Costs of Automobile Air Emissions in U.S. Metropolitan Areas

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Automobile air emissions are a well-recognized problem and have been subject to considerable regulation. An increasing concern for greenhouse gas emissions draws additional considerations to the externalities of personal vehicle travel. This paper provides estimates of the costs for automobile air emissions for 86 U.S. metropolitan areas based on county-specific external air emission morbidity, mortality, and environmental costs. Total air emission costs in the urban areas are estimated to be $145 million/day, with Los Angeles, California, and New York City (each $23 million per day) having the highest totals. These external costs average $0.64 per day per person and $0.03 per vehicle mile traveled. Total air emission cost solely due to traffic congestion for the same 86 U.S. metropolitan areas was also estimated to be $24 million per day. These estimates are compared with others in the literature and are found to be generally consistent. These external automobile air emission costs are important for social benefit and cost assessment of transportation measures to reduce vehicle use. However, this study does not include any abatement costs associated with automobile emission controls or government investments to reduce emissions such as traffic signal setting.

The modern U.S. urban transportation system has been a resounding success in providing mobility to residents and businesses (*1*, *2*). Nonetheless, there are continuing concerns for secondary effects including accidents, air emissions, congestion, lack of physical exercise, mobility for those without motor vehicles, noise, petroleum dependence, and urban sprawl (*3–7*). Previous work has estimated the costs of some of these externalities, notably congestion and accidents (*8*, *9*). This paper provides estimates of the external costs of air pollutant emissions from personal motor vehicles in 86 major U.S. metropolitan areas, both in total for all urban travel and for the specific air emission costs due to congestion. Quantifying these external costs can allow society to better understand the total costs of driving. In addition, identifying the external costs associated with congestion can lead to a better understanding of the total benefits that result from congestion management strategies.

Urban air pollution from private vehicles has been declining since the 1970s (*10–12*) even as the number of vehicles and vehicle miles traveled (VMT) in the United States have been increasing (*13*). These reductions in overall and per-VMT criteria air emissions have resulted from the introduction of emission regulations and the resulting implementation of exhaust controls. In 2009, for example, only one county in the United States (Clark County, Nevada) had carbon monoxide levels exceeding the National Ambient Air Quality Standard (*14*), a significant improvement from 1995 when 42 areas exceeded the 8-h standard (*15*). At the same time, however, carbon dioxide emissions from private vehicles have been increasing. Motor vehicle fuel economy, which determines carbon dioxide emissions, has not had major improvements, and emissions regulation has not, until recently, targeted carbon dioxide (CO_2) (*16*). In 2007, the transportation sector accounted for approximately 33% of total carbon dioxide emissions from fossil fuel combustion in the United States, of which about 60% resulted from gasoline consumption by personal vehicles (*17*). Total CO_2 emissions are also increasing more quickly than other sources of emissions, increasing 29% from 1990 to 2007.

Because of the extensive U.S. effort for emission controls on motor vehicles from the 1970s onwards, external air emission costs are small compared with the overall cost of motor vehicle use, including ownership, fuel, insurance, and depreciation. For example, in 2007 dollars, the National Research Council (NRC) estimated that external health effects for criteria air emissions [including sulfur oxides (SO_x), oxides of nitrogen (NO_x), carbon monoxide (CO), particulate matter (PM), volatile organic compounds (VOC), and ammonia (NH_3)] cost 1.3 to 1.4 cents per VMT for automobiles using gasoline (and 10% ethanol RFG E10) (*14*). Other vehicle fuels had similarly low external costs, ranging from 1.1 to 1.2 cents per VMT for compressed natural gas to 1.5 to 1.6 cents per VMT for hybrid-electric vehicles. For 2007, the American Automobile Association (AAA) estimated that the average cost of automobile driving was 52.2 cents per VMT (*18*). A comparison of the NRC and AAA findings indicates that pollution costs are roughly 2.5% of the direct out-of-pocket cost of driving.

Yet while the costs of external air emissions are small relative to the overall cost of driving, the total external costs imposed on society are substantial. In 2007, 3 trillion VMT (*19*) multiplied by the NRC (*14*) average external cost of 1.3 cents per VMT results in an estimated overall external cost of $40 billion, and this does not include the costs of greenhouse gas emissions. Measures to reduce this social cost might include congestion management measures, public transit incentives, carpooling incentives, hybrid and plug-in hybrid vehicles, and shifting to nonmotorized modes of travel.

Costs of congestion exceed these air emission external costs. The Texas Transportation Institute (TTI) estimates that the cost of congestion was $87.2 billion in 2007, causing urban Americans to travel 4.2 billion hours more and to purchase an extra 2.8 billion gallons of

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fuel (*8*). While literature such as the TTI *2009 Urban Mobility Report* evaluates costs of congestion in U.S. urban areas, urban pollution costs associated with driving and traffic congestion are not reported. The much-cited TTI report focuses mostly on time and fuel costs and could benefit from the inclusion of estimates of pollution costs such as derived here.

In this paper, the external air pollution costs of driving are estimated for 86 metropolitan areas utilizing air pollution valuation data (*20*). These cities were chosen from the data reported by the TTI for 90 metropolitan areas (*8*). Four areas from the TTI list of 90 urban areas were excluded because of lack of air pollution valuation data. In addition to the valuation of criteria air pollutants, carbon dioxide costs from existing literature on the social cost of carbon are included. Finally, an estimate of the proportion of this external cost that is due to congestion is given.

