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Technical Appendix

Climate Change Challenges

Vehicle Emissions and Public Health in California

Louise Wells Bedsworth
with research support from Sarah Swanbeck

Contents

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Data and Methods

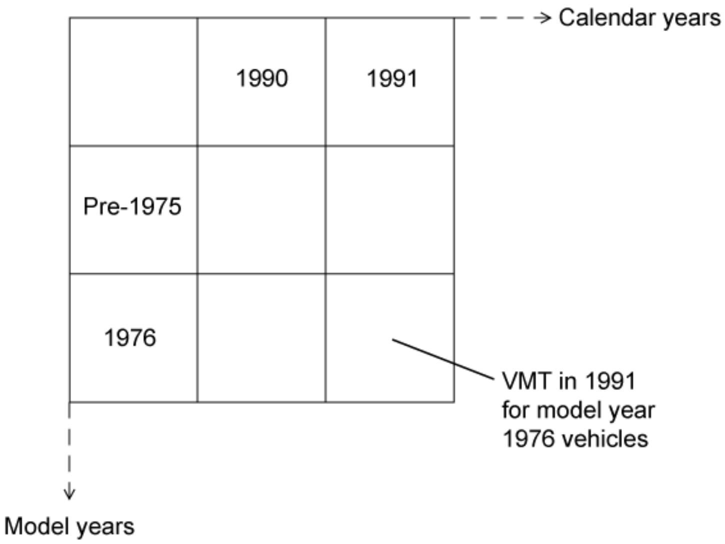
The basis for the analysis conducted in this paper was obtained from the state's vehicle stock model, EMFAC 2007. Estimates of the impacts of different policy options were based on projections of future vehicle activity (VMT) and the generation of smog-forming emissions.

Baseline Fleet Information

Estimating GHG and smog-forming emissions from the vehicle fleet in the future was based on information obtained from CARB's EMFAC 2007 model. EMFAC2007 is a vehicle fleet model that provides estimates of vehicle population, VMT, and emissions by model year for each calendar year. This model output was generated for the whole state using an annual average. All of the parameters in EMFAC 2007 were kept as defaults.

The output provided estimates of emissions, VMT, and vehicle population for each calendar year, by model year. The calendar years spanned 1970 to 2040 and the model years included 1965 through 2040. For the purposes of this analysis, calendar years 1990 through 2040 were included in the analysis since the state's climate goals are relative to 1990 emissions. The resulting output from the model was a series of matrices where each column corresponds to a calendar year and each row corresponds to a model year. A cell in the matrix corresponds to a characteristic of a vehicle of model year x in year y (Figure A1).

FIGURE A1
Example of a Matrix of Output from EMFAC 2007



Calculating GHG Emissions

For each calendar year, GHG emissions were calculated according to the following formula:

$$GHG_i = \sum_j \frac{VMT_{ij}}{FE_{ij}} CI \text{ , where}$$

i = calendar year

j = model year

VMT_{ij} = vehicle miles traveled by vehicle of model year j in year i

FE_{ij} = fuel economy of vehicle of model year j in year i in miles per gallon gasoline equivalent (gge)

CI = carbon intensity of fuel in use in g CO2-eq/gge

GHG emissions were calculated based on the amount of fuel consumed on a per unit energy basis. VMT was used as the constraining output from EMFAC 2007. That is, for a given model year and calendar year, the VMT would be completed "driven" using different vehicle and fuel assumptions. The carbon intensities of the different fuel options were gathered from the LCFS regulatory materials. The values are listed in Table A1.

TABLE A1
Fuel carbon intensities

Fuel	Carbon intensity (g CO_2-eq/gge)
Baseline (E10)	11083.8
E85 – CA average ethanol, no indirect emissions	8116.6
E85 – CA average ethanol, including indirect emissions	11065.3
E85 – cellulosic ethanol, no indirect emissions	1898.6
E85 – cellulosic ethanol, including indirect emissions	3667.9
Electricity	4035.7
Hydrogen	3826.1

SOURCE: Calculated based on California Air Resources Board 2009a, page VI–7).

The calculations were carried out for two categories of vehicles. The first included cars and the lightest light trucks and the second included all remaining light trucks up to 8,500 pounds. These categories correspond to the following grouping of EMFAC 2007 output: car and light light-trucks include light-duty automobiles (LDA) and light-duty trucks 1 (LDT1); light trucks include light-duty trucks 2 (LDT2) and medium-duty vehicles (MDV) (California Air Resources Board 2006a).

