Cutting Greenhouse Gas Emissions Is Only the Beginning: A Literature Review of the Co-Benefits of Reducing Vehicle Miles Traveled

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Introduction

Traditional evaluation of the transportation system focuses on automobile traffic flow and congestion reduction. However, this paradigm is shifting. In an effort to combat global warming and reduce greenhouse gas (GHG) emissions, a number of cities, regions, and states across the United States have begun to deemphasize vehicle delay metrics such as automobile Level of Service (LOS). In their place, policymakers are considering alternative transportation impact metrics that more closely approximate the true environmental impacts of driving. One metric increasingly coming into use is the total amount of driving or Vehicle Miles Traveled (VMT).

Since passing the seminal Global Warming Solutions Act (AB 32) in 2006, California has enacted two major laws over the past decade that are spurring efforts to reduce VMT: Senate Bill 375 (2008) and SB 743 (2013). SB 375 addresses regional GHG emissions reductions from passenger travel. For each region in the State with a metropolitan planning organization (MPO), the law requires the California Air Resources Board (ARB) to set and regularly update per capita GHG emissions reduction targets for 2020 and 2035. To achieve those targets, SB 375 requires each MPO to adopt a "sustainable communities strategy" (SCS) as part of its regional transportation plan. VMT reductions are a key strategy in SCSs.

Senate Bill 743 (2013) directs the Governor's Office of Planning and Research (OPR) to revise the guidelines for determining the significance of transportation impacts during analyses conducted under the California Environmental Quality Act (CEQA). SB 743 requires a replacement metric that will "promote the reduction of greenhouse gas emissions, the development of multimodal transportation networks, and a diversity of land uses." It mandates that "automobile delay, as described solely by [LOS] shall not be considered a significant impact on the environment" under CEQA, except in "locations specifically identified in the guidelines, if any." VMT is OPR's currently recommended replacement metric (OPR, 2016).

While state goals for reducing GHG emissions have been one motivation for the shift to VMT measures, reductions in VMT produce many other potential benefits, referred to as "co-benefits," such as reductions in other air pollutant emissions, water pollution, wildlife mortality, and traffic congestion, as well as improvements in safety and health, and savings in public and private costs. Such benefits may provide additional justification for reducing VMT. In this paper, we review the literature to explore the presence and magnitude of potential co-benefits of reducing VMT, providing California-specific examples where available.

Figure 1 shows the conceptual framework guiding our literature review. Items shaded in green indicate characteristics that can influence VMT. Items shaded in red indicate co-benefits potentially sensitive to VMT.
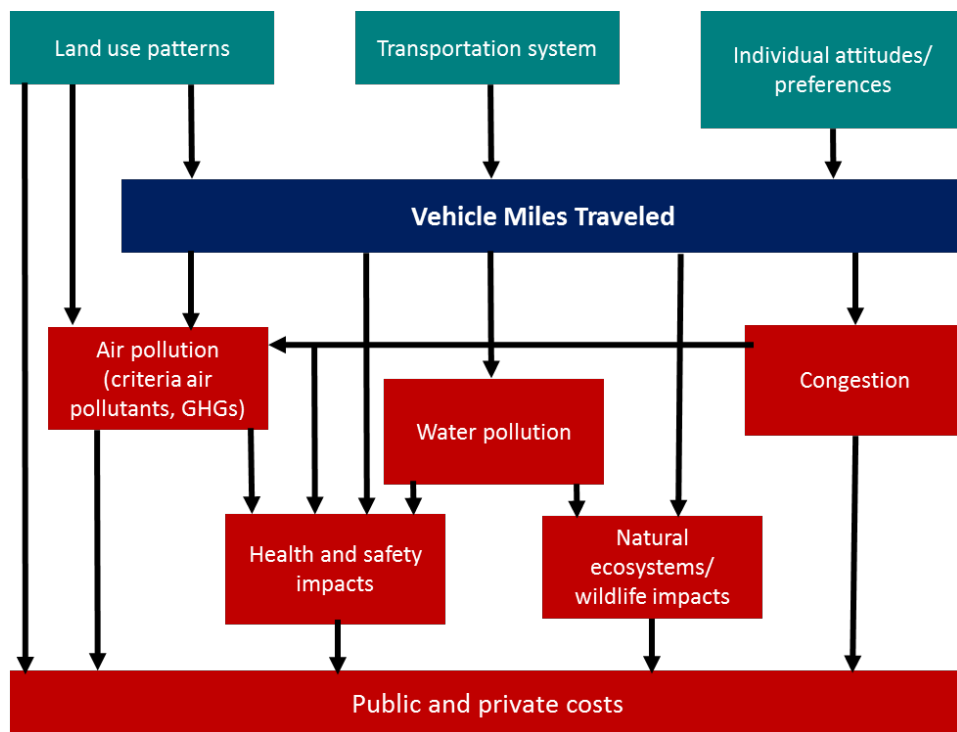
Figure 1. Conceptual Framework

Air Pollutant Emissions

GHG and Criteria Air Pollutant Emissions from Vehicular Operation

Motor vehicles emit pollutants into the atmosphere as by-products of combustion (tailpipe emissions) and through other mechanisms such as fuel evaporation, tire and brake wear, and creation of road dust from the wearing of pavement. Emissions of major concern include greenhouse gases and criteria air pollutants, each of which is a major policy concern in California. Reducing the State's GHG emissions has been state priority for over a decade, as reflected by the aforementioned AB 32, SB 375 and SB 743. Criteria air pollutants are substances for which national and state standards have been set on the basis of human health. California has long standing air quality problems, with large areas of the state unable to attain national ambient air quality standards (NAAQS) for criteria pollutants. Of 52 counties, 39 are in non-attainment for at least one pollutant. Four counties are in non-attainment for five pollutants, and nine counties are in non-attainment for four pollutants.