EXISTING TRANSPORTATION EXTERNAL COST ASSESSMENTS

The external costs of air emissions have been evaluated and the majority of the literature focuses on the United States and Europe. However, no study to date has performed a cross-urban comparison for a country to illustrate how costs can change from dynamics in vehicle travel to congestion effects. Several studies have quantified the economic costs associated with mortality, morbidity, and environmental impacts, among other external cost components. Small and Kazimi (*21*) evaluate the regional air pollution costs for Los Angeles, California, considering three main categories: mortality from particulates, morbidity from particulates, and morbidity from ozone. In this region, Small and Kazimi (*21*) evaluate several cost accounting frameworks and produce a baseline estimate of 2.05 cents (1992) per vehicle kilometers traveled (VKT). Mayeres et al. (*22*) develop external urban transportation costs for air pollution in addition to accidents and noise. For Brussels, Belgium, Mayeres et al. (*22*) estimate air pollution costs at 21 to 29 mECU (1990) per VKT (an ECU is a European currency unit that was replaced by the euro in 2001) for gasoline cars and 15 to 30 mECU (1990) per VKT for diesel cars. The study goes on to develop marginal congestion cost estimates under the concept that time is lost when an additional vehicle on the road reduces the speed to other road users. Air emissions external costs of 0.02, 0.04, 0.36, and 0.30 £ (1993) per VKT for diesel cars, light goods vehicles, buses and coaches, and heavy goods vehicles are developed by Maddison et al. (*23*) for the United Kingdom. Maddison et al. (*23*) also consider congestion externalities through lost time evaluation to road users. Focusing on particulate and ozone pollution's contribution to mortality and chronic illnesses, McCubbin and Delucchi (*24*) develop air pollution–related costs for light and heavy gasoline and diesel vehicles in the United States. Additionally, Sen et al. (*25*) develop external air pollution cost estimates for Delhi, India, at 0.28 to 0.31 Rs per VKT (Rs is Indian rupees) for gasoline cars and 1.03 to 2.74 Rs per VKT for diesel cars. Some of these studies also develop total cost estimates for their region, similar to TTI (*8*), which reports external economic impacts in the United States from congestion. While existing air pollution cost studies are sparse and often rolled up into more comprehensive externality assessments (including components such as noise, accidents, and value of time), several existing studies provide new methodological approaches for improving cost estimates.

Two recent studies quantify air pollution costs by evaluating high-resolution geographic-specific external cost data and improved emissions profiles that account for variations in speed and congestion effects. By combining U.S. county-level air pollution costs (*20*) and vehicle travel, NRC (*14*) develop external cost estimates for passenger and freight modes for more than 3,000 U.S. counties. These costs range from 1.33 to 1.8 cents (2007) per VMT for light-duty automobiles to 3.23 to 10.41 cents (2007) per VMT for heavy-duty vehicles. Evaluating the San Francisco, California; Chicago, Illinois; and New York City regions, Chester et al. (*12*) combine vehicle emission profiles that are dependent on speed and age with travel surveys to evaluate costs. Across the three cities and considering only private transit, the costs range from 0.5 to 64 cents (2008) per vehicle trip and are further disaggregated by off-peak and peak times as well as passenger loading. In their assessment, Chester et al. (*12*) include indirect and supply chain life-cycle effects that can have larger impacts than emission from operating the vehicle. The following section compares this study and these past studies with a conversion of all costs to 2008 cents per VMT.

METHOD FOR ESTIMATING EXTERNAL AIR EMISSIONS COSTS

The external air emissions costs are estimated here from national vehicle emission factors, metropolitan-specific travel data, and metropolitan-specific external unit cost damage factors. Vehicle per mile emission factors are used to build regional emissions inventories in both uncongested and congested scenarios using travel data. These regional inventories are then joined with unit external cost damage factors for specific metropolitan areas to determine total damage costs. CO_2, SO_x, NO_x, $PM_{2.5}$, NH_3, and CO emissions are considered in this study because of the availability of pollution valuation data.

Vehicle emission factors were determined with the U.S. Environmental Protection Agency's MOBILE6.2 (MOBILE6) software (*26*). MOBILE6 uses vehicle operation and fuel parameters to determine emissions from fuel combustion, evaporative losses, brake wear, and tire wear. The software evaluates the range of on-road vehicles including light- and heavy-duty cars and trucks, motorcycles, and buses. For this study, 2007 fleet light-duty gasoline vehicles were included to match with the most recent TTI (*8*) data year. Iterative runs were created in MOBILE6 to evaluate 1-mph incremental speed changes, allowing an estimation of how emissions change when average speed changes due to congestion. All runs were configured with freeway conditions in July and a Reid vapor pressure of 8.7 psi. The resulting output was a grams per mile emission factor for each vehicle and pollutant at each mile per hour increment.

MOBILE6 has several weaknesses relevant to the goals of this paper, including failing to account for speed-specific fuel economy, emissions of sulfur dioxide (SO_2), $PM_{2.5}$, and NH_3, or driving cycles specific to each metropolitan area. To capture the variation of fuel economy and CO_2 emissions with speed, the relationships developed by Ross (*27*) were employed. The amount of fuel consumed by a vehicle and the resulting CO_2 emissions are the result of the power needed to overcome tire rolling resistance, air drag, vehicle acceleration, hill climbing, and vehicle accessory loads (*27*). These factors in combination produce a fuel energy-to-speed profile that is used to adjust the MOBILE6 fuel economy and CO_2 emission baseline factors to develop speed-specific factors (*12, 27*).

To convert the estimated air emissions to cost, the air pollution emission experiments and policy (APEEP) analysis model was utilized. APEEP is designed to calculate the marginal human health and environmental damages corresponding to emissions of $PM_{2.5}$, VOC, NO_x, NH_3, and SO_2 on a dollar-per-ton basis (*14, 20*). The APEEP model evaluates emissions in each U.S. county with their exposure, physical effects, and the resulting monetary damages. APEEP evaluates emissions at different release heights and the ground-level subset is used to evaluate vehicle effects. For each county and each pollutant, APEEP estimates mortality, morbidity, and environmental (e.g., crop loss, timber loss, materials depreciation, visibility, forest recreation) damages. APEEP factors for a value of statistical life of $6 million are used for this paper. Population weighted average APEEP factors are determined for each urban region analyzed in this study.