Baseline GHG Emissions

Estimates of baseline vehicle fuel economy, that is fuel economy absent the implementation of the state's GHG emission standards, were taken from the EPA's Fuel Economy Trends report (EPA, 2008). It was assumed that the average fuel economy for a model year 2008 vehicle would apply to all future model years. Table A2 shows the fuel economy values used in the model.

TABLE A2
Fuel economy values use for baseline scenario (miles/gallon)

Model year	Cars and light-light trucks	Light trucks
Pre-1975	13.5	11.6
1976	14.9	12.2
1977	15.6	13.3
1978	16.9	12.9
1979	17.2	12.5
1980	20.0	15.8
1981	21.4	17.1
1982	22.2	17.4
1983	22.1	17.8
1984	22.4	17.4
1985	23.0	17.5
1986	23.7	18.2
1987	23.8	18.3
1988	24.1	17.9
1989	23.7	17.6
1990	23.3	17.4
1991	23.4	17.8
1992	23.1	17.4
1993	23.5	17.5
1994	23.3	17.6
1995	23.4	17.0
1996	23.3	17.2
1997	23.4	17.0
1998	23.4	17.1
1999	23.0	16.7
2000	22.9	16.9
2001	23.0	16.7
2002	23.1	16.7
2003	23.2	16.9
2004	23.1	16.7
2005	23.5	17.2
2006	23.3	17.5
2007	24.1	17.7
2008	24.1	18.1

SOURCE: Environmental Protection Agency, 2008.

NOTE: Value for model year 1975 was assumed to apply to model year 1975 and all previous model years.

The baseline GHG emissions were calculated assuming that the fuel in use would be an ethanol-gasoline blend that was 10 percent ethanol by volume (E10). This is consistent with the assumptions in the LCFS (California Air Resources Board 2009a, 2009b).

GHG Emission for Policy Scenarios

The GHG emissions for each of the policy scenarios were calculated by varying the fuel economy and the carbon intensity factors. In all cases, except for the baseline, fuel economy was assumed to follow the current GHG emission standards for new passenger vehicles. These estimates are shown in Table A3.

TABLE A3
Fuel economy under GHG standards for new passenger vehicles

Model year	Car and light light-trucks (mpg)	Light trucks (mpg)
2009	26.5	19.5
2010	28.4	20.4
2011	32.1	22.0
2012	36.7	23.7
2013	37.7	24.1
2014	38.6	24.5
2015	40.2	25.1
2016	41.8	25.8

SOURCE: Calculated based on the model year emission standards from the regulatory documents (California Air Resources Board 2004).

For the VMT reduction scenarios, VMT per capita was adjusted to reflect the reductions from business as usual over each time horizon. For each time horizon, it was assumed that the VMT reduction increased linearly over the time period. For each calendar year, the per capita reduction in VMT was translated into an overall VMT reduction using population data from the California Department of Finance. The total adjusted VMT was then distributed across model years assuming the same shares as the baseline. In other words, it was assumed that VMT reduction would occur uniformly across all vintages of vehicles.

