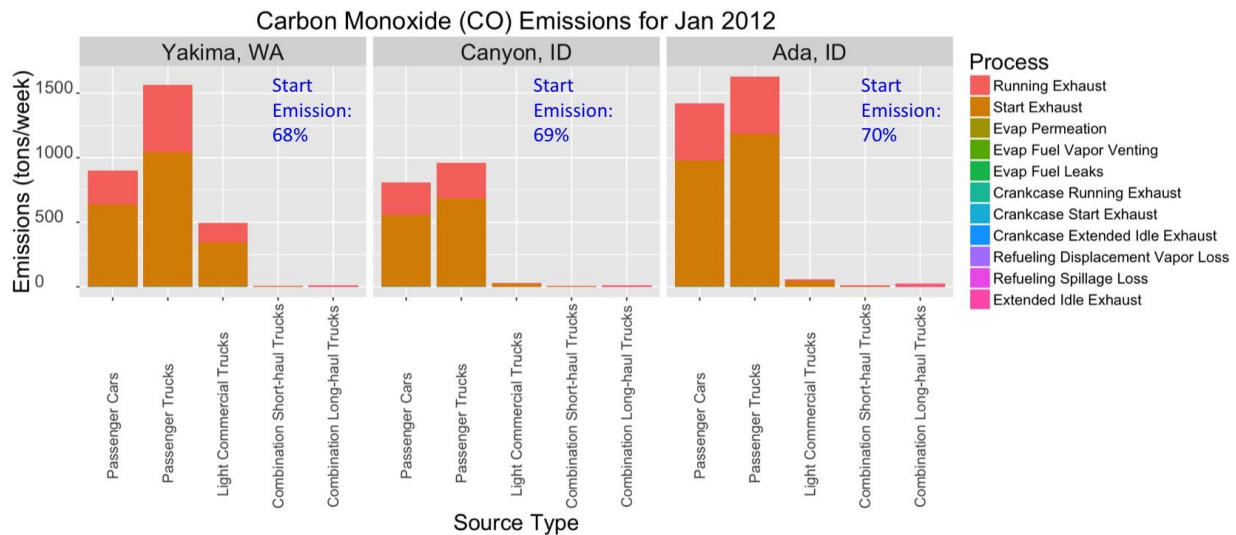


Figure 3.1 MOVES2010b estimates of county-total CO emission rates (tons/week) by process (color coded) from passenger cars, passenger trucks, light commercial trucks, combination short-haul trucks, and combination long-haul trucks for Yakima County, Washington (left), Canyon County, Idaho (middle), and Ada County, Idaho (right). The results are based on vehicle fleet and activity data from 2012 (see Section 2.2). Blue text indicates contributions of start emissions to the county total from all processes and the five vehicle types.

Figure 3.1 shows county total CO emissions based on vehicle fleet and activity data from 2012 and January climatology. Carbon monoxide is a byproduct of combustion and is not present in fuels; therefore, only processes involving engine operation (start, running, and idling) result in CO emissions. Passenger cars and trucks account for almost all the CO emissions in all three counties, though in Yakima County, light commercial trucks also make a significant contribution. These patterns are similar to those of the vehicle population and VMT data shown in Figure 2.2 and Figure 2.4, respectively. In all three counties, start exhaust contributes to approximately 70% of all CO emissions, and the remaining contributions are almost all from running exhaust (29–32%), with a very small contribution from idling exhaust (<1%).

