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The role of light duty vehicles in future air pollution: a case study of Sacramento

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On-road light-duty vehicles (LDVs) play an important role in contributing to urban air pollution. Although vehicles are getting cleaner, regional growth in vehicle population and vehicle miles traveled would somewhat offset California's efforts in transportation pollution reduction. To better understand the role of LDVs in future air pollution, we conduct a case study for Sacramento, California, and investigate future trends in urban air pollution attributable to the light-duty fleet. Results indicate that ambient concentrations of CO, NO_x, and total organic gases (TOGs) caused by future light-duty fleets would dramatically decrease over coming years. The resulting concentrations in 2030 might be as low as approximately 20% of the 2005 concentrations. These reflect the improvements in vehicle/fuel technologies and standards in California. However, the future particulate matter (PM_{10}) pollution could be slightly worse than that caused by the 2005 fleet. This is a result of the growing fleet-average emission factors of particulates from 2005 to 2030. For purposes of future particulate control, more attention needs to be paid to LDVs, besides heavy-duty vehicles.

Keywords: transportation pollution; light-duty vehicles; air quality; travel demand; particulate matter

1. Introduction

The current petroleum-powered transportation system emits a huge amount of emissions. Closer to human activities in the urban area than many large stationary sources, motor vehicles contribute significant and even major fractions to ambient pollutant concentration levels (Wang *et al*. 2009). To address air pollution and protect human health, mobile sources control has been a challenging problem for the past several decades in California, even though many meaningful efforts have been made.

Of on-road mobile sources, light-duty vehicles (LDVs) inevitably play an important role. In 2005, LDVs accounted for 90% of vehicle miles traveled (VMT) and 91% of the vehicle population in California (California Air Resources Board 2007). Here the term 'LDVs' refers to passenger cars (including sedans, wagons, etc.) and light trucks of 8500 lbs (3856 kg) or less (including pickup trucks, vans, and sports utility vehicles [SUVs]) (Davis and Diegel 2007).

On the one hand, California's vehicles are getting cleaner. In particular, both technologies and standards for vehicles and transportation fuels keep making

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progress in reducing (criteria pollutant and greenhouse gas) emissions and energy consumption, such as the Pavley clean car program, low carbon fuel standard, and zero emission vehicle program (California Air Resources Board 2008). On the other hand, regional growth in vehicle population and VMT steadily occurs, which somewhat offsets California's efforts in vehicle pollution reduction. Apparently, the role of LDVs in future air pollution is changing and needs to be better understood. In this paper, we conduct a case study for the Sacramento metropolitan area, and investigate future trends in urban air pollution resulting from the light-duty fleet in California.

2. Methodology

2.1. Scope: light-duty vehicles (LDVs) and their emissions

We focus on the light-duty fleet, as compared to the regional fleet which includes not only LDVs but also heavy-duty vehicles and others (such as motorcycles). A light-duty fleet is composed of all vehicles in classes 1–4, part of a total of 13 vehicle types defined in the EMFAC2007 model (see Table 1) (California Air Resources Board 2007).

We only consider the following primary emissions: carbon monoxide (CO), nitrogen oxides (NO_x), total organic gases (TOGs), and particulate matter (PM_{10}) (see Table 2). Note that both tailpipe exhaust and those emissions from tire wear and brake wear are taken into account for particulates in this study.

2.2. Modeling

The Sacramento metropolitan area, which we use as the modeling domain, includes six counties with the majority of vehicle and human populations in the urbanized Sacramento.

Table 1. Vehicle classes modeled in EMFAC 2007.

Vehicle class[a]	Fuel type	Description	Weight class (lbs)	Abbreviations
1	All[b]	Passenger cars	All	LDA
2	All[b]	Light-duty trucks	0–3750	LDT1
3	Gas, diesel	Light-duty trucks	3751–5750	LDT2
4	Gas, diesel	Medium-duty trucks	5751–8500	MDV
5	Gas, diesel	Light-heavy-duty trucks	8501–10000	LHDT1
6	Gas, diesel	Light–heavy-duty trucks	10001–14000	LHDT2
7	Gas, diesel	Medium–heavy-duty trucks	14001–33000	MHDT
8	Gas, diesel	Heavy–heavy-duty trucks	33001–60000	HHDT
9	Gas, diesel	Other buses	All	OB
10	Diesel	Urban buses	All	UB
11	Gas	Motorcycles	All	MCY
12	Gas, diesel	School buses	All	SBUS
13	Gas, diesel	Motor homes	All	MH

[a]This study is focused on 'light-duty vehicles,' including the first four vehicle classes in this table.
[b]Includes gasoline, diesel, and electric.
Source: California Air Resources Board (2007).

