Climate damages to the U.S. economy from U.S. transportation emissions

September 2025

Justin S. Mankin[1], Alexander R. Gottlieb[1], Christopher W. Callahan[2,3]

[1]Department of Geography, Dartmouth College
[2]Doerr School of Sustainability, Stanford University
[3]O'Neill School, Indiana University

Peer-review status: This is a non-peer reviewed preprint.

Data and code can be downloaded at: https://github.com/jsmankin/transportation
And at Zenodo:

Prepared by Justin S. Mankin, Alexander R. Gottlieb, and Christopher W. Callahan, with analysis from Gottlieb and Callahan. Questions should be sent to mankin@dartmouth.edu

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Summary

Using an ‘end-to-end’ climate damage attribution method, we estimate that climate damages to the U.S. economy from its own transport sector emissions total $68.0 billion [2015 USD; 95% confidence interval (CI) of $36.5-113.9] over the 1973-2023 period. Damages will continue to accrue from the warming attributable to those historical emissions.

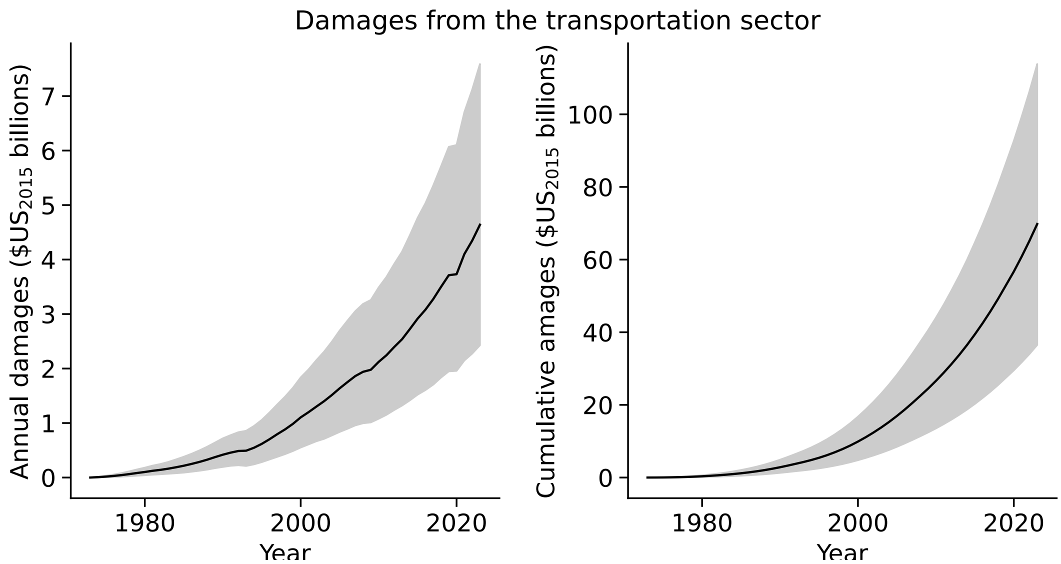

Figure 1 | *Left*: Annual-scale direct economic damages to the U.S. economy from the U.S. transport sector emissions over the 1973-2023 period in billions of U.S. dollars benchmarked to the 2015 dollar value ($\$US_{2015}$). *Right*: Cumulative direct economic damages from U.S. transport emissions, equivalent to the integral under the curve at the left. In both panels, the confidence interval represents the 95% range in attributable damages estimated via a bootstrap resampling (see *Methods*, below).

Methods

Our approach extends peer-reviewed end-to-end climate damage attribution methods from Callahan & Mankin, *Climatic Change* (2022) and Callahan & Mankin, *Nature* (2025), using U.S. transport sector emissions (in gigatons of carbon dioxide per year) from the U.S. Energy Information Administration (EIA) that spans the 1973-2023 period (Fig. 1, top), and a damage function tailored for the U.S. economy from Hsiang et al., *Science* (2017). We note we have performed this same analysis for the U.S. power sector, which can be seen archived here.

The steps are as follows: (1) simulate the contribution of U.S. transport sector emissions to global mean surface temperature (GMST) change via a "leave-one-out" experimental design, and (2) estimate the U.S. economic damages incurred from that U.S. transport sector-driven warming.

To do step (1), we use a simple climate model called the Finite Amplitude Impulse Response (FaIR) Model (version 2.2.2). We run ~1000 simulations of global mean temperature responses from 1750 to present-day that include all known emissions, sampling a range of climate model parameters related to the carbon cycle and climate feedbacks. This provides a probability distribution of warming consistent with all emissions (i.e., temperature changes with likelihoods attached to them), given physical variations in the coupled climate system. This is our "treatment" group in the experimental design—a probability distribution of historical warming in each year from all emissions.

