Machine Learning for Activity-Based Road Transportation Emissions Estimation

Tackling Climate Change with ML Workshop at NeurIPS 2022

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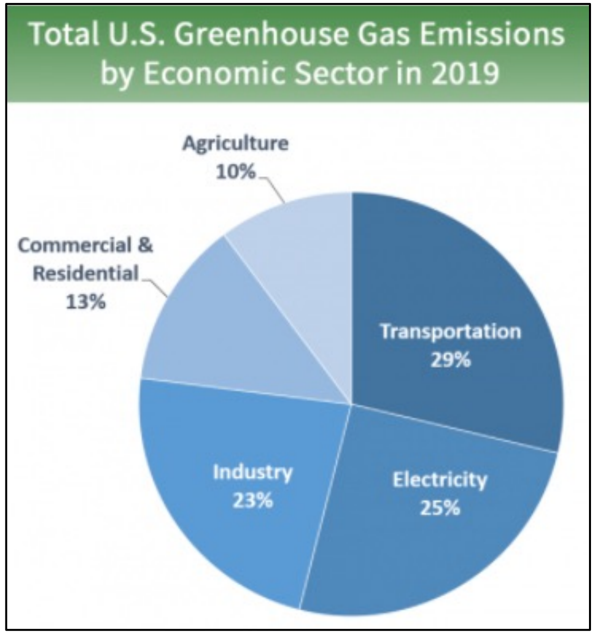
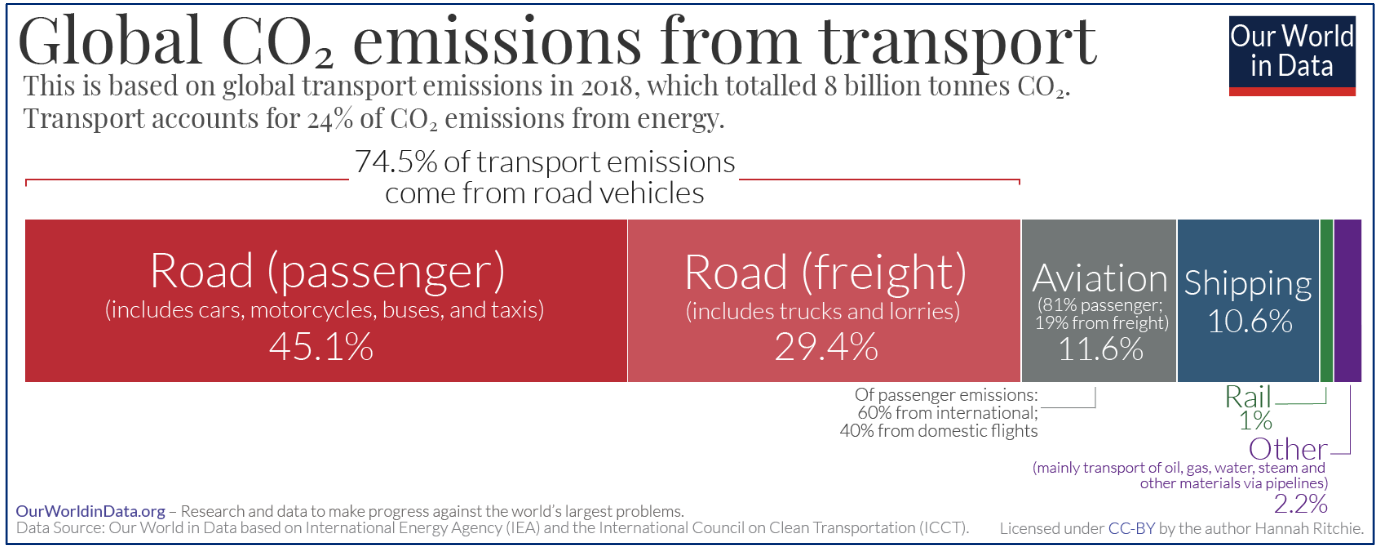
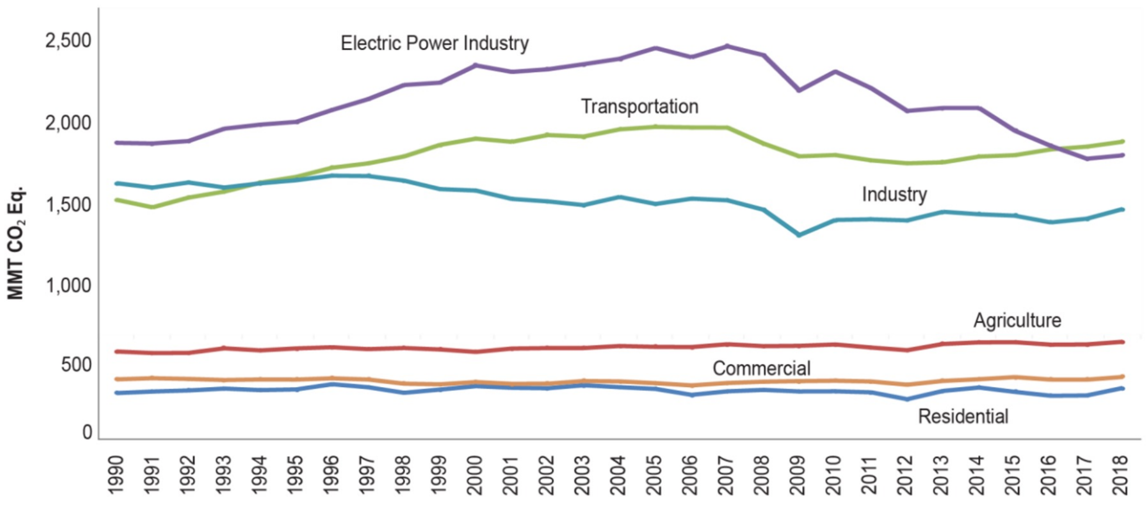
Motivation

- Transportation is **one of the largest sectors** of greenhouse gas emissions
  - 27% of all U.S. GHG emissions in 2020 [1]
  - 12.6% of