Table 2. Vehicle emission activities.

Pollutant	Emission processes
CO	Running exhaust, idle exhaust, and starting exhaust
NO_x	Running exhaust, idle exhaust, and starting exhaust
TOG	Running exhaust, idle exhaust, starting exhaust, diurnal, hot soak, running loss, and resting loss
PM_{10}	Running exhaust, idle exhaust, starting exhaust, tire wear, and brake wear

A flow chart of the methodology is presented in Figure 1. A number of models and datasets are sequentially used in our modeling approach. For more details, see Wang *et al*. (2008).

Vehicle emission rates are derived from California's regulatory mobile emissions model, EMFAC2007 (California Air Resources Board 2007). Regional transportation networks and traffic activities are obtained from a travel demand model, SACMET (SACMET2005, 2005). According to temporal and spatial distributions of vehicle activities, regional transportation emissions are disaggregated and assigned

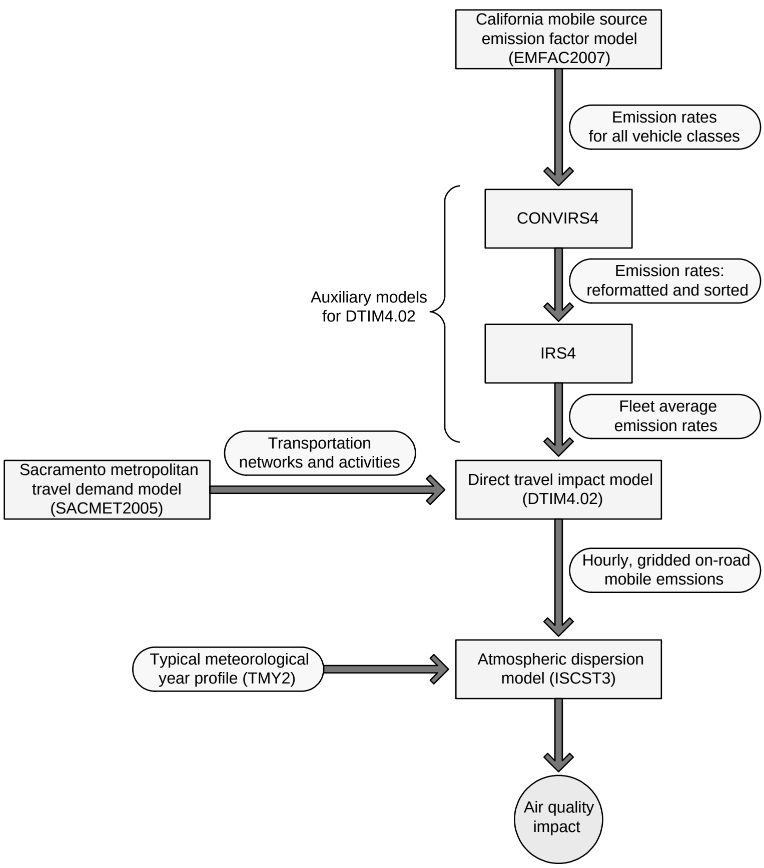

Figure 1. Methodological framework and model running sequence.
Source: Wang *et al.* (2008).

to predefined minor grid cells by hour. Emissions at the grid level are treated as small area sources, and their resulting concentrations at a pollution receptor are then estimated by using the Gaussian atmospheric dispersion model, ISCST3 (US Environmental Protection Agency 1995).

Note that weighted average emission rates for the LDV fleet are used to develop the grid-based emission inventory. Vehicle class weights are calculated as proportions of VMT by each vehicle class in the fleet (California Department of Transportation 2001).

We employ the Typical Meteorological Year data (TMY2, 2006) for Sacramento County to represent the whole region. Because TMY2 is not necessarily identical to the actual 2005 meteorological conditions (even for Sacramento County), this might cause inconsistency when we compare predicted air pollutant concentrations with measured concentrations at air quality monitoring stations. However, to better understand the role of LDVs in future air pollution, the predicted results associated with typical meteorological conditions are more statistically meaningful, particularly for future years with uncertain meteorology, say 2010–2030.

