

Cities, traffic, and CO₂: A multidecadal assessment of trends, drivers and scaling relationships

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Objectives:

- This paper describes the development of a new emissions inventory, the Database of Road Transportation Emissions (DARTE).
- DARTE is an annual 1-km resolution CO₂ emissions inventory for the United States on-road transportation sector, based on archived data of roadway-level vehicle traffic for the years 1980-2012.
- Raw vehicle activity data were obtained from the Federal Highway Administration's (FHWA's) Highway Performance Monitoring System (HPMS).
- HPMS roadway-level vehicle miles traveled (VMT) were combined with year- and state-specific emissions factors for five vehicle types to calculate CO₂ emissions from motor gasoline and diesel fuel consumption on six classes of urban and rural roads.
- DARTE was used to quantify the spatiotemporally varying effects of population density, income, employment and transit use on on-road CO₂ emissions across the United States.
- The authors estimated vehicle emissions directly at the scale of individual road segments without the need to downscale emissions using spatial predictors.
- The authors also characterize multidecadal trends across all rural and urban road types.
- DARTE was compared with several existing inventories of on-road CO₂ emissions.

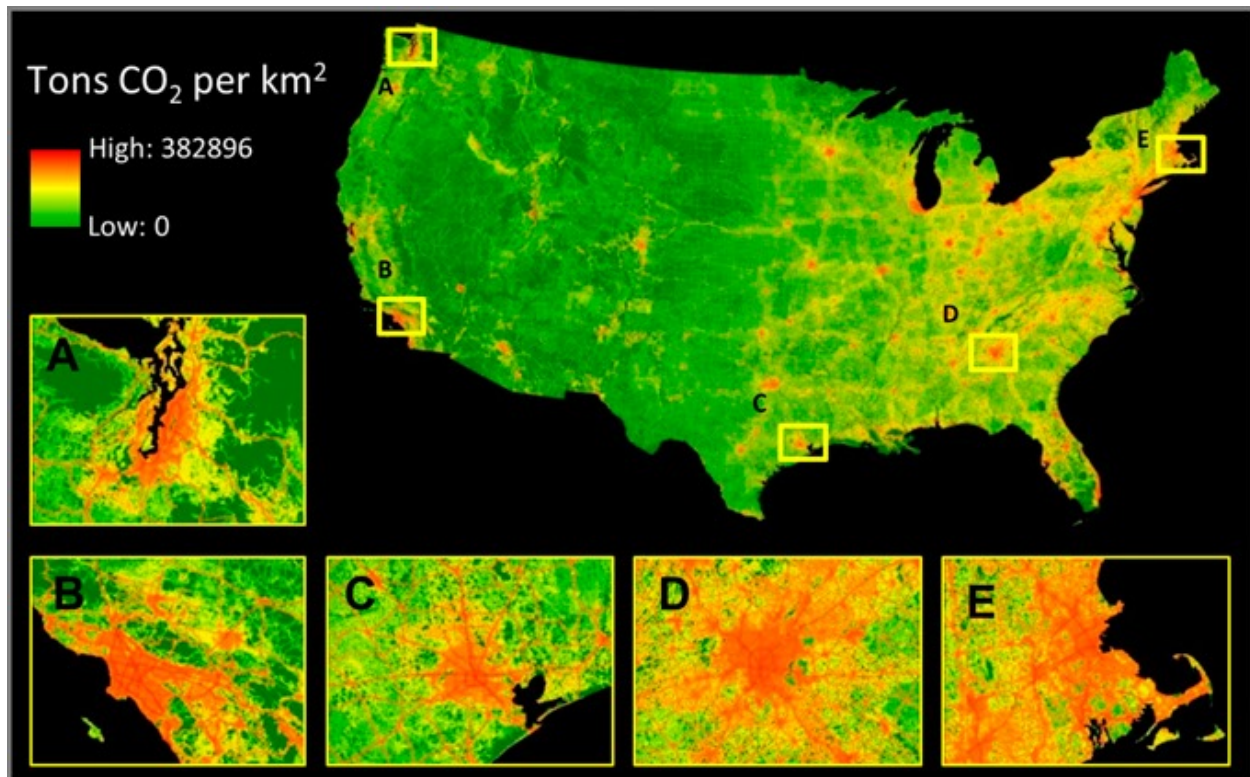
New Science:

- The study found increases in both per capita and total on-road emissions for cities with population densities below 1,650 persons per square kilometer –while cities with densities between 1,650 and 4,000 persons per square kilometers showed varying trends in per capita and total emissions.
- Comparing DARTE to existing downscaled inventories, the study finds biases of 100% or more in the spatial distribution of urban and rural emissions, largely driven by mismatches between inventory downscaling proxies and the actual spatial patterns of vehicle activity at urban scales.
- The inventory reveals large biases in regional estimates of CO₂ from inventories that rely on population as a linear predictor of vehicle activity; differences exceeded 500% for several major metropolitan areas.
- The DARTE inventory reveals that urban areas are responsible for 80% of on-road emissions growth since 1980 and 63% of total 2012 emissions.
- Total U.S. on-road emissions increased by 50% from 1.04 gigatonnes (Gt) in 1980 to 1.55 Gt in 2012.
- Rural emissions were 556 megatonnes (Mt) in 2012, an overall increase by 23% since 1980, but there has been a notable recent decline from the peak of 637 Mt in 2002.
- Urban area gasoline emissions rose steadily throughout the study period, despite the observed decline in overall emissions between 2008 and 2012.
- The rural area population declined slightly between 1980 and 2010 while rural per capita emissions rose by 22%, meanwhile the urban per capita emissions grew by 15%.

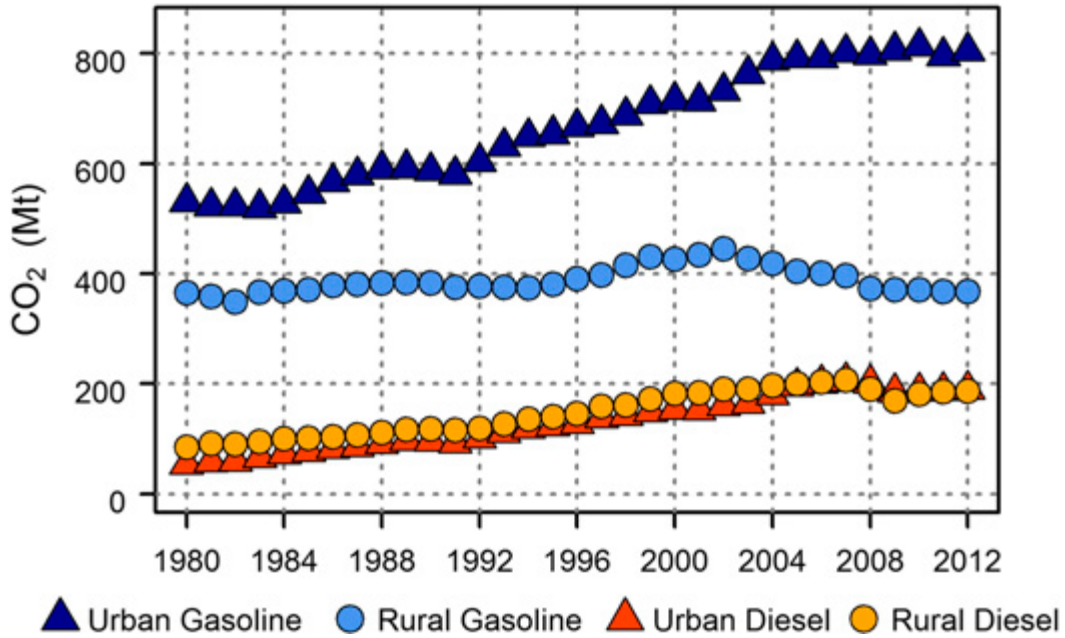
- Nationally, per capita emissions peaked in 2004, although suburban and rural per capita emissions have begun to rise again since 2009.
- With a limited sample size, it is difficult to make firm conclusions about public transit use and emissions in small cities, but cities with a >15% transit share of the overall population all show notable decreases in per capita CO₂ emissions between 2000 and 2010, concurrent with increases in the transit share use of their total population.

Significance:

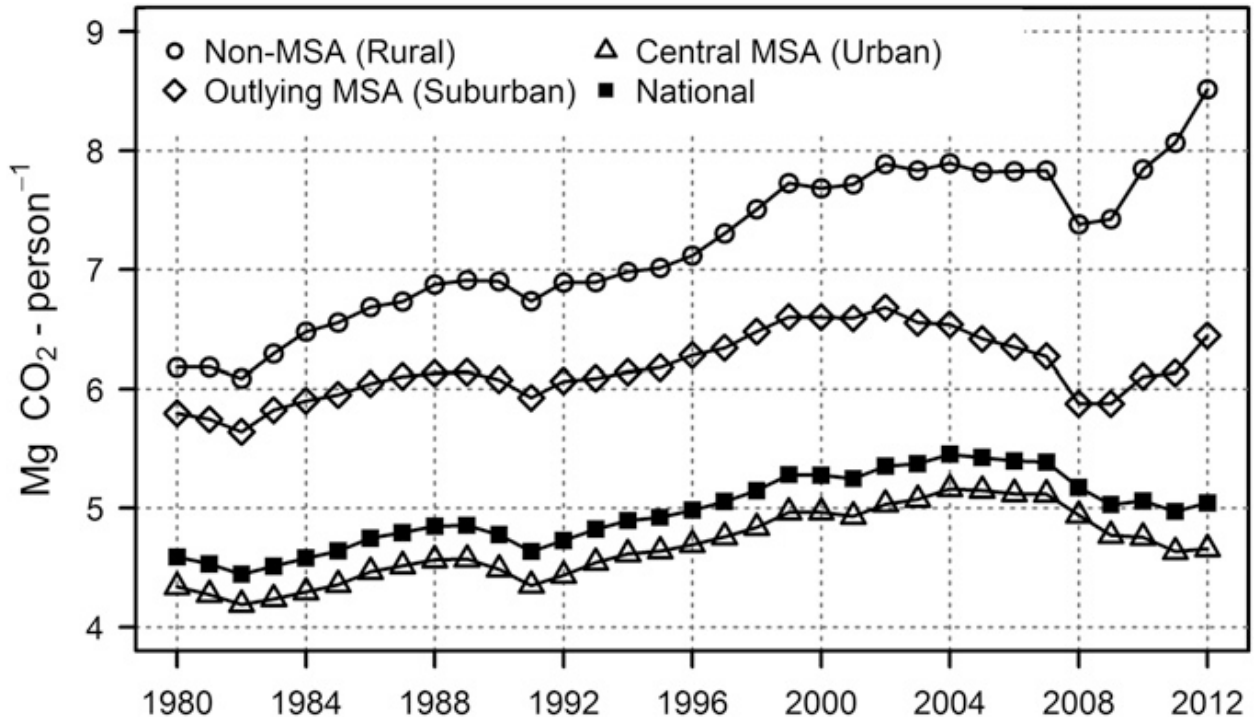
- Although the United States has 5% of the world's population and 30% of the world's automobiles, it emits 45% of global transportation CO₂ emissions.
- Despite the large contribution of emissions from road vehicles, the spatial distributions of these emissions are highly uncertain and poorly quantified at substate and urban scales.
- The results highlight the importance of cities as sources of CO₂ and the need for improved fine-scale inventories for monitoring and reporting of emissions.
- Given cities' dual importance as sources of CO₂ and as an emerging nexus of climate mitigation initiatives, high-resolution estimates such as DARTE are critical for accurately quantifying surface carbon fluxes and for verifying the effectiveness of emissions mitigation efforts at urban scales.
- Reducing the uncertainty of on-road CO₂ emissions at finer spatial scales is central to understanding the determinants of motor vehicle emissions, constraining carbon budgets, and supporting greenhouse gas emission monitoring and abatement, particularly at the scale of cities, which have emerged as hubs of climate change mitigation activity.
- The correlations between population density, employment density, income and lagged population growth estimated by DARTE suggest that these factors may be sufficient to explain the majority of variance in on-road emissions at the county scale, but further research into the influence of urban typology and mobility patterns will be vital to understanding emissions trends at city and municipal scales.
- Used alone, population may be a valid predictor for residential and commercial sector emissions, but it performs poorly when used to model emissions from power stations or the on-road sector.
- Geographic differences in the density-emissions relationship suggest that "smart growth" policies to increase urban residential densities will have significantly different effects on emissions depending on location conditions, and may be the most effective at low densities.
- From a regional planning perspective, it may make more sense for policy makers to focus on reducing local per capita emissions rather than total emissions, because most growing urban areas should expect total on-road emissions to continue to rise with population over the next decades.
- DARTE is, to the author's knowledge, the first nationally consistent inventory of US on-road CO₂ emissions built from bottom-up source activity data and it not only establishes a national benchmark for monitoring, reporting and verification of emissions that are vital for regulating greenhouse gases (GHG), but provides previously unidentified insights into how key features of urban areas contribute to climate change.
- DARTE can provide valuable information to local and regional climate change mitigation initiatives (such as state and city climate action plans) whose success turns on the ability to accurately assess both city-scale GHG emissions and their responsiveness to policy.



Map of 2012 on-road CO₂ emissions for the coterminous United States and selected urban areas at a resolution of 1 km. (Insets) Maps show details of metro areas surrounding Seattle (A), Los Angeles (B), Houston (C), Atlanta (D) and Boston (E).



Time series of US on-road CO₂ emissions. Urban roads accounted for 80% of total emissions growth since 1980. Rural roads have been declining since 2002.



Time series of US per-capita on-road CO₂ emissions by county, using a Census 2000 Metropolitan Statistical Area (MSA) classification. Per capita emissions increased from 1980, both in urban and nonurban counties, with brief declines during the 1981-1982, 1990-1991, and 2007-2009 economic recessions. Since 2009 per capital emissions in non-MSA (rural) and outlying MSA (suburban) counties have grown rapidly, whereas central MSA (urban) per capital emissions have continued to decrease.