We then compare this "all emissions" distribution of historical global mean surface temperature change to a second distribution of temperature changes, from a second set of FaIR simulations. This second set of simulations is exactly the same as the "treatment" that includes all emissions, except that we remove the emissions inventories from the U.S. transport sector using the EIA data. This second distribution of annual-scale global mean surface temperature change thus represents our "control" group, as it is the annual warming due to all emissions *except those from the U.S. transport sector.*

The difference between the two sets of simulations (treatment and control) is the probability distribution of annual-scale global mean surface temperature change attributable to the U.S. transport sector's emissions (Fig. 1, bottom). It is clear that U.S. transport sector emissions have discernibly warmed the planet. Moreover, we find this range of attributable temperature change aligns with published best estimates of the transient climate response at the global scale (e.g., Matthews et al., *Nature Communications Earth & Environment* (2021)), implying it is consilient with other independent research.

To do step (2), we use a damage function from Hsiang et al., *Science* (2017) that translates global mean temperature changes into aggregate economic damages in the United States (Tabel 1). Specifically, we use the specification described in column 2 in supplementary table 16, which models total direct damages as a function of global mean surface temperature as a quadratic function. To provide the damage estimate, we multiply our estimated changes in global mean surface temperature in both the "treatment" and "control" simulations by the distribution of coefficients in column 2 given sampling 100 times across their standard errors. We bootstrap the confidence intervals to provide the range of damage values consistent with each trajectory of temperature change. We then difference these damages estimates to provide the attributable, but-for damages due to U.S. transport sector emissions. Actual GDP data in $\$US_{2015}$ to convert these damages into dollar values come from the World Bank. Because GDP data for 2024 are not yet available, we only calculate damages from 1973-2023 inclusive.

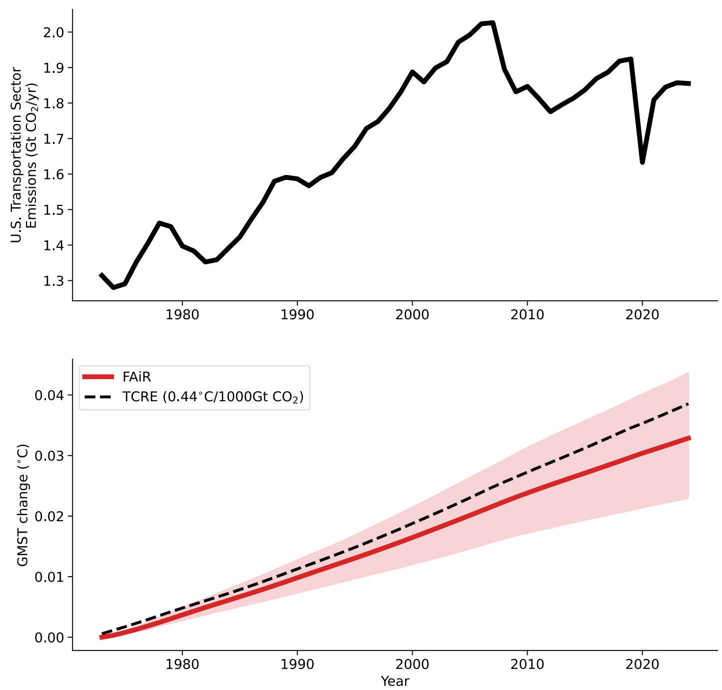

Figure 2 | *Top*: U.S. electric transport sector emissions over the 1973-2024 period in gigatons (Gt) of CO2 per year from the EIA. *Bottom*: Global mean surface temperature (GMST) change attributable to U.S. transport sector emissions, red line ('FaIR'). The red shading indicates the 95% confidence interval (CI) of the temperature change. The dotted line shows the transient climate response (TCRE) of 0.44°C per 1000 Gt of CO2, highlighting the skill of FaIR.

Polynomial		Total Direct Damages		
order:	linear	2nd	3rd	4th
$\Delta GMST$	1.189***	0.283**	-0.0325	0.907*
	(0.082)	(0.110)	(0.233)	(0.469)
$\Delta GMST^2$		0.146***	0.249***	-0.281
		(0.017)	(0.074)	(0.251)
$\Delta GMST^3$			-0.00901	0.0989**
			(0.006)	(0.048)
$\Delta GMST^4$				-0.00697**
				(0.003)
Constant	-1.091***	-0.0547	0.182	-0.292
	(0.179)	(0.134)	(0.185)	(0.248)
Obs.	109000	109000	109000	109000
Adj. R^2	0.726	0.774	0.775	0.777

Standard errors are clustered at the level of the climate realization m in parentheses. Stars denote statistical significance: * ($p<0.10$), ** ($p<0.05$), *** ($p<0.01$)

Table 1 | Damage function estimates from Hsiang et al., *Science* (2017). The present analysis uses the 2nd order polynomial function presented in column 2. This model estimates U.S. total economic damages as a function of changes in global mean surface temperature (GMST) and its squared term.