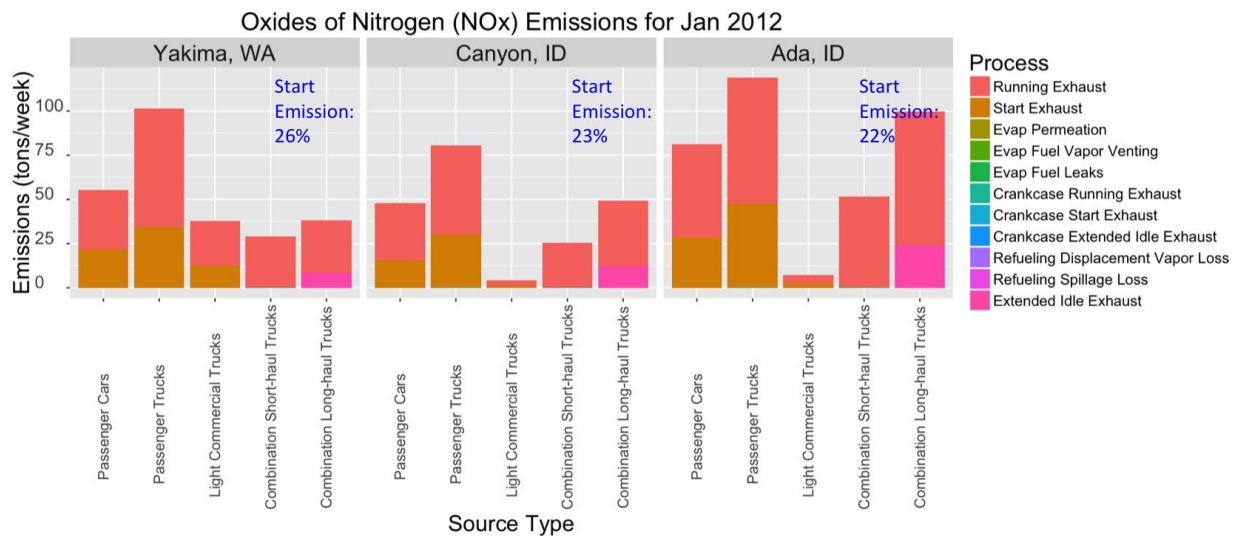


Figure 3.2 MOVES201b estimates of county-total NO_x emission rates (tons/week) by process (color coded) from passenger cars, passenger trucks, light commercial trucks, combination short-haul trucks, and combination long-haul trucks for Yakima County, Washington (left), Canyon County, Idaho (middle), and Ada County, Idaho (right). The results are based on vehicle fleet and activity data from 2012 (see Section 2.2). Blue text indicates contributions of start emissions to the county total from all processes and the five vehicle types.

Figure 3.2 shows county total NO_x emissions based on vehicle fleet and activity data from 2012 and January climatology. As is the case with CO, NO_x is a byproduct of combustion and is not present in fuels; therefore, only processes involving engine operation result in NO_x

emissions. Similar to CO, VOCs, and benzene emissions, passenger cars, passenger trucks, and light commercial trucks are major contributors to NO_x emissions. In contrast to CO, VOCs, and benzene, however, combination short-haul and long-haul trucks also contribute significantly to NO_x emissions despite relatively low vehicle population (Figure 2.2) and VMT (Figure 2.4) in these two vehicle types. These results are indicative of a combination of lower fuel economy (more fuel burned per mile traveled) for combination short-haul and long-haul trucks and higher emission factors (larger amount emitted per amount of fuel burned) for NO_x. In contrast to CO, VOCs, and benzene, NO_x emissions are dominated by running rather than start emissions, with running emissions contributing 71–72%, start emissions contributing 22–26%, and idling emissions contributing 3–7%.