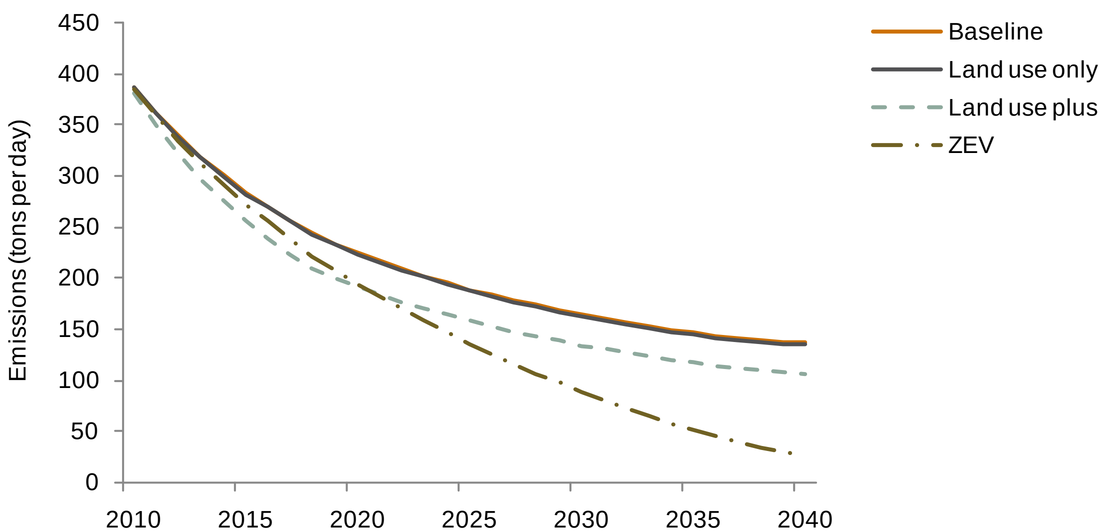
Calculating Health Impacts

Air quality-related health impacts of different policy options were calculated as deaths avoided and reductions in several morbidity endpoints through the reduction of three criteria pollutants: particulate matter with a diameter less than 2.5 microns (PM-2.5), ROG, and NOx. The calculation proceeded in two steps. The first step was to calculate the emission reductions under each policy scenario relative to the baseline and the second was to translate this reduction into an estimate of deaths avoided and avoided morbidity impacts. Unlike the analysis of GHG emissions, this calculation only considers tailpipe emissions. The upstream (e.g., refinery or plant) emissions of smog-forming pollutants may or may not be local and are regulated under the current rules for stationary sources.

Calculating Emissions Avoided

For this calculation, we estimate emission reductions in 2020 for each of the policy scenarios shown in Figure 9 in the text. For both FCVs and BEVs, we assume that tailpipe emissions are zero. Therefore, for model year 2010 and later, the emissions of criteria pollutants for those model years in each calendar year was set to zero. Figure A2 shows the impact on emissions of ROG for the baseline, ZEV, and VMT reduction scenarios.

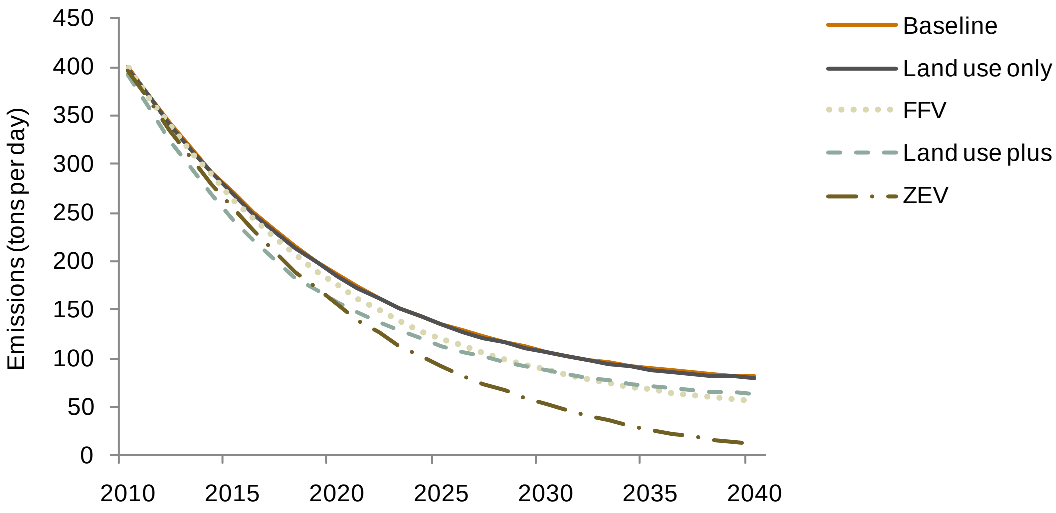
FIGURE A2
ROG emissions under three scenarios, 2010 to 2040



For the E85 scenarios, we examined two scenarios. The first assumed no change in tailpipe emissions relative to the baseline. This scenario is plausible given the FFVs are on the road today and comply with California's current emission standards. Given the scarcity of E85 fueling stations and the flexibility of the vehicles, it is likely that they will run on gasoline rather than E85. Therefore, this is a conservative assumption.