Transportation is a major source of emissions. Table 1 shows emissions of criteria air pollutants and GHGs from the operation of on-road vehicles in California (not including life-cycle emissions). For criteria air pollutants, operation of on-road vehicles are the source for a majority of carbon monoxide (CO), a near majority of nitrogen oxides (NOx), and a double-digit percent share of particulate matter (PM) 2.5. For greenhouse gases, approximately 33 percent of carbon dioxide equivalent (CO_2e) emissions comes from the operation of on-road vehicles.

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Estimates of vehicles nationwide project that the average passenger vehicle emits approximately 5.5 metric tons of CO_2e per year (US Environmental Protection Agency, 2005). This equates to approximately 1.01 pounds of CO_2e per mile.

Table 1. Criteria air pollutant/greenhouse gas emissions from on-road transportation operations in California and potential emissions reduction[1]

	Emissions (Tons/yr)							
	ROG	CO	NOx	SOx	PM	PM 10	PM 2.5	CO₂e
Total	634,596	2,690,886	768,555	38,354	928,560	532,849	152,574	486,670,304
From on-road transportation*	147,278	1,437,220	373,585	1,964	15,764	28,309	15,721	159,559,517
Share of emissions from road transportation*	23.2%	53.4%	48.6%	5.1%	1.7%	5.3%	10.3%	32.8%
If on-road transportation emissions decreased by…	**Emissions (tons/yr) would decrease by…**							
	ROG	CO	NOx	Sox	PM	PM 10	PM 2.5	CO₂e
1%	1,473	14,372	3,736	20	158	283	157	1,595,595
5%	7,364	71,861	18,679	98	788	1,415	786	7,977,976
10%	14,728	143,722	37,358	196	1,576	2,831	1,572	15,955,952
15%	22,092	215,583	56,038	295	2,365	4,246	2,358	23,933,927
If on-road transportation emissions decreased by…	**Total statewide emissions would drop by…**							
	ROG	CO	Nox	Sox	PM	PM 10	PM 2.5	CO₂e
1%	0.2%	0.5%	0.5%	0.1%	0.0%	0.1%	0.1%	0.3%
5%	1.2%	2.7%	2.4%	0.3%	0.1%	0.3%	0.5%	1.6%
10%	2.3%	5.3%	4.9%	0.5%	0.2%	0.5%	1.0%	3.3%
15%	3.5%	8.0%	7.3%	0.8%	0.3%	0.8%	1.5%	4.9%

*Includes tailpipe and other operational emissions (e.g. evaporation, brake dust, tire wear) from mobile transportation sources. Does not include other transportation-related lifecycle emissions (e.g. vehicle manufacturing, fuel refining)

Table 1 also shows potential mass reductions of pollutants if on-road transportation emissions decreased by modest percentages. There could be reductions of up to millions of tons of reduced CO_2e emissions and up to hundreds of thousands of tons of criteria air pollutant emissions.

State targets for some emissions (e.g. CO_2) require a steep reduction over the coming years and decades. In order to reach those targets, improvements in vehicle efficiency, fuels, and VMT will each need to contribute substantially. If per-capita VMT does not decline, VMT increases (through population growth) would likely preclude achieving GHG reduction goals by outweighing improvements in vehicle efficiency and fuel carbon content (California Air Resources Board, 2016). Thus, while improvements in vehicle efficiency and fuel pollutant content will mean each reduced mile of vehicle travel eliminates less pollution in an absolute

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[1] Criteria air pollutant emissions from California Air Resources Board (2013) – California Almanac of Emissions and Air Quality [2012 data]
CO_2e emissions from California Air Resources Board (2016) – California Greenhouse Gas Inventory [2014 data]

sense, steeply reducing targets mean that, for the foreseeable future, VMT reduction will continue to provide a substantial share of the needed emissions reduction to hit targets. Vehicles which have no tailpipe emissions (e.g. plug-in hybrid and fully electric vehicles) still lead to some air pollutant emissions, through the electricity generation required for charging. Emissions can be substantially less depending on the carbon content of the energy grid (McLaren, et al. 2016). California has a relatively high proportion of energy generated from renewables; however, a substantial (though shrinking) share of electricity used in California is generated from sources that emit GHGs or criteria air pollutants (California Energy Commission, 2016). Thus, reducing even the VMT driven by zero tailpipe emissions vehicles would reduce GHG and local air pollutant emissions.