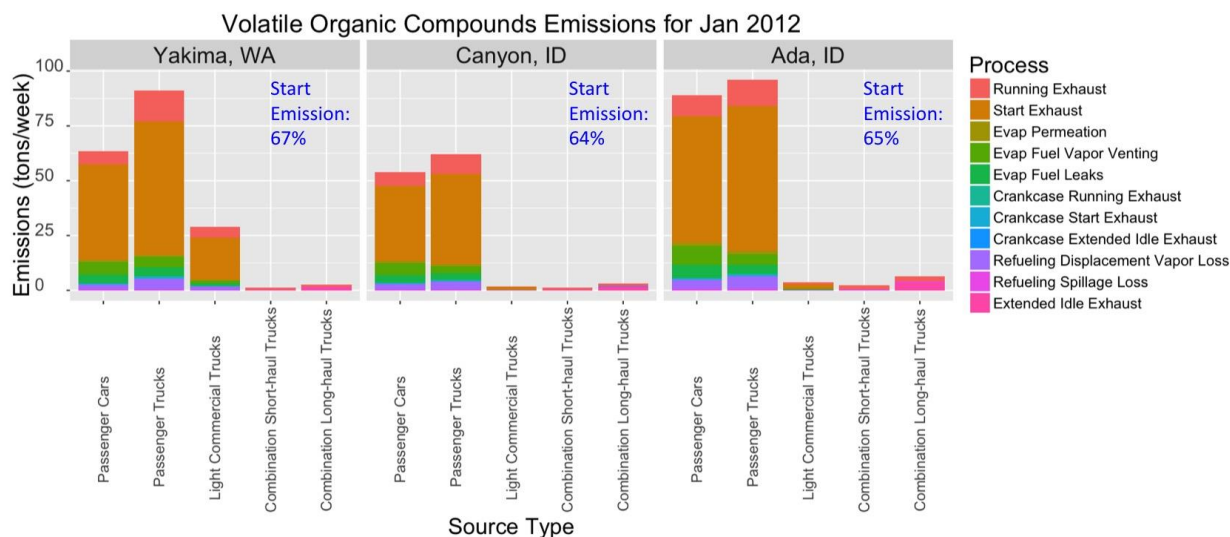


Figure 3.3 MOVES201b estimates of county-total VOC emission rates (tons/week) by process (color coded) from passenger cars, passenger trucks, light commercial trucks, combination short-haul trucks, and combination long-haul trucks for Yakima County, Washington (left), Canyon County, Idaho (middle), and Ada County, Idaho (right). The results are based on vehicle fleet and activity data from 2012 (see Section 2.2). Blue text indicates contributions of start emissions to the county total from all processes and the five vehicle types.

Figure 3.3 shows the county total emissions for VOCs, which are ozone and PM precursors and contain air toxics. Across the five vehicle types and three counties, the pattern for

VOCs is similar to that of CO (Figure 3.1); that is, emissions of VOCs are predominantly from passenger cars and trucks, with light commercial vehicles contributing in Yakima County as well. Volatile organic compound emissions are similar to CO emissions in that they are dominated by start emissions, which contribute 64–67% of total VOC emissions. Slightly lower relative contributions from start emissions compared with CO reflect the fact that VOCs are present in fuels and are emitted through leaking, venting, and vapor loss, which contribute to 19–22% of total VOC emissions. Running emissions contribute 14–15%.