In the future, one would expect an increase in the number of E85 fueling stations; therefore, E85 could be used most, if not all, of the time in FFVs. Under this case, it makes sense to consider an alternative emissions scenario. In general, studies of emissions of E85 vehicles relative to those that run on gasoline have yielded mixed results (see summary in Graham, Belisle, and Baas, 2008). Graham, Belisle, and Baas (2008) conducted a direct comparison of E85 FFV to vehicles running on California reformulated gasoline (CARFG) and found a statistically significant reduction in NOx emissions, ranging from 23 to 47 percent. To capture this potential effect, we calculated the health impacts assuming a 35 percent reduction in NOx emissions, but no change in emissions of ROG or PM. Emissions testing results on ROG are mixed and the assumption of no change on PM emissions is consistent with Jacobson (2007). Figure A3 shows the resulting NOx emissions.

FIGURE A3
NOx emissions under different policy scenarios, 2010 to 2040



Emissions of PM were provided as emissions of PM with a diameter smaller than 10 microns (PM-10) by the EMFAC model. For this analysis, we were interested in emissions of PM-2.5, PM with a diameter less than 2.5 microns in diameter. PM-10 emissions were converted to emissions of PM-2.5 using the conversion factor developed by Bailey at al. (2008, page viii) for light-duty gasoline vehicles.

Table A4 summarizes the emission reductions in 2020 for each scenario.

TABLE A4
Criteria pollutant emission reductions in 2020 for each policy scenario

Scenario	NOx (tons per day)	ROG (tons per day)	PM-10 (tons per day)
E85 FFV	0	0	0
E85 FFV with NOx benefit	10.7	0	0
ZEV	30.7	29.9	23.9
VMT-land use only	1.1	1.3	0.3
VMT-land use +	27.6	33.4	6.7

It is important to note that this analysis only considers tailpipe emissions. Analysis has shown that E85 results in increased evaporative emissions from vehicles as well as increases in emissions of air toxics such as formaldehyde, benzene, and 1,3-butadiene. In addition to having direct health effects, these toxics also can result in increased ozone formation. Jacobson (2007) shows that this increase in emissions can result in an increase in ozone formation. Therefore, these estimates may underestimate the impact on smog-forming emissions.

Calculating Morbidity and Mortality Endpoints

Criteria pollutant emission reductions were translated into each morbidity and mortality endpoint using the methodology outlined in the Good Movement Emission Reduction Plan (GMERP) (California Air Resources Board 2006b) and applied by Bailey et al. (2008). The criteria pollutant emission reductions were converted to a ton per year emission reduction estimate, and deaths and morbidity impacts avoided were calculated according to the following formula:

$$Endpoint_j = \sum_{i,j} \frac{ER_i}{fHEP_{i,j}}, \text{ where}$$

i = pollutant

j = health endpoint

ER_i = emission reductions of pollutant i

$fHEP_{i,j}$ = health endpoint factor for pollutant i for endpoint j

In this case, the health endpoint factor was for death.

The health endpoint factors are provided in the GMERP for each air basin (California Air Resources Board 2006b, page 49). Using population estimates from CARB's California Almanac of Emissions and Air Quality, we calculated a population-weighted statewide average health endpoint factor for each pollutant (Cox et al., 2009). For this analysis, the health endpoint factor for diesel particulate matter (DPM) was used for emissions of PM-2.5. Table A5 shows the resulting statewide health endpoint factors for each pollutant.

TABLE A5
Health endpoint factors for criteria pollutant emissions

	Endpoint factor (tons/case)						
	Death	Hospitalization (respiratory)	Hospitalization (cardiovascular)	Asthma and other LRS	Acute bronchitis	Work loss days	Minor restricted activity days
DPM	15.9	78.9	42.9	0.6	7.7	0.1	0.02
NOx	634.6	3089.5	1678.4	25.2	305.2	4.1	0.7
ROG	1238.2	6001.1	3264.5	46.6	559.8	7.8	1.3

SOURCE: California Air Resources Board 2006b, page 49).

NOTE: LRS = lower respiratory symptom.

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PUBLIC POLICY INSTITUTE OF CALIFORNIA
500 Washington Street, Suite 600
San Francisco, California 94111
phone: 415.291.4400
fax: 415.291.4401
www.ppic.org

PPIC SACRAMENTO CENTER
Senator Office Building
1121 L Street, Suite 801
Sacramento, California 95814
phone: 916.440.1120
fax: 916.440.1121