The cost of CO, not provided by APEEP, was assumed to be $0.70/kg (*6*). This value was regionally scaled for each urban area analyzed with the ratios for NO_x observed in the APEEP data, since both pollutants were predominantly tropospheric ozone precursors. CO_2 costs are based on a literature survey performed by NRC in 2010 (*14*). A summary of CO_2 equivalent units costs from roughly 50 studies shows a median cost of $10/ton, mean cost of $30/ton, and 5th and 95th percentile costs of $1 and $85/ton (*14*). The mean $30/ton cost is implemented for vehicle CO_2 emissions here.

Vehicle emission factors were increased by 4.9% annually for CO, 1.4% for NO_x, 4.5% for $PM_{2.5}$, and 5.9% for VOCs to capture the effects of fleet age and improving emissions trends due to more stringent emissions standards and improved fuel programs (*12*). The average vehicle age is assumed to be 5 years (*28*).

The above calculated emission factors and costs were then applied to the 2007 TTI mobility data (*8*) for 86 urban areas. As previously discussed, four urban areas in TTI (*8*) were discarded because of lack of valuation data in the APEEP model. Volume and speed (congestion and free flow) data utilized in the TTI report were all collected from freeway operation centers in various urban areas. TTI provides the percentage of miles traveled in each urban area during peak times and nonpeak times. For nonpeak miles, free-flow speeds of 60 and 35 mph for freeways and arterials, respectively, were used in this analysis. For peak times, TTI provides the percentage of travel that is congested and an average congested speed. Rather than unrealistically assuming constant speed under congested conditions, it was assumed that some percentage of vehicles operating during congested peak times drove at a stop-and-go speed of 5 mph and the remaining vehicles drove close to free-flow speeds (free-flow speed less 1 mph). The percentages were estimated so that the weighted average speed matched the congested speed given by TTI. For noncongested peak travel, free-flow speeds prevailed.

RESULTS FOR EXTERNAL AIR EMISSIONS COSTS

The total external air emissions costs of light-duty vehicle travel for the 86 urban areas used in this analysis is estimated to be $145 million per day in 2007 U.S. dollars. This averages to around 1.7 million dollars per day per urban area. Normalizing the results by population and VMT, the external cost of driving is $0.64 per person per day or $0.03/VMT. These estimates are higher than the national average of 1.3 cents per VMT in NRC (*14*) because only urban areas are considered and a cost for carbon dioxide emissions is included. Table 1 shows a subset of the urban areas with the top 10 external costs (due to a combination of large populations and high external cost factors). The complete list of the external air emissions costs is available from the authors.

Los Angeles and New York have the largest population among the 86 urban areas and their total external emissions cost, each around $23 million per day, are roughly twice as large as the next largest cost area (Chicago, $10 million per day). After Chicago, another halving occurs to Philadelphia, Pennsylvania; Washington, D.C.; San Francisco; and so on. The largest driver for having large external costs is clearly population, as 8 of the top 10 most populous metropolitan statistical areas (MSAs) are represented in the top external cost list—only Miami, Florida, and Boston, Massachusetts, MSAs are not and they represent the 12th and 13th rank on external costs. The variation in dollars per VMT is also related to the size of the population exposed to air emissions, but the variation is less than for total external costs per day because the larger cities have higher VMT. A look at the normalized data shows a wide variation between the top three areas—Los Angeles, New York, and Chicago—and the others, though some other areas have high per capita (Washington,

TABLE 1 External Air Emissions Costs of Driving, Population, per Capita Vehicle Miles Traveled, and Percentage of Peak Travel That Is Congested for Top 10 Urban Areas

Urban Area (States)	U.S. Million $/Day	$/Day/Person	$/VMT	U.S. Population	VMT/Person	% Peak Travel Congested
Los Angeles–Long Beach–Santa Ana (Calif.)	23	1.8	0.086	12,800,000	21	86
New York–Newark (N.Y., N.J., Conn.)	23	1.3	0.10	18,225,000	12	69
Chicago (Ill., Ind.)	10	1.2	0.10	8,440,000	12	79
Philadelphia (Pa., N.J., Del., Md.)	4.9	0.9	0.058	5,310,000	16	63
Washington, D.C. (Va., Md.)	4.6	1.1	0.057	4,330,000	19	81
San Francisco–Oakland (Calif.)	4.5	1.0	0.056	4,480,000	18	82
Atlanta (Ga.)	4.3	1.0	0.046	4,440,000	21	75
Dallas–Fort Worth–Arlington (Tex.)	4.2	0.95	0.042	4,445,000	23	66
Detroit (Mich.)	3.9	1.0	0.045	4,050,000	21	71
Houston (Tex.)	3.9	1.0	0.043	3,815,000	24	73
Total[a]	145			158,355,000		
Average[a]	1.7	0.64	0.034	1,841,000	19	48
Maximum[a]	23.0	1.8	0.10	18,225,000	30	86
Minimum[a]	0.038	0.18	0.013	145,000	10	8.0

[a] Values are for all 86 urban areas.

D.C.) or per VMT (Philadelphia) costs. The differences between normalized values are attributable to density and the APEEP factors, which evaluate pollutant transport, chemistry, and impact on nearby populations (*20*).

The $145 million total external emissions cost of driving and congestion is disaggregated by pollutant for all 86 urban areas (in million dollars per day) as follows: CO_2, 32; NO_x, 7.6; VOC, 39; CO, 31; SO_x, 0.65; PM, 3.4; and NH_3, 31.

Carbon dioxide emissions valued at $30/metric ton are comparable in external costs to VOC, CO, and NH_3 costs, while three other pollutants (nitrogen oxides, sulfur dioxide, and particulates) have lower magnitudes. Figures 1 and 2 illustrate the total external air emissions costs of driving and cost per VMT for each urban area.

With all 86 regions, some explanatory variables were explored for potential causation, such as per kilogram cost factors for emissions, population density, VMT per capita, and percent of peak travel that is congested. The strongest correlations between per capita external costs were found to be the average damage factor for emissions ($r = 0.76$), percent of peak travel congested ($r = 0.54$), and per capita VMT ($r = 0.30$).