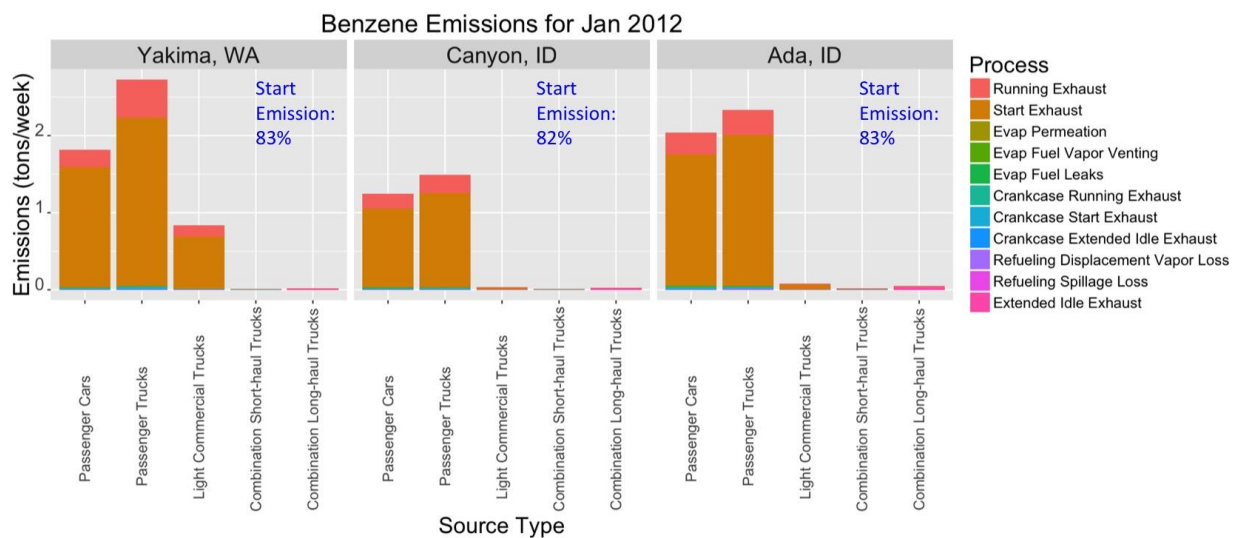


Figure 3.4 MOVES201b estimates of county-total benzene emission rates (tons/week) by process (color coded) from passenger cars, passenger trucks, light commercial trucks, combination short-haul trucks, and combination long-haul trucks for Yakima County, Washington (left), Canyon County, Idaho (middle), and Ada County, Idaho (right). The results are based on vehicle fleet and activity data from 2012 (see Section 2.2). Blue text indicates contributions of start emissions to the county total from all processes and the five vehicle types.

Figure 3.4 shows the county total emissions for the air toxics benzene, which is one of the VOCs. Across the five vehicle types, the pattern for benzene is similar to those of CO (Figure 3.1) and VOCs (Figure 3.3); that is, benzene emissions are predominantly from passenger cars and trucks, with light commercial vehicles also contributing in Yakima County. As with CO and VOCs, benzene emissions are dominated by start emissions. The relative contribution of start

emissions for benzene is even greater than that of CO and VOCs. Start and running emissions contribute 82–83% and 15–16%, respectively, of the total. Leaking, venting, and vapor loss make a small contribution (~1%); the contribution from idling exhaust is even less (<1%).

3.2 Temperature-Dependence of Start Emissions

This section presents results on the temperature dependence of emissions from engine starts as predicted by MOVES2010b. The results are presented for temperatures from -10°F to 70°F, and all results are normalized to emissions at the temperature of -10°F. As with the results presented in the previous section, the results here are shown for only five of the thirteen vehicle types: (1) passenger cars, (2) passenger trucks, (3) light commercial trucks, (4) combination short-haul trucks, and (5) combination long-haul truck. Results are shown for CO, NO_x, and VOCs. Because the temperature response curves for VOC start emissions and those of benzene are the same, curves for benzene are not shown here.

Figure 3.5, Figure 3.6, and Figure 3.7 show the temperature response curves for CO, NO_x, and VOCs, respectively. These results are based on the year 2012 (to specify vehicle age for a given vehicle model year) and based on relative humidity of 80%. While all three pollutants show strong dependence on temperature, the curves are different for different pollutants, vehicle types, vehicle model year, and fuel types. For CO, start emissions can decrease by as much as 90% when the temperature increases from -10°F to 70°F for passenger cars, passenger trucks, and light commercial trucks for both diesel and gasoline engines. For gasoline engines, it appears that newer cars are more sensitive to temperature than older cars. For combination short-haul and long-haul trucks, emission rates decrease by about 60% when the temperature increases from -10°F to 70°F. The model year/age of the vehicle has little influence on the temperature-response curves for CO start emissions from these trucks.