A potential confounding factor when discussing potential emissions benefits of reduced VMT is travel speed, as emissions of several criteria air pollutants and GHGs are sensitive to travel speed (Transportation Research Board, 1995; Barth and Boriboonsomsin, 2009). In conventional vehicles, powered by internal combustion engines (ICEs), greater per-mile emissions tend to take place at higher speeds (e.g. 60 mph or greater) where more energy is required to move a vehicle, as well as at lower speeds (e.g. less than 30 mph average travel speeds), where the stop-and-go conditions of congestion cause extra acceleration cycles, energy lost to braking, longer vehicle operation time.

The effect of speed is different on hybrid and battery electric vehicles. Nikowitz, et al. (2016) show that unlike ICEs, which have greatest energy use (and in turn emissions) at low and high speeds, hybrid and battery electric vehicles have greatest energy use under high speed and aggressive driving scenarios (see Table 2). Emerging advanced vehicle technologies such as regenerative braking recovers some of the energy lost in stop and go conditions. Electric motors in battery electric and hybrid vehicles shut off when the vehicle is stopped. Similar "start-stop" technology is increasingly common in ICE-powered vehicles. Increased deployment of technology points to a decreased sensitivity of emissions reductions to the speed of VMT in the future.

Table 2. Relative energy consumption for internal combustion, hybrid, and battery electric vehicles under different drive cycle scenarios[2]

		Scenario		
		City driving	Highway driving	Aggressive driving
Test cycle		UDDS	HWFET	US06
Test cycle parameters		19.59 mph average speed, frequent stops and starts	48.3 mph average speed, one start/stop	48.4 mph average speed, some stops, rapid acceleration
Make	Vehicle type	Energy consumption relative to lowest energy consumption		
2012 Ford Focus	Internal Combustion Engine	32% greater	Lowest	37% greater
2010 Toyota Prius	Hybrid	Lowest	4% greater	60% greater
2012 Nissan Leaf	Battery electric	Lowest	19% greater	72% greater

Life Cycle Emissions

Beyond reducing tailpipe emissions, VMT reduction also reduces life cycle emissions, such as those from fuel refining, vehicle manufacture, roadway construction, and roadway maintenance (Chester and Horvath, 2009; Chester and Madanat, 2010, Chehovitz and Galehouse, 2010; Hendriks, et al., 2004). These additional sources increase estimates of GHG emissions from road vehicles by approximately 63 percent over tailpipe emissions alone, and increase estimates of criteria air pollutant emissions from 1.1 to 800 times greater. To the extent that VMT reductions (1) reduce fuel purchases, (2) cause or are the result of decisions of would-be drivers to sell their vehicles or forego purchasing an additional vehicle, or (3) reduce roadway repair burdens, they reduce life-cycle emissions.

Emissions from Building-Related Energy Use

Compact development is a key VMT reduction strategy, as it leads to both shorter trip distances and greater use of alternative modes (Ewing and Cervero, 2010, Transportation Research Board 2009). Stone et al. (2007) estimate that building compact development to reduce VMT would also reduce criteria air pollutant and carbon dioxide emissions at a regional level between five and six percent over a conventional growth scenario, even when accounting for changes in travel speeds.

Compact development can also promote air pollutant and GHG emissions reductions through decreased building energy use. More compact housing units have a smaller volume of air to heat and cool. Additionally, attached housing units have less exposed surface area through which energy is lost. Overall, Ewing and Rong (2008), estimate households living in compact counties use approximately 20 percent energy than households living in sprawling counties, even while taking into account other factors such as income, and the urban heat island effect.

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[2] Drive cycles – US Environmental Protection Agency (2016)
Energy consumption – Adapted from Nikowitz, et al. (2016)

Water Pollution

Motor vehicle travel can cause deposition of pollutants onto roadways, which can then be carried by stormwater runoff into waterways. Fuel, oil, and other liquids used in motor vehicles can leak from vehicles onto the ground (Delucchi, 2000). Brake dust and tire wear can further cause particles to be deposited onto the ground (Thorpe and Harrison, 2008). Brake pads and tire compounds are made out of compounds that include metal. One study estimates that approximately half of all copper in San Francisco Bay could have originated from brake pads (Nixon and Saphores, 2003). In California as a whole, up to 232,000 pounds of copper, 13,280 pounds of lead, and 92,800 pounds of zinc in stormwater are attributable to brake pad dust (Nixon and Saphores, 2003).

Motor vehicles require roadways for travel. Paved roadways are generally impervious surfaces which prevent infiltration of storm water in the ground. Impervious surfaces can increase the rate, volume, speed, and temperature of stormwater runoff (US Environmental Protection Agency, 2003), and can transport pollutants via that runoff into waterways. Wearing down of roadways can further cause particles to be deposited onto the ground (Thorpe and Harrison, 2008).

Most motor vehicles also consume liquid fuel, the storage and handling of which can result in fuel tank leaks and spills (Delucchi, 2000). California has had at least 38,000 confirmed cases of leaks from underground storage tanks (Nixon and Saphores, 2003). Reducing VMT cuts consumption of fuel and could reduce fuel spillage risks. These reductions would be additional to reductions gained through greater vehicle efficiency and adoption of alternative fuel vehicles.