COMPARISON OF RESULTS FOR EXTERNAL AIR EMISSIONS COSTS

The existing literature provides an opportunity to externally compare and validate results. The cost estimates in the literature typically focus on light-duty vehicles and subsets of criteria air pollutants (some studies include greenhouse gases). Relevant existing reported costs are shown in Table 2 and normalized to cents (2008) per VMT.

The variation in estimates in the literature can be the result of many factors. The differing temporal and geographic boundaries imply varying vehicle emissions profiles. The vehicle fleet sets evaluated can also change emission profiles. Most studies acknowledge the uncertainty in estimating mortality and morbidity costs, including the effects of using different values of statistical life. The air pollutant damages considered across the studies are also inconsistent. Some studies include human health impacts only, while others capture climate, vegetation, visibility, material, and aquatic damages as well. The studies also differ in which air pollutants are included, with studies including more pollutants resulting in larger external cost estimates. For example, NRC (*14*) had an estimate of external costs of 1.4 to 1.8 cents (2008) per VMT while this study estimated an average of 3.4 cents (2008) per VMT including 1 cent per VMT for CO_2 which was omitted in the NRC study. With the exclusion of life-cycle components, Chester et al. (*12*), in evaluating the same pollutants (with the exception of NH_3), reports 2.7 to 3.5 cents (2008) per VMT, very close to this study. While these factors lead to an inconsistency in external cost comparisons, the literature results produce a range of 5.1 □4 cents (2008) per VMT. This range is consistent with the results of this study at 1.15 to 10.28 cents (2008) per VMT for different urban areas.

ESTIMATION OF EXTERNAL AIR EMISSIONS COSTS DUE TO CONGESTION

With disaggregated congestion costs from total costs, external cost estimates associated with low-speed and higher per VMT emissions were assessed. To calculate this cost, the authors started by using a

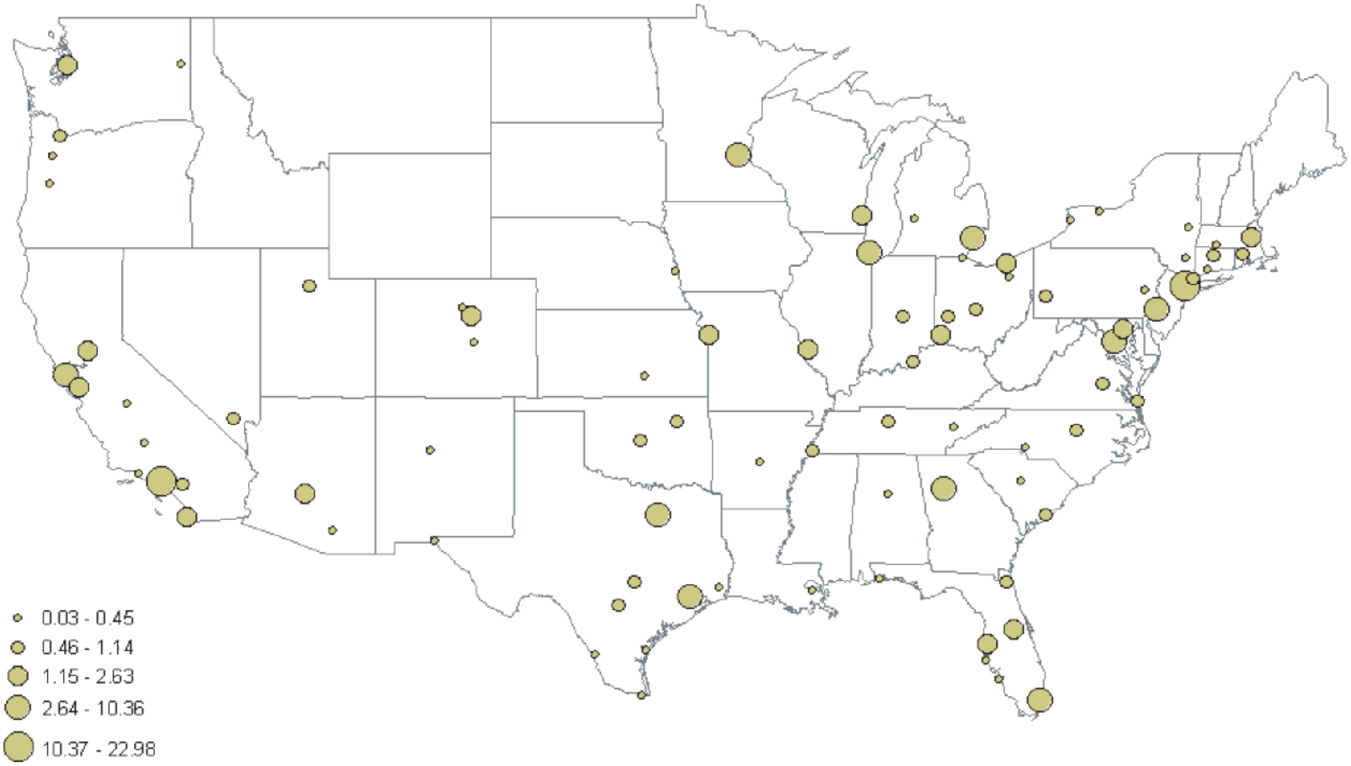

FIGURE 1 Total external air emissions cost of driving for each urban area (million US$/day).