Furthermore, a VMT-scaling approach is used to scale the output from the modeling sequence shown in Figure 1. The base VMT level, VMT_0, is equal to the magnitude of VMT by all 13 vehicle types in 2005; $VMT_0 = 57{,}203{,}211$ miles/day. The predicted air pollution level resulting from a future LDV fleet is the concentration output from our model running sequence (based on the future vehicle emission rates, accordingly) scaled by this fleet's VMT level relative to VMT_0.

2.3. Air pollution receptors

The Air Quality System has measured ambient pollution data for monitoring stations throughout the USA (US Environmental Protection Agency 2007). Nine air quality stations located in urban Sacramento are chosen to serve as the dispersion model pollution receptors (see Figure 2). We use estimated annual average concentrations over all receptors to represent the urban pollution level, and doing so somewhat reduces the randomness of extreme occurrences and is especially meaningful for a future year with uncertain meteorology.

3. Results and discussion

3.1. Projections for light-duty fleets

Table 3 shows six scenario years with projected or actual on-road LDV fleets in the Sacramento metropolitan area, based on EMFAC2007 using its default assumptions. These light-duty fleets are a mix of in-use on-road vehicles, spanning generally 45 vehicle model years. Apparently, the fleet size increases over future years, and the aggregate VMT level dramatically goes up from 2005 to 2030. Relative to 2005, the 2030 LDV population is projected to increase by 47%, and the total VMT in 2030 will increase by 36%. These patterns are consistent with Sacramento transportation planning, because travel demand increases with regional development to satisfy personal mobility.

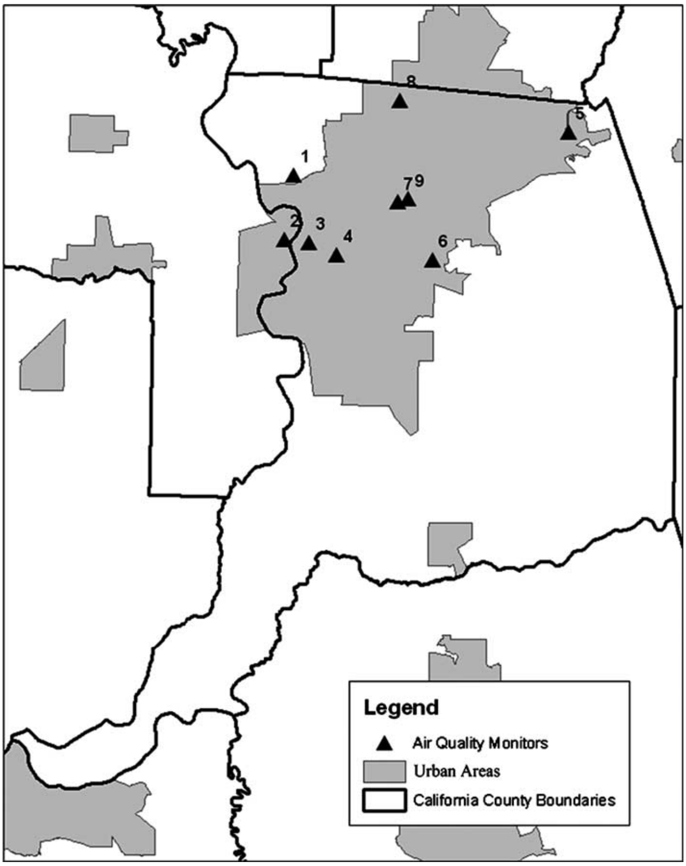

Figure 2. Air pollution receptors in urban Sacramento.

3.2. Future trends in air quality resulting from light-duty vehicles

The focus of this study is on estimating future trends in air quality resulting from LDVs. Figure 3 and Table 4 present estimated annual average concentrations, averaged over all the nine receptors shown in Figure 2. Our results indicate that the

Table 3. Scenario years with various light-duty fleets.

Scenario year	Model years	Vehicle population	VMT per day
2005	1965–2005[a]	1,510,255	51,124,896
2010	1966–2010	1,602,841	52,072,888
2015	1971–2015	1,782,149	57,434,764
2020	1976–2020	1,926,950	61,481,513
2025	1981–2025	2,091,542	66,498,532
2030	1986–2030	2,215,694	69,574,001

[a]The earliest model year is 1965 in EMFAC2007 (California Air Resources Board 2007). Thus, the year 2005 LDV fleet only comprises vehicles spanning 41 model years.