The Victoria Transportation Policy Institute (2015) estimates that motor vehicle-related water pollution from roadway runoff, oil spills, and road salting cost approximately 42 billion dollars per year or 1.4 cents per mile.

Health and Safety

Vehicle Collisions and Fatalities

A plurality of "unintentional injury deaths" (deaths not caused by old age, disease, suicide and homicide) are transportation related (Savage, 2013). According to the National Highway Traffic Safety Administration's Fatality Analysis Reporting System (FARS), 32,675 individuals were killed in motor vehicle crashes in 2014 (NHTSA, 2015). 3,074 of these fatalities occurred in California, 7.9 fatalities per every 100,000 people per year. These fatalities are not just borne by motor vehicle occupants, but by other users as well. In California, more than one quarter of those killed in motor vehicle collisions are pedestrians, bicyclists, or users of other non-motorized modes.

Where there is more driving, there are more vehicle-related fatalities. Comparing motor vehicle fatalities by state from FARS and VMT data from the Bureau of Transportation Statistics (2015) shows a strong positive correlation (r = 0.82) between VMT per capita and fatalities from motor vehicle crashes per capita (authors calculation, see Figure 3).

Data also indicates that each mile driven is also more dangerous in areas with high VMT. Again comparing data from FARS and the BTS, there is a moderately strong positive correlation (r = 0.50) between VMT per capita and deaths per mile traveled (authors calculation, see Figure 4). If the number of vehicle-related fatalities were purely a matter of exposure, every mile traveled should have the same amount of risk regardless of where that mile was driven. There would thus be no correlation between VMT per capita and fatalities per mile. However, states with higher VMT tend to have more motor vehicle crash deaths per mile than lower VMT states. Since increasing VMT is associated with more vehicle-related fatalities per capita and per mile, residents of states where they can fulfill their travel needs with fewer or shorter vehicle trips (and thus with lower VMT) enjoy reduced transportation safety risks.

Using public transit alternatives is associated with less risk than motor vehicle travel. Savage (2013) estimates that drivers or passengers of cars or light trucks experienced 7.28 fatalities per billion miles traveled from 2000-2009. Comparatively, riders of Amtrak, commuter rail, urban mass transit rail systems, buses, and commercial aviation experience 0.43 fatalities per billion miles traveled or fewer.
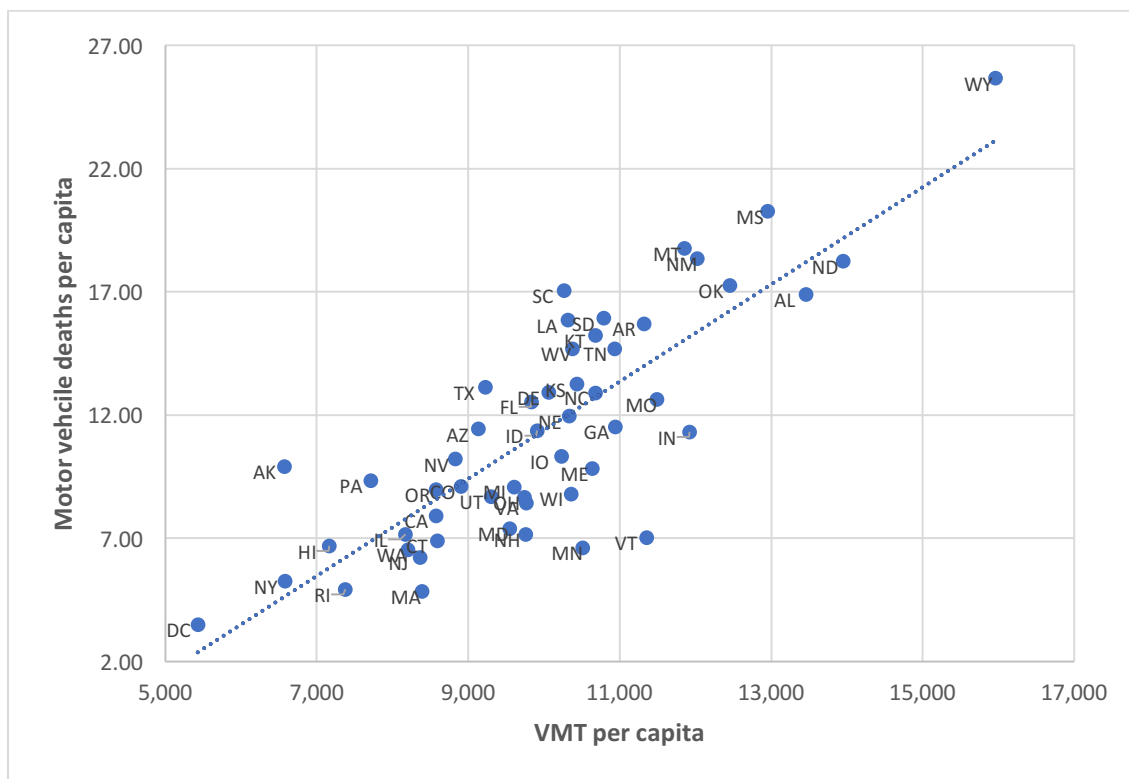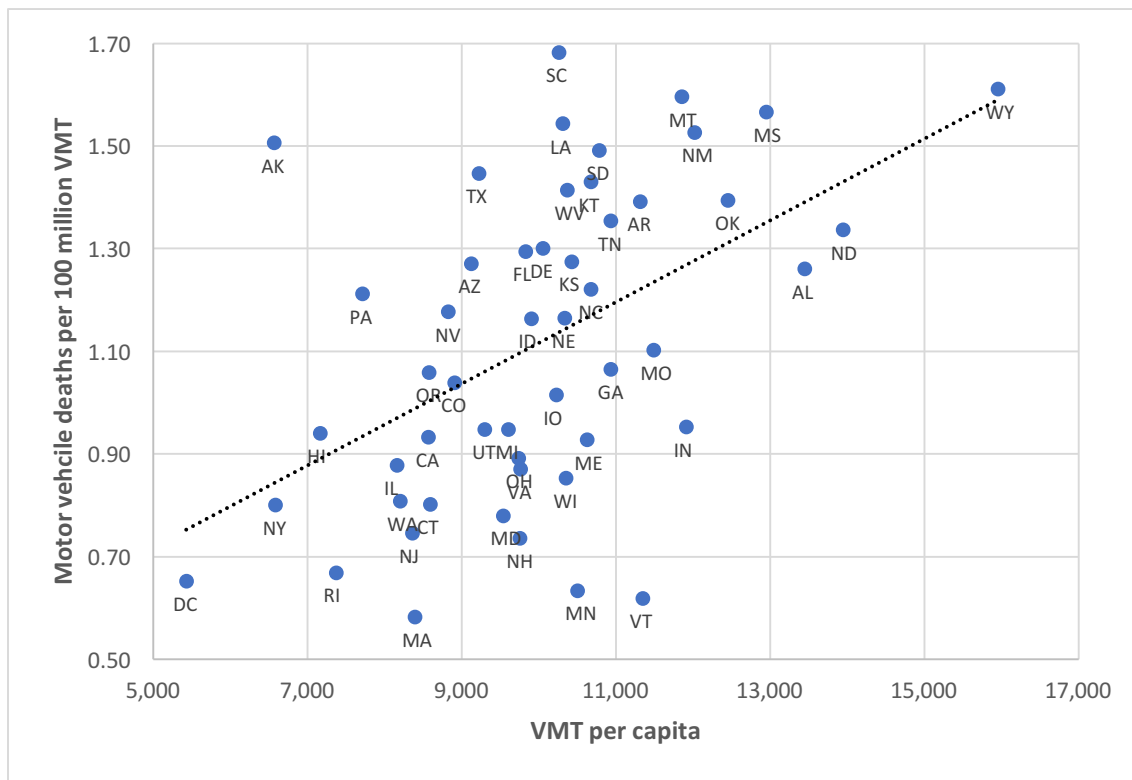