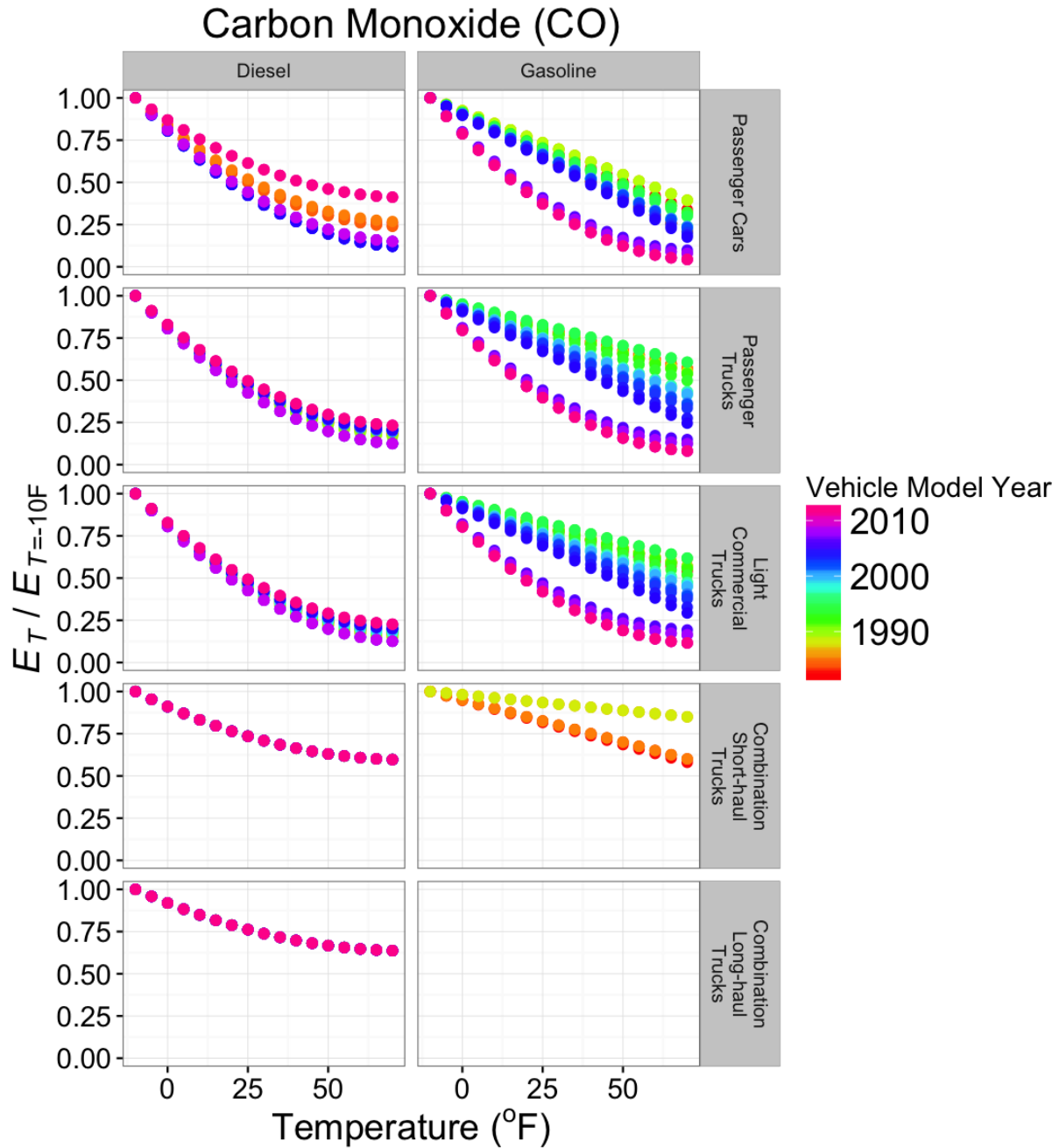


Figure 3.5 Temperature-dependence curve for start emissions of CO for the year 2012 assuming relative humidity of 80%

The temperature response curves for NO_x start emissions are linear (Figure 3.6).

Emissions can decrease by as much as 75% when the temperature increases from -10°F to 70°F for passenger cars, passenger trucks, and light commercial trucks for both diesel and gasoline

engines. This percentage is less than the 90% for CO. As with CO, for gasoline engines, newer cars are more sensitive to temperature than older cars are for start emissions of NO_x. For combination short-haul and long-haul trucks with diesel engines, NO_x start emissions decrease by as much as 96% when the temperature increases from -10°F to 70°F, regardless of vehicle model year. For gasoline-powered combination short-haul trucks (which consisted of only model years 1982 to 1988), the decrease is less than 10% when the temperature increases from -10°F to 70°F, regardless of model year.