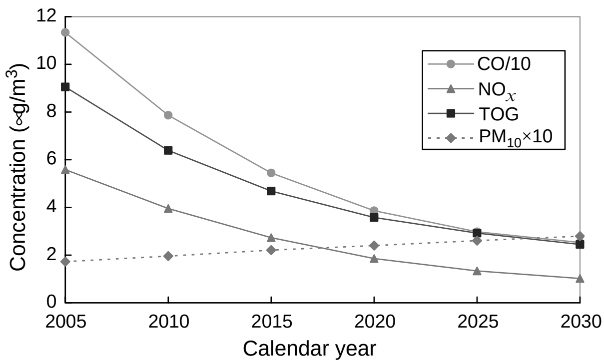

Figure 3. Future trends in ambient air quality resulting from light-duty vehicles.

future fleets would make significant progress in environmental impacts, with the exception of PM_{10}, over the 2005 fleet. Actually, the PM_{10} pollution resulting from the future fleets would be slightly worse than that caused by the 2005 fleet.

Obviously, ambient CO, NO_x, and TOG concentrations will dramatically decrease over years from 2005 to 2030. The resulting 2030 concentrations are expected to be as low as approximately 20% of the 2005 concentrations. These reflect the improvements in vehicle/fuel technologies and standards in California. Note, however, that these concentrations correspond to light-duty fleets, in which we are interested in this study, and these concentrations are only part of transportation-related pollution (and ambient air pollution).

On the contrary, the LDV-caused PM_{10} concentrations will steadily increase from 0.17 $\mu g/m^3$ in 2005 to 0.28 $\mu g/m^3$ in 2030. This is a result of the growing fleet-average emission factors of particulates. See Section 3.3 for more discussion.

As shown in Figure 3, the light-duty fleets will contribute to the following air pollution levels: CO $>>$ TOG $>$ NO_x $>>$ PM_{10}. The LDV-resulted NO_x and TOG concentrations have the same level of magnitude in each scenario year. However, the CO concentrations will be an order of magnitude higher than NO_x or TOG. Generally, LDVs run on gasoline and are not a significant source of particulate

Table 4. Annual average concentrations attributable to light-duty fleets ($\mu g/m^3$).

	Light-duty fleet							
Pollutant	2005	2010	2015	2020	2025	2030	Regional fleet (2005)[a]	LDV share (%) (2005)[b]
CO	113	79	54	39	30	25	156	73
NO_x	5.6	4.0	2.7	1.9	1.3	1.0	14.8	38
TOG	9.1	6.4	4.7	3.6	2.9	2.4	12.3	74
PM_{10}	0.17	0.20	0.22	0.24	0.26	0.28	0.91	19

[a]The 2005 regional fleet includes all of vehicle types 1–13 defined in EMFAC2007. Some of these concentrations due to the regional fleet tend to be slightly underestimated (Wang *et al.* 2009).
[b]The last column presents the LDV-resulted concentration shares. For example, the 2005 LDV fleet is estimated to cause 73% ($=\frac{113}{156}\times 100\%$) of total transportation-related concentrations of CO.

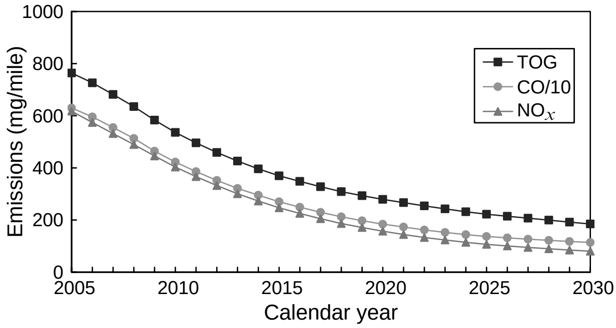

Figure 4. Trends in the LDV fleet-average emissions per mile traveled.

emissions, which explains that LDV-resulted PM_{10} concentrations are roughly one-tenth of NO_x or TOG. These are especially true in future years 2015–2030.

Again, because of the methodological limitation of directly using travel demand model data from SACMET (see Figure 1), transportation-related air pollution tends to be underestimated compared to directly using emissions data from EMFAC (Wang *et al.* 2009). This indicates that the concentration numbers here could reflect the future air pollution trends, but they might not be estimates with very high accuracy, as they are likely to be consistently underestimated.

3.3. Comparison to vehicle emission trends

Figure 4 shows the trends in the LDV fleet-average vehicle emissions per mile traveled, on a per-vehicle basis, for aggregate CO, TOG, or NO_x emissions (including emissions from vehicle running, idle, starting, etc., shown in Table 2). According to the EMFAC dataset, CO, NO_x, and TOG emissions from an average LDV would steadily decrease from 2005 to 2030, on a per-mile-traveled basis. This is consistent with common sense, reflects technological advance over time, and thus explains the improvements in air quality for these future fleet scenarios.