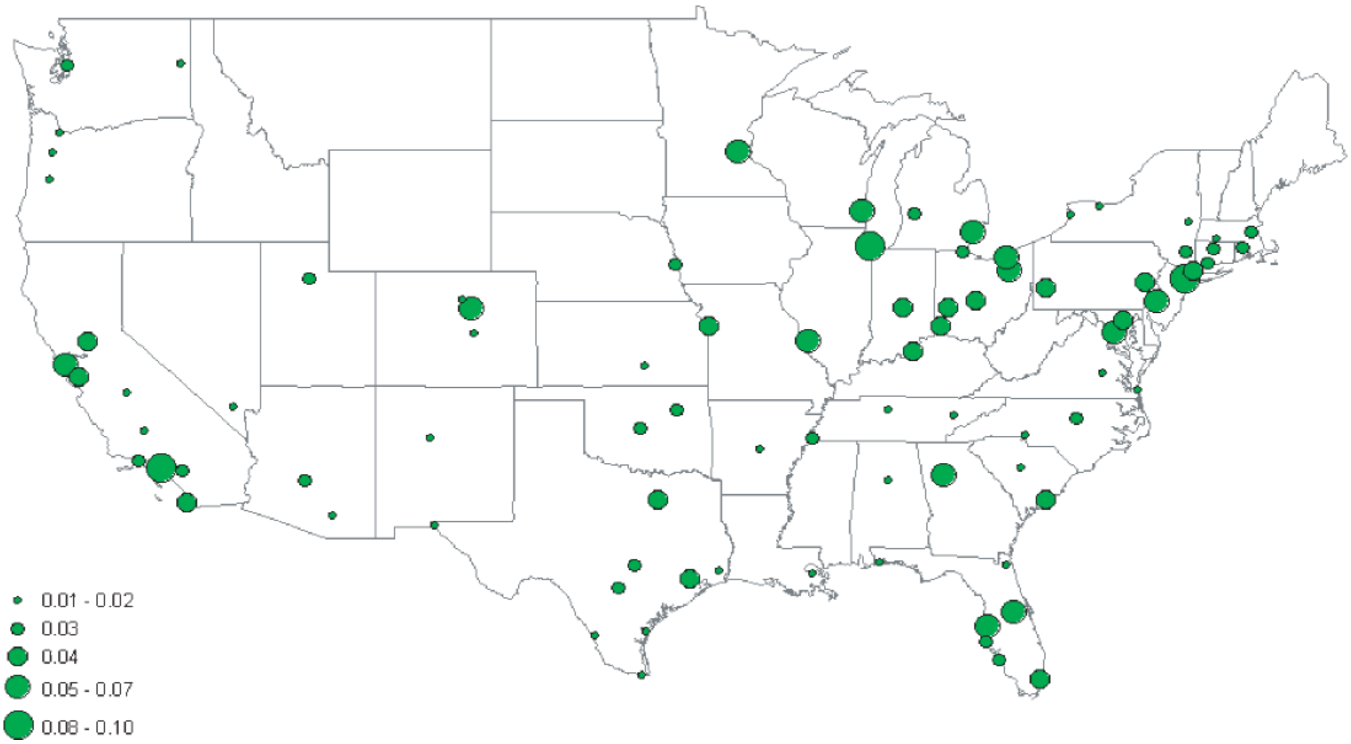

FIGURE 2 Total external air emissions cost of driving for each urban area (US\$/VMT).

TABLE 2 Comparison of External Cost Estimates

Study	Geographic Area	Vehicle Set	Air Pollutants Included	Cost in ¢$_{2008}$/VMT
This study	U.S. urban areas	LDVs	CO_2, CO, NO_x, SO_2, $PM_{2.5}$, VOCs, NH_3	1.15–10.28
Small and Kazimi (*21*)	Los Angeles region	LDGVs	NO_x, SO_x, PM_{10}, VOCs	2.12–18.28
Mayeres et al. (*22*)	Brussels	Gasoline cars Diesel cars	CO_2, CO, NO_x, SO_x, PM_{10}, VOCs	7.25–11.51 5.28–10.37
Maddison et al. (*23*)	United Kingdom	Diesel cars	NO_x, SO_x, PM_{10}, VOCs (+ Benzene), lead	2.80
McCubbin and Delucchi[a] (*24*)	United States	LDGVs	O_3, CO, NO_2, PM, toxics	0.89–11.83
Sen et al. (*25*)	Delhi, India	Gasoline cars Diesel cars	CO, NO_x, PM, HC	1.07–1.23 4.09–10.87
NRC (*14*)	U.S. counties	LDAs	NO_x, SO_x, $PM_{2.5}$, VOCs	1.37–1.87
Chester et al. (*12*)[b]	San Francisco, Calif., Chicago, and New York City	LDVs	GHGs, CO, NO_x, SO_2, PM_{10}, VOCs	2.70–3.50

NOTE: All costs are adjusted to ¢$_{2008}$ based on U.S. Bureau of Labor Statistics (*29*). Currency conversion factors of 1.7 £$_{1993}$ per \$$_{1993}$, 1.3 ECU$_{1990}$ per \$$_{1990}$, and 44 Rs$_{2005}$ per \$$_{2005}$ are used. £ = British pound, ECU = European currency unit, and R$_s$ = Indian rupees. LDV = light-duty vehicles; LDG-V = light-duty gasoline vehicles; LDA = light-duty automobile; and GHG = greenhouse gas.

[a] The Delucchi cost range is for vehicle emissions while the study also reports upstream impacts.

[b] The Chester et al. cost range is for vehicle emissions only while the study also reports life-cycle emissions and associated costs.

noncongested scenario in which all miles in the urban areas are driven at free-flow speeds to establish a baseline. The difference between the costs of this noncongested scenario and the existing costs of pollution at congested speed provides an estimate of the incremental external cost of congestion. A speed distribution profile, where a fraction of vehicles drive at 5 mph during congested peak times and the remaining vehicles drive close to free-flow speed, was used to determine a weighted average congestion speed that matches that reported by TTI (*8*). This method is believed to provide a more realistic and accurate result than assuming that a single congested speed applies to all vehicles driving during congested times. Of course, better estimates could be obtained with data on actual driving patterns in specific metropolitan areas. Moreover, TTI estimates of congested travel do not include local road congestion and likely overestimate average speeds. As a result, the authors expect that their estimates of congested travel external costs have greater uncertainty than the overall external cost estimate.