Figure 2. Motor-vehicle related deaths per capita increases as VMT per capita increases

Figure 3. Motor-vehicle related deaths per mile increases as VMT per capita increases

Physical Health

Driving or riding in motor vehicles is a sedentary behavior. Several studies find associations between VMT and weight. For example, obesity and Body Mass Index (BMI) are positively associated with VMT per licensed driver (Jacobson and King, 2009; Behzad, King, and Jacobson, 2012). Geographic areas with high VMT per capita are also associated with poorer health outcomes resulting from reduced physical activity. Residents of counties in the United States with high VMT per capita are less likely to walk for leisure, more likely to be obese, have higher BMI levels, and have a greater prevalence of hypertension (Ewing, et al. 2003). Among California counties, those with the highest mean obesity also tend to have the highest mean VMT per capita (Lopez-Zetina, Lee, and Friis, 2006). Potentially contributing to this pattern are more nights with insufficient sleep and higher smoking rates found with increased driving time (Ding, et al. 2014).

While transit users also ride in motorized vehicles, transit users are more likely to engage in significant physical activity, walking to and from transit stops. Besser and Dannenberg (2012) found that bus and rail users walk an average of 24 minutes per day to and from transit. More than a quarter of transit riders fulfill the US Surgeon General's recommendation of 30 minutes of physical activity per day just from walking to/from stops and stations. On the other hand,

increased time driving is significantly associated with not meeting the physical activity recommendation (Ding, et al. 2014).

Users of non-motorized modes by definition engage in physical activity while traveling. The Caltrans Strategic Management Plan (CSMP) sets a goal of doubling 2010 walking and transit levels, and tripling bicycling levels by 2020. An epidemiological analysis of that CSMP describe that achieving this goal would reduce chronic disease and "would constitute a major public health achievement on par with California's successful efforts at tobacco control." (Maizlish, 2016, p. 5).

Health Impacts of Air Pollution

As discussed previously, road transportation and VMT contribute to air pollutant emissions. Criteria air pollutants can lead to a variety of health effects. For example, nitrogen oxides and volatile organic compounds react with oxygen in the air to create ozone, which can have several negative health effects including chest pain, coughing, throat irritation, airway inflammation, reduced lung function, and aggravation of other respiratory conditions (US Environmental Protection Agency, 2016a). Particulate matter poses particularly acute health impacts as small particulates (less than 10 µm in diameter) can enter the lungs or bloodstream and cause or exacerbate heart and lung issues, and even lead to premature death (US Environmental Protection Agency, 2016b). California has especially poor air quality attainment for both ozone and particulate matter.