Figure 3.7 shows temperature response curves for VOCs. These temperature response curves are the same as those for benzene because the model assumes that the benzene portion of VOCs emitted during engine starts is the same regardless of temperature. The temperature response curves are linear for diesel-powered vehicles and non-linear for gasoline-powered vehicles. The curves for diesel-powered vehicles exhibit small differences among the five vehicle types and across vehicle model year: emissions decrease by 81–94% when the temperature increases from -10°F to 70°F. For gasoline-powered passenger cars, passenger trucks, and light commercial vehicles, the temperature response curves differ substantially for different model years. Emissions decrease by up to 97% for newer vehicles in contrast to 47% for older vehicles. Over the same temperature range for gasoline-powered short-haul trucks, the decrease is 47–60%, with newer vehicles being less sensitive to temperature than older vehicles.

Oxides of Nitrogen (NO_x)

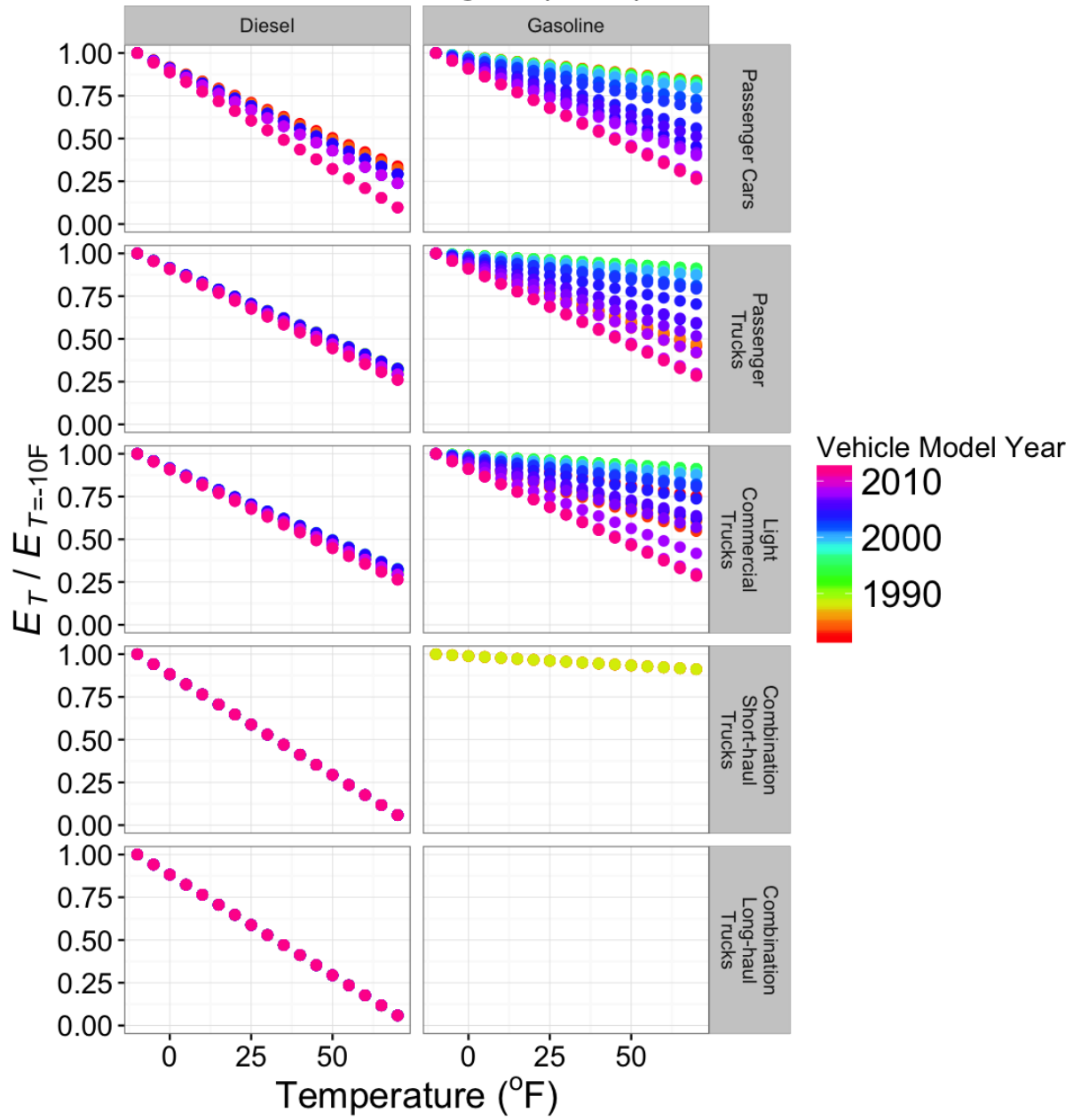


Figure 3.6 Temperature-dependence curve for start emissions of NO_x for the year 2012 assuming relative humidity of 80%