Table 3 shows comparable estimates for the external air emissions costs due solely to congestion in urban areas. The total estimate of \$24 million per day due to congestion is a portion of the \$145 million per day in total external emission costs. These amounts are relatively small compared with travel time costs of congestion, since emissions do not vary substantially with changes in average speeds. However, this small variation may be due to limitations in the MOBILE6 model; as discussed above, many of the emissions factors do not vary with speed. Nevertheless, they represent savings that could be realized in at least some portion by effective congestion management schemes.

The top 10 highest external congestion cost cities are clearly quite similar to cities with the highest total costs—9 of the top 10 are on both lists. For congestion, Los Angeles and New York score high above all other cities, particularly related to per capita external costs where Los Angeles nearly doubles its closest competitor, \$0.42/person-day compared with second-ranking New York at \$0.24/person-day. As might be expected, the difference between the maximum and minimum per capita and per-VMT cost values (~2 orders of magnitude) are higher for congestion costs than for total costs (~1 order of magnitude), since in some cities congestion is a much larger problem than in others. In the calculation of correlations similar to those for total costs, the most important variables explaining a high congestion cost were percent of peak travel congested ($r = 0.84$), pollution cost ($r = 0.76$), and population density ($r = 0.52$).

The total external emissions cost of congestion for each specific pollutant for all 86 urban areas (in million dollars per day) is as follows: CO_2, 9.4; NO_x, 0.4; VOC, 6.9; CO, 2.0; SO_x, 0.0; PM, 0.0; and NH_3, 0.0. NH_3 and VOC have the largest estimated costs for criteria pollutants.

Carbon dioxide valued at \$30/metric ton shows the largest total of external cost due to congestion. Figures 3 and 4 graphically illustrate total external air emission costs due solely to congestion for each urban area and the cost per VMT.

CONCLUSIONS

This paper provides estimates of the costs for external air emissions associated with light vehicle automobile travel in urban metropolitan areas. The cost estimates are limited to public health and climate change costs. These estimates can be used in benefit–cost studies to assess the avoided health burdens and climate impacts of travel reduction, congestion management, and the like. Emissions due to congestion contribute roughly 10% of the total costs of urban congestion when compared with the estimate of \$87 billion in 2007 by TTI (*8*). While other external costs, such as congestion time, are larger in magnitude, the external air emission costs are still appreciable, amounting to \$9 billion annually with a total cost of driving estimated at \$53 billion annually.

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TABLE 3 External Air Emissions Costs of Congestion

Urban Area (States)	U.S. Million \$/Day	\$/Day/Person	\$/VMT	U.S. Population	VMT/Person	% Peak Travel Congested
Los Angeles–Long Beach–Santa Ana (Calif.)	5.3	0.42	0.020	12,800,000	21	86
New York–Newark (N.Y., N.J., Conn.)	4.4	0.24	0.020	18,225,000	12	69
Chicago (Ill., Ind.)	1.3	0.15	0.012	8,440,000	12	79
San Francisco–Oakland (Calif.)	0.95	0.21	0.012	4,480,000	18	82
Washington, D.C. (Va., Md.)	0.87	0.20	0.011	4,330,000	19	81
Atlanta (Ga.)	0.77	0.17	0.008	4,440,000	21	75
Houston (Tex.)	0.73	0.19	0.008	3,815,000	24	73
Dallas–Fort Worth–Arlington (Tex.)	0.72	0.16	0.007	4,445,000	23	66
Miami (Fla.)	0.71	0.13	0.008	5,420,000	17	82
Philadelphia (Pa., N.J., Del., Md.)	0.69	0.13	0.008	5,310,000	16	63
Total[a]	24			158,355,000		
Average[a]	0.28	0.08	0.004	1,841,000	19	48
Maximum[a]	145	0.42	0.02	18,225,000	30	86
Minimum[a]	0.03	0.0042	0.0002	145,000	10	8.0

[a] Values are for all 86 urban areas.