Table 3 shows per mile estimates of the cost of motor vehicle-related air pollution by McCubbin and Delucchi (1999). Costs range from several cents per mile for most ozone, carbon monoxide, nitrogen oxides, and air toxics, to more than 12 dollars per mile for particulate matter. The higher estimate for particulate matter reflects the greater health effects, including mortality, that can be triggered by particulate matter.

Table 3. Gasoline-powered motor vehicle air pollution cost per mile[3]

	PM	O_3	CO	NO_2	Air Toxics
Cost (2015 $)	12.60	0.08	0.08	0.65	0.05

*Original data in 1991 dollars. Data above is average of low/high estimate from original study. Costs include emissions from tailpipe, upstream fuel and vehicle production, and road dust.

Mental Health

In addition to physical health, long driving commutes can also have a negative impact on mental health. Hennessy (2008) identifies several examples from studies associating long driving commutes with poor mental health outcomes and related consequences, including stress, negative mood, poor concentration, driver error and traffic collisions. Hennessy also

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[3] Based off McCubbin and Delucchi (1999)

finds that as stress drivers experience while driving increases, workplace hostility and obstructionism rise among men. Other studies corroborate Hennessy's findings. Gee and Takeuchi (2004), for example, find that traffic stress correlates with depressive symptoms. Ding, et al. (2014) find the more total time a person spends driving per day, the more likely they are to report a poor/fair quality of life, high/very high physiological distress, being stressed for time, and that their health interferes with social activities.

In addition to negative mental health outcomes for drivers, VMT can also cause worse mental health for people in the neighborhoods where that driving occurs or originates. A review of literature by Pohanka and Fitzgerald (2004) notes that residents of dispersed, and thus generally auto-dependent, suburban areas can face increased blood pressure, headaches, and social isolation, which is disadvantageous as the presence of social relationships is positively correlated with health. Additionally, the aforementioned depressive symptoms identified by Gee and Takeuchi are significantly worse in neighborhoods with a high "vehicular burden", which increases with motorized transport in an area. Built environments that reduce automobile dependence and promote walking can result in lower rates of dementia (Xia et al., 2013).

Wildlife Impacts

Many of the same roadway impacts that affect the health of people can also affect wildlife. Forman and Alexander (1998) outline several potential ecological impacts of roads. For instance, vehicles can directly harm wildlife in "roadkill" events, with an estimated one million vertebrates killed per day on US roads. Shilling and Waetjen (2016) discuss that in California, 5,950 wildlife-related incidents were reported to the California Highway Patrol from a one-year period between 2015 and 2016. Additionally, about 7,000 reports of animal carcasses are made annually to the volunteer California Roadkill Observation System. Overall, Shilling and Waetjen estimate that reported and unreported animal-vehicle collisions cost California approximately $225 million per year. Due to varying avoidance of roadways, impacts differ by species types. Amphibians and reptiles are especially at risk on narrow, low-traffic roads, larger mammals are at risk on narrow, high-speed roads, and birds and small mammals at risk on wide, high-speed roads, Forman and Alexander (1998).

Roadway avoidance is itself an impact, with lower populations of species adjacent to roadways Forman and Alexander (1998). Species can be affected and deterred by characteristics such as road noise, air pollution, altered or polluted water runoff, and nighttime lighting. Roadway avoidance tends to be higher adjacent to higher speed and higher traffic roads. Due to the impacts of roadkill and road avoidance, roadways also act as barriers for species movement. Roadways cutting through habitat can isolate populations of species into smaller groups. Isolated populations have a higher risk for extinction and can have negative impacts on genetic diversity (Coffin, 2007; Holderegger and DiGiulio, 2010).

More compact development patterns that are associated with lower VMT would consume less land and conceivably subject less territory to road avoidance and potential habitat fragmentation. A comparison of various development scenarios across the Sacramento and San Francisco Bay Areas predicted that the most compact growth scenario would save nearly 50 percent of agriculturally sensitive land acreage and steep-sloped areas, and close to 100 percent of wetland areas (Landis, 1995).

Congestion and Accessibility

Broadly, congestion occurs when the free-flow capacity of a roadway is either exceeded by demand (e.g. freeways entering central business districts during peak-hour commutes) or impeded (e.g. when there are auto accidents, roadwork or other road closures). In either case, congestion increases as more vehicle travel is loaded onto the roadway (Falcocchio and Levinson, 2015; Downs, 2004). Conversely, reducing total VMT in a region can reduce congestion on the regional road network, albeit subject to temporal and spatial caveats.

From a temporal standpoint, unless there is an explicit cost imposed on using congested roadways (e.g. a congestion charge) or driving passenger vehicles in general, congestion reductions on those roadways will commonly increase the demand for using them and ultimately cause congestion to rebound to near-preexisting levels in the long-term. This is called the "Principle of Triple Convergence" – some trip makers in the region change their travel locations (routes), times and/or modes to take advantage of the reduced congestion on the roadways in question (Downs, 2004). This "triple convergence" is the reason why roadway expansions often do not reduce congestion in the long-term (Handy and Boarnet, 2014), and why, according to Downs (2004, p. 22]), "building light rail systems or subways rarely reduces peak-hour traffic congestion."