Volatile Organic Compounds

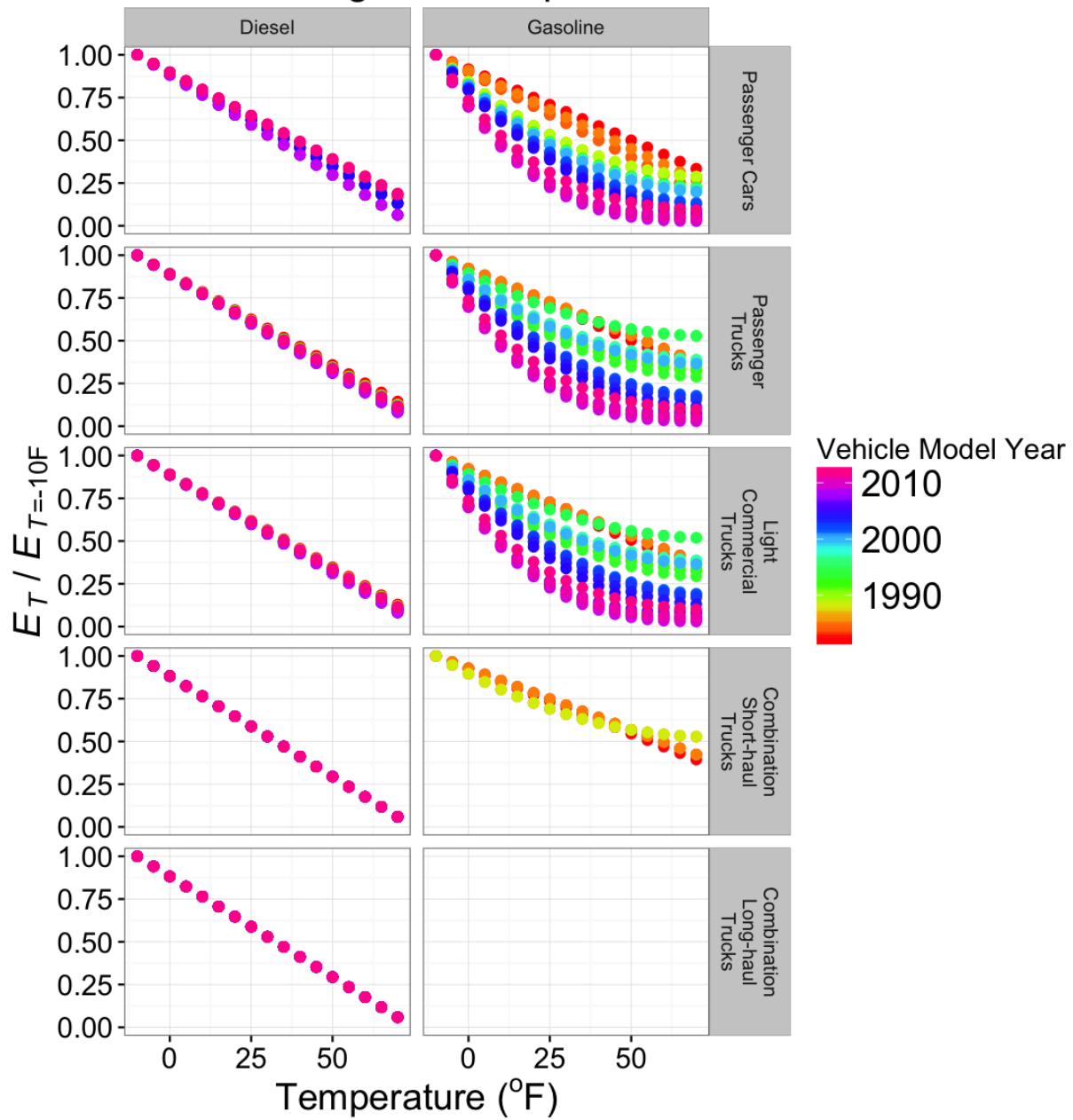


Figure 3.7 Temperature-dependence curve for start emissions of VOCs for the year 2012 assuming relative humidity of 80%

CHAPTER 4. CONCLUSIONS

To evaluate the contributions of cold-start emissions in the Pacific Northwest, the MOVES2010b emission model was used to estimate the contributions of vehicle start emissions to total vehicle emissions for January 2012 for three counties in the U.S. Pacific Northwest. The three counties evaluated in this study were Ada and Canyon counties in Idaho and Yakima County in Washington. All three counties are characterized by cold winter temperatures, which increase vehicle start emissions. In these three counties, stagnant conditions are present in winter, with temperature inversions that reduce dilution and trap pollutants close to the ground where human exposure occurs.

Four important pollutants that have been linked to adverse human health impacts were the focus of this study: carbon monoxide (CO), oxides of nitrogen (NO_x), volatile organic compounds (VOCs), and benzene. Based on MOVES2010b results, the following five vehicle types account for greater than 85% of the total emissions of CO, NO_x, VOCs, and benzene from all vehicle types in the three counties: (1) passenger cars, (2) passenger trucks, (3) light commercial trucks, (4) combination short-haul trucks, and (5) combination long-haul truck. For all three counties, passenger cars and passenger trucks are the dominant contributors to vehicle emissions of CO, VOCs, and benzene, and in Yakima County, light commercial trucks also contribute significantly. In addition to these three vehicle types, combination short-haul and long-haul trucks contribute significantly to total vehicle NO_x emissions in all three counties. MOVES2010b indicates that vehicle start emissions dominate total vehicle emissions for CO, VOCs, and benzene, and include a significant portion of total vehicle NO_x emissions. Depending on the county, vehicle start emissions contribute 68–70%, 22–26%, 65–67%, and 82–83% to total vehicle emissions of CO, NO_x, VOCs, and benzene, respectively.