Figure 5 presents the trends in aggregate PM_{10} emissions from a light-duty fleet-average vehicle on a per-mile-traveled basis, using data extracted from EMFAC as well. Note that these particulate emissions include those from vehicle running, idle, and starting; however, particulates from tire wear and brake wear are not included in

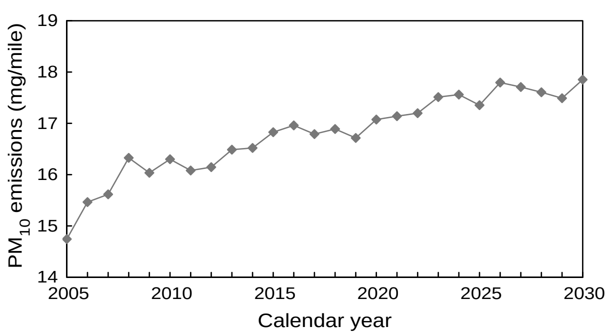

Figure 5. Trends in the LDV fleet-average emissions per mile traveled.

Figure 5. Different from the other three emissions, per-vehicle PM_{10} emissions would frequently, though not smoothly, increase from 2005 to 2030, on a per-mile-traveled basis. One reason to explain the trends of PM_{10} increase is that the vehicle fleet compositions change over time and the average LDV is getting larger in size; e.g. light-duty trucks and SUVs are increasingly popular in the USA. Moreover, it is also possible that LDV PM_{10} emissions cannot be calculated accurately by mobile emission inventory models due to the small magnitude of emissions, e.g. in the range 14.7–17.9 mg/mile spanning 2005–2030.

In addition, those PM_{10} emissions from tire wear and brake wear will certainly increase from 2005 to 2030, as vehicle population and VMT go up over time (see Table 3). This provides further evidence supporting that the future PM_{10} air quality caused by LDVs will somewhat degrade.

Note that emission factors presented in Figures 4 and 5 are calculated as total LDV emissions divided both by total vehicle population and by total VMT. They are highly aggregated. However, to address the variability of four LDV classes, we apply the weighted average emission factors (weighted by VMT proportions) to simulate air pollution in our modeling approach shown in Figure 1.

3.4. Light-duty vehicles (LDVs) vs. the rest of the fleet: the 2005 case

Air pollution resulting from the year 2005 regional fleet, as compared to the light-duty fleet, is also presented in Table 4. The regional fleet is composed of all the on-road vehicles, including 13 vehicle types in Table 1. Our results indicate that, in 2005, LDVs were responsible for the majority of transportation-related CO and TOG pollution, approximately three-fourths. Note that the rest of the regional fleet mainly comprises heavy-duty vehicles running on diesel, rather than gasoline. Typically, internal combustion engines have a greater efficiency for heavy-duty vehicles than for LDVs. Therefore, the gasoline-fueled light-duty fleet with a relatively huge population accounts for the most pollution from incomplete combustion, say CO and TOG.

In addition, the light-duty fleet contributed to approximately 40% of, lower than half, the transportation-related NO_x level in 2005. This means that both LDVs and heavy-duty vehicles are significant NO_x emitters, almost equally important. Although particulate matter emitted from LDVs, generally, is not of much interest to policy-makers, our results show that the light-duty fleet significantly accounted for about 20% of overall transportation-related PM_{10}. In recognition of the growing trend of PM_{10} concentrations from 2005 to 2030, more attention needs to be paid to LDVs, besides heavy-duty vehicles.

4. Conclusions

To better understand the role of LDVs in future air pollution, we conducted a case study for Sacramento, California, and investigated future trends in urban air pollution resulting from the light-duty fleet. Although both fleet size and VMT dramatically increase from 2005 to 2030, the CO, NO_x, and TOG concentrations caused by future light-duty fleets would dramatically decrease over time. The resulting 2030 concentrations might be as low as approximately 20% of the 2005 concentrations. These reflect the improvements in vehicle/fuel technologies and standards in California. However, the future PM_{10} pollution would be slightly worse than that caused by the 2005 fleet. This is a result of the growing fleet-average emission factors of particulates.

Our results also indicate that LDVs accounted for approximately 75% of transportation-related CO and TOG pollution, approximately 40% of NO_x, and about 20% of PM_{10} in 2005. In recognition of the growing trend of PM_{10} concentrations from 2005 to 2030, more attention needs to be paid to LDVs, besides heavy-duty vehicles.

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