However, recent research indicates that transit may cause a more sizeable and enduring reduction in peak-hour congestion than previously thought. Anderson (2014) used a choice model, calibrated using data from the Los Angeles metro area, that unlike most previous studies accounted for the heterogeneity in congestion levels on roadways in the region, which increased the predicted congestion-reducing effects of transit by six times. As Anderson (2014, p. 2764) explains, since "drivers on heavily congested roads have a much higher marginal impact on congestion than drivers on the average road," and since transit riders are often those who would have to drive on "the most congested roads at the most congested times," transit has a "large impact on reducing traffic congestion."

Spatially, VMT reductions alleviate congestion in the specific locations where net vehicle travel is curtailed. And even where urban (or suburban) densification increases net localized vehicle travel and congestion despite reducing per capita (or even net regional) VMT, it generally increases local *accessibility* to jobs and other desired destinations, decreasing the time and cost of reaching those destinations. In a study of congestion and accessibility in the Los Angeles

region, Mondschein et al. (2015, p. v) found that "high-density areas in the region provide better access to jobs than those areas where traffic conditions are relatively less congested." Similarly, for Los Angeles firms, they found that "physical proximity to other firms, rather than area congestion levels, is the primary component of firms' ability to access other similar firms" (Mondschein et al., 2015, p. viii).

In sum, increasing regional VMT, all else equal, will increase regional congestion. And conversely, reducing regional VMT can reduce regional congestion, though congestion levels may rebound somewhat in the long-term. Even where VMT-reducing densification increases local congestion, it tends to improve local accessibility.

Fiscal Matters

Reducing VMT also has major fiscal impacts. It has both direct and indirect impacts on both household and public costs. VMT can also have major impacts on governmental revenues.

Household Costs – Direct Impacts

American households pay more for transportation than any other category of household expenditures except housing (Haas et al., 2013). According to Bureau of Labor Statistics data, households spent nearly 20 percent of their income on transportation on average in both 2000 (18%) and 2010 (16%) (Moeckel, 2017; Haas et al., 2013). A major reason for that is auto ownership and use are expensive – "the most expensive component of transportation cost is auto ownership" – and many U.S. households live in suburban and exurban areas with poor accessibility and transit connectivity (Haas et al., 2013, 20). Reducing household VMT (and car ownership) can thus reduce total household costs both directly and indirectly.

The direct cost reductions of driving less are well known, and include reduced fuel use and parking costs, lower maintenance costs averaged over time, and, for those households that reduce their VMT enough to sell one of their vehicles, license, registration, insurance, and additional maintenance cost savings (Levinson and Gillen, 1998; Cui and Levinson, 2016). The cost of alternatives to driving vary greatly by location, alternative, value of time, and other factors Active transportation options like walking and bicycling can be much cheaper for shorter trips than driving because they have lower capital and operating costs (e.g. the cost of walking shoes or a bicycle versus the cost of a vehicle and gasoline). And transit (e.g. buses and commuter rail) can be cheaper than driving for longer trips. Keeler et al. (1975), for example, estimated the comparative costs of a hypothetical commute in the San Francisco Bay Area by driving (1.5 passengers per auto), riding Bay Area Rapid Transit (BART), and riding a bus. They concluded that both bus and rail transit can be cheaper for the user on an average basis than driving at sufficiently high passenger densities. However, the potential for a given household to reduce its transportation costs by reducing VMT largely depends on availability of sufficient regional transit connectivity, accessibility to jobs and other amenities (Haas et al., 2013; Haas et al., 2008; Renne and Ewing, 2013).

Household Costs – Indirect Impacts

As is frequently discussed in both the academic literature and California policy circles, one way to reduce VMT – and achieve the associated household cost savings – is to increase residential and employment densities within existing urban areas, and especially near transit stations (Ewing and Cervero, 2010). For residences, a benefit of this type of "smart growth" is that it can substantially reduce household costs, particularly transportation costs. Haas et al. (2008), for example, developed a model for estimating average household transportation costs by Census block based on annual household VMT, household car ownership and annual household transit use. They tested their model in the Minneapolis-St. Paul metropolitan region and found that reductions in average annual household transportation costs correlated with decreasing VMT, decreasing auto ownership, increasing transit trips and denser, more transit- and job-accessible areas. From that original model, the Center for Neighborhood Technology (CNT) developed the Housing + Transportation Index. CNT has since expanded and refined the model, but its results continue to show that residential density is the single largest predictor of auto ownership and use, and thus household transportation costs (Haas et al., 2013).

Households in denser and more accessible urban areas often also demand less energy and water because they have smaller units and lots (Litman, 2016; Busch et al., 2015). When all the cost savings of living in denser urban areas are combined, the available evidence shows that they "more than offset" the increased housing costs in those areas (Litman, 2016, p. 19; Ewing and Hamidi, 2014). In other words, when all costs are considered, rather than just housing costs, living in smart growth communities is generally less expensive than living elsewhere.