As an initial step to evaluate how MOVES2010b captures the temperature sensitivity of start emissions, the MOVES2010b model was run to generate temperature response curves for vehicle start emissions of CO, NO_x, and VOCs (MOVES2010b assumes that VOCs and benzene have the same temperature response curves). Start emissions of CO, NO_x, and VOCs all show a strong dependence on temperature, but the temperature response curves are different for different pollutants, vehicle types, vehicle model years, and fuel types. For CO, start emissions from newer gasoline-powered passenger cars are the most sensitive to temperature, with a decrease as high as 90% when the temperature increases from -10°F to 70°F. For NO_x, start emissions from diesel-powered combination short-haul and long-haul trucks are the most sensitive to temperature, with a decrease as high as 96% when the temperature increases from -10°F to 70°F. Over the same temperature range, start emissions of VOCs decrease by 81–94% for diesel-powered vehicles and 47–97% for gasoline-powered passenger vehicles and light commercial trucks.

The results of this study highlight the importance of start emissions in contributing to air pollution due to motor vehicles during winter and the strong sensitivities of start emissions to temperature assumed in the MOVES model. For regions with colder climates, such as Montana and Alaska, contributions from start emissions would be even greater. Accurate estimates of vehicle start emissions require accurate models. Experimental measurements of vehicle emissions at the full range of wintertime temperatures should be carried out to systematically evaluate the accuracy of MOVES predictions.

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