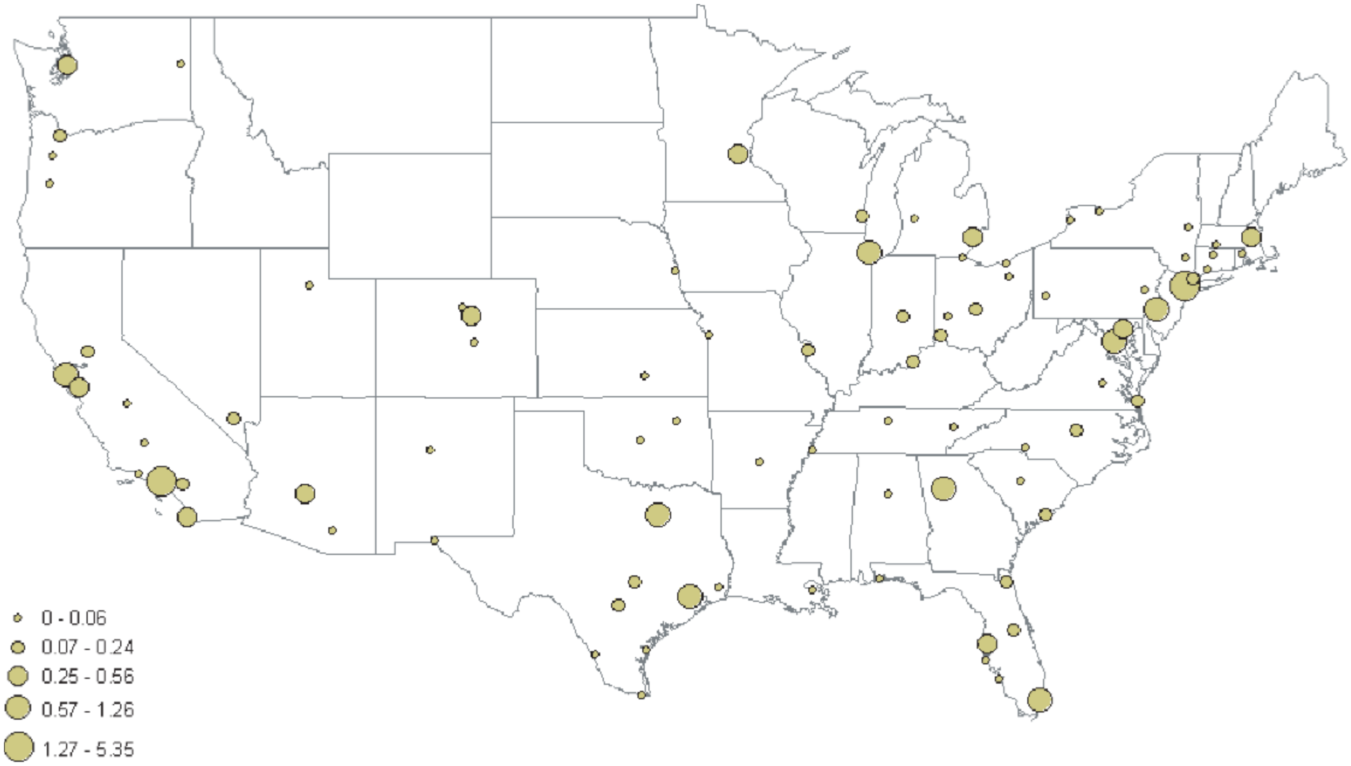

FIGURE 3 Total external air emission cost of congestion for each urban area (million US$/day).

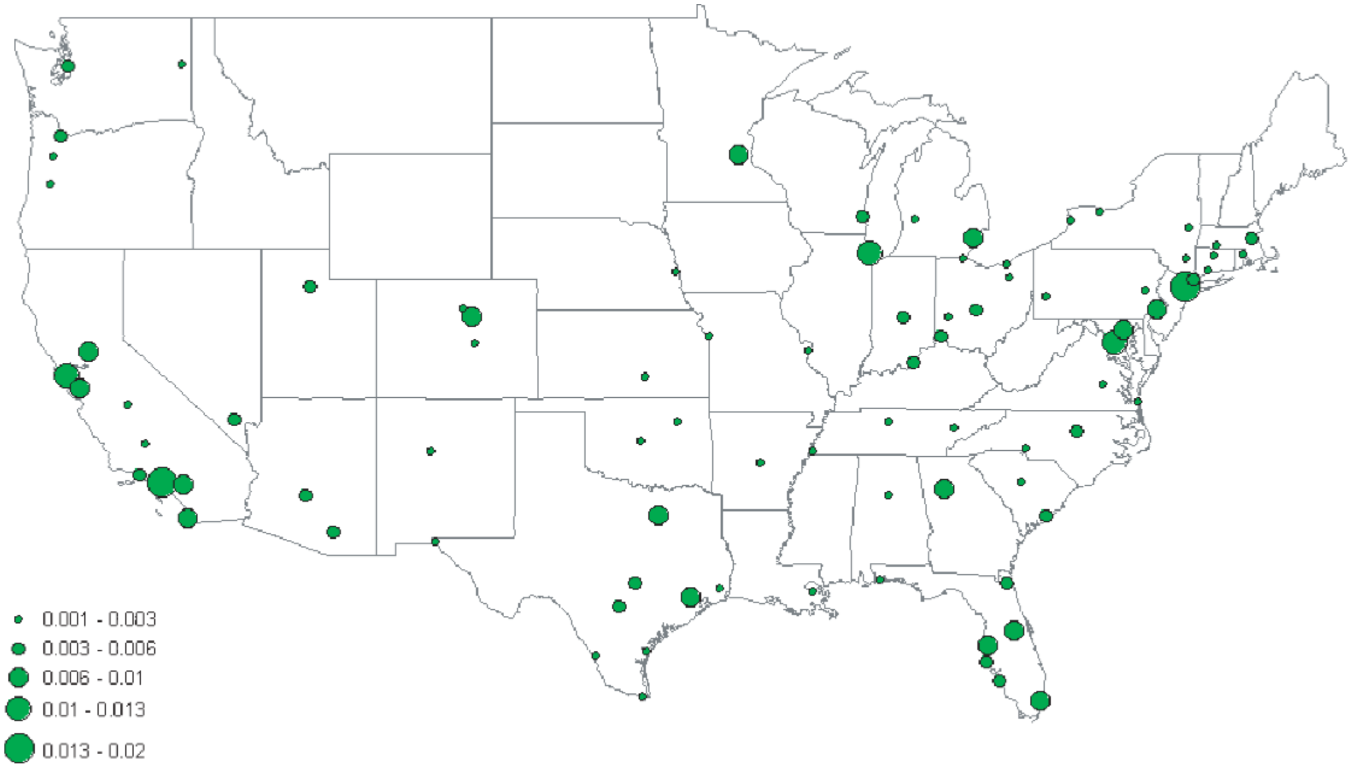

FIGURE 4 Total external air emission cost of congestion for each urban area (US$/VMT).