With specific respect to California, one recent study estimated that if 85 percent of new housing and jobs added in the state until 2030 were located within existing urban boundaries, it would reduce per capita VMT by about 12 percent below 2014 levels (Busch et al., 2015). That combination of reduced VMT and more compact development would, in turn, result in an estimated $250 billion in household cost savings cumulative to 2030 (with an average annual savings per household in 2030 of $2,000) (Busch et al., 2015). Household costs analyzed in the study include auto fuel, ownership and maintenance costs, as well as residential energy and water costs.

Public Costs – Indirect Impacts

In addition, denser development usually reduces the per capita costs of providing many types of public infrastructure and services. Denser development can, among other things, reduce road and utility line lengths, and in turn reduce travel distances needed to provide public services like police, garbage collection, emergency response and transporting school children (Litman, 2016; Busch et al., 2015; Burchell and Mukherji, 2003). Indeed, in his review of the literature, Litman (2016) found that "[n]o credible, peer-reviewed studies demonstrate that comprehensive Smart Growth policies fail to significantly reduce public infrastructure and service costs."

With specific respect to California, the recent Busch et al. (2015) study estimated that if 85 percent of new housing and jobs added in the state through 2030 were located within existing urban boundaries, it would result in $8.2 billion in avoided public health costs and $18.5 billion in infrastructure cost savings cumulative to 2030 (Busch et al., 2015). Public health costs considered include those related to passenger vehicle air pollutant emissions, such as respiratory-related ER visits, mortality, etc. Infrastructure costs estimated include "one-time capital costs for building local roads, water and sewer infrastructure; and ongoing annual operations and maintenance costs" (Busch et al., 2015). All cost savings estimates are in 2015 dollars.

Government Revenues – Direct Impacts

VMT reduction can reduce public revenues from volumetric gas taxes or VMT fees, if those fees are held constant per gallon or mile. As VMT declines, so does the volume of gas consumed or miles tolled, and, correspondingly, the amount of revenue received. However, decreases in gas tax or potential future VMT tax revenue could be made up by increasing the tax rates. And as between volumetric gas taxes and VMT-based taxes, revenue stability would likely be more easily achieved with a VMT-based fee, given the rapidly advancing shift to electric and more fuel-efficient vehicles that are reducing liquid fuel consumption (National Highway Traffic Safety Administration, 2014; California Energy Commission, 2016). That is one reason states including California have been studying VMT fees (California Department of Transportation, 2016). A VMT fee would also be one of the "most effective way[s] to change behavior" to reduce VMT (Chapple, 2015). However, fees, like taxes, are commonly politically unpopular, even those with immense social benefit (Bedsworth et al., 2011).

Government Revenues – Indirect Impacts

As with household and governmental costs, VMT-reducing "smart growth" land use patterns also impact governmental revenues. Litman (2016) surveyed the literature and found that "Smart Growth tends to increase economic development, including productivity, business activity, property values and tax revenue." For example, the Chicago Metropolitan Agency for Planning (CMAP) (2014) concluded, based on a comparison of Chicago-area residential project case studies, that "denser projects drive higher revenues." Per capita gross domestic product (GDP) also tends to decline with rising VMT and increase with per capita transit ridership, which in turn can increase tax revenues (Kooshian and Winkelman, 2011).

Most studies look primarily at either the cost impacts or the revenue impacts of smart growth and reducing VMT, not both. But in two recent studies of Madison, Wisconsin and West Des Moines, Iowa, respectively, Smart Growth America (SGA) did a more comprehensive fiscal impact analysis (SGA, 2015a, 2015b). In the studies, SGA calculated both costs and revenues – the net fiscal impact – to the cities and their associated school districts across a range of high- and low-development density scenarios.

The West Des Moines study assessed the fiscal impact of the estimated residential and commercial growth in the city over 20 years using four different density scenarios (holding the

product mix constant), and estimated that the net fiscal benefit for the city and the local school district would be 50 percent greater for the most compact development scenario as compared to the base density scenario (current West Des Moines density) (SGA, 2015a).

The Madison study was narrower in scope. It analyzed the fiscal impact of developing a 1,400-acre site across a range of development densities and product mixes. Comparing the baseline density and product mix scenario to the more compact development scenario with the same product mix, the study estimated that the latter – compact development – would have a slightly greater (about 5 percent) net fiscal benefit. However, the authors also concluded that their model likely underestimated the net fiscal benefit of the more compact scenario (SGA, 2015b).

Conclusion

Reducing VMT can provide many additional benefits beyond reducing GHG emissions. Studies show a broad array of co-benefits including environmental, human, and fiscal health. VMT reductions can provide these co-benefits directly (e.g. lowering air pollutant emissions and operating costs of vehicles with reduced use) and indirectly (e.g. realizing the benefits of alternatives to driving). As noted, there are some variations in the depth of these benefits (e.g. spatial differences in impacts, and impacts dependent on other factors in addition to VMT), but the evidence is clear that, overall, VMT reductions can help forward multiple goals in addition to GHG reduction. Additional research measuring costs and benefits of transportation on a per distance traveled basis, which was not yet available for all impacts reviewed in this paper, would be helpful in further ascertaining the depth and breadth of potential co-benefits of VMT reductions.

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