REFERENCES

1. Altshuler, A. A., J. P. Womack, and J. P. Pucher. *The Urban Transportation System: Politics and Policy Innovation Cambridge,* 1st ed. MIT Press, Cambridge, Mass., 1979.
2. Victoria Transport Policy Institute. *Evaluating Transport Benefits*. Victoria, British Columbia, Canada, Jan. 2009. www.vtpi.org. Accessed May 2010.
3. Delucchi, M. A. *The Annualized Social Cost of Motor-Vehicle Use in the United States, Based on 1990–1991 Data. Report 1: Summary of Theory, Data, Methods, and Results*. UCD-ITS-RR-96-3 (1). Institute of Transportation Studies, University of California, Davis, 1998. http://www.fhwa.dot.gov/scalds/delucchi.pdf.
4. Moffet, J., and P. Miller. *The Price of Mobility*. Natural Resources Defense Council, New York, 1993.
5. Maibach, M., C. Schreyer, D. Sutter, H. P. van Essen, B. H. Boon, R. Smokers, A. Schroten, C. Doll, B. Pawlowska, and M. Bak. *Handbook on Estimation of External Cost in the Transport Sector*. Produced within the Study Internalisation Measures and Policies for All External Cost of Transport (IMPACT), Version 1.1. CE Delft, for the European Commission DG TREN, Delft, Netherlands, 2008. http://ec.europa.eu/transport/costs/handbook/doc/2008_01_15_handbook_external_cost_en.pdf. Accessed May 2010.
6. Matthews, H. S., C. H. Hendrickson, and A. Horvath. External Costs of Air Emissions from Transportation. *ASCE Journal of Infrastructure Systems,* Vol. 7, 2001, pp. 13–17.
7. Matthews, H. S., and L. B. Lave. 2000. Applications of Environmental Valuation for Determining Externality Costs. *Environmental Science and Technology,* Vol. 34, No. 8, 2000, pp. 1390–1395.
8. Shrank, D., and T. Lomax. *The 2009 Urban Mobility Report*. Texas Transportation Institute, Texas A&M, Austin, 2009.
9. Saito, K., T. Kato, and T. Shimane. Traffic Congestion and Accident Externality: A Japan-U.S. Comparison. *The B.E. Journal of Economic Analysis and Policy,* Vol. 10, No. 1, Article 14, 2010. http://econpapers.repec.org/RePEc:bpj:bejeap:v:10:y:2010:i:1:n:14. Accessed May 2010.
10. Granell, J., C. Ho, T. Tang, and M. Roberts. Analysis of MOBILE6.2's PM Emission Factor Estimating Function. *Proc., U.S. Environmental Protection Agency's 13th International Emission Inventory Conference,* Clearwater, Fla., June 8–10, 2004. http://www.epa.gov/ttn/chief/conference/ei13/mobile/granell.pdf. Accessed May 2010.
11. Parrish, D. D. Critical Evaluation of U.S. On-Road Vehicle Emission Inventories. *Atmospheric Environment,* Vol. 40, No. 13, 2006, pp. 2288–2300.
12. Chester, M., A. Horvath, and S. Madanat. Comparison of Life-Cycle Energy and Emissions Footprints of Passenger Transportation in Metropolitan Regions. *Atmospheric Environment,* Vol. 44, No. 8, 2010, pp. 1071–1079.
13. Fairfield, H. Driving Shifts into Reverse. *New York Times,* May 1, 2010. http://www.nytimes.com/imagepages/2010/05/02/business/02metrics.html. Accessed June 2010.
14. Committee on Health, Environmental, and Other External Costs and Benefits of Energy Production and Consumption and National Research Council. *Hidden Cost of Energy: Unpriced Consequences of Energy Production and Use*. National Academies Press, Washington, D.C. 2010.
15. U.S. Environmental Protection Agency. *Air Trends 1995*. http://www.epa.gov/air/airtrends/aqtrnd95/report/o3co.html. Accessed May 2010.
16. U.S. Environmental Protection Agency. *Transportation and Climate: Regulations and Standards*. 2010. http://www.epa.gov/otaq/climate/regulations.htm. Accessed May 2010.
17. U.S. Environmental Protection Agency. *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2008*. Report EPA430-R-10-006. April 2010. http://www.epa.gov/climatechange/emissions/usinventoryreport.html. Accessed May 2010.
18. *AAA Calculates Driving Cost at 52.2 Cents per Mile for 2007*. American Automobile Association, Orlando, Fla., March 2007. http://www.aaanewsroom.net/main/Default.asp?CategoryID=4&ArticleID=529. Accessed May 2010.
19. FHWA. *Highway Statistics*, 2008. http://www.fhwa.dot.gov/policyinformation/statistics/2008/. U.S. Department of Transportation, Washington, D.C. Accessed May 2010.
20. Muller, N. Z., and R. O. Mendelsohn. Measuring the Damages from Air Pollution in the U.S. *Journal of Environmental Economics and Management,* Vol. 54, No. 1, 2007, pp. 1–14.
21. Small, K. A., and C. Kazimi. On the Costs of Air Pollution from Motor Vehicles. *Journal of Transport, Economics, and Policy,* Vol. 29, No. 1, 1995, pp. 7–32.
22. Mayeres, I., S. Ochelen, and S. Proost. The Marginal External Costs of Urban Transport. *Transportation Research Part D: Transport and Environment,* Vol. 1, No. 2, 1996, pp. 111–130.
23. Maddison, D., D. Pearce, O. Johansson, E. Calthorp, T. Litman, and E. Verhoef. *Blueprint 5: The True Costs of Road Transport*. Earthscan Publications Limited, United Kingdom, 1996.
24. McCubbin, D. R., and M. A. Delucchi. The Health Costs of Motor-Vehicle-Related Air Pollution. *Journal of Transport, Economics, and Policy,* Vol. 33, No. 3, 1999, pp. 253–286.
25. Sen, A. K., G. Tiwari, and V. Upadhyay. Estimating Marginal External Costs of Transport in Delhi. *Transport Policy,* Vol. 17, No. 1, 2010, pp. 27–37.
26. U.S. Environmental Protection Agency. MOBILE6 Vehicle Emission Modeling Software, 2003. http://www.epa.gov/otaq/m6.htm. Accessed May 2010.
27. Ross, M. Automobile Fuel Consumption and Emissions: Effects of Vehicle and Driving Characteristics. *Annual Review of Energy and the Environment,* Vol. 19, 1994, pp. 75–112. http://dx.doi.org/10.1146/annurev.eg.19.110194.000451. Accessed May 2010.
28. *The Greenhouse Gas, Regulated Emissions, and Energy Use in Transportation (GREET) Model*. U.S. Department of Energy, Argonne National Laboratory. Argonne, Ill. http://www.transportation.anl.gov/modeling_simulation/GREET. Accessed May 2010.
29. U.S. Bureau of Labor Statistics. *Consumer Price Index*. U.S. Department of Labor, ftp://ftp.bls.gov/pub/special.requests/cpi/cpiai.txt. Accessed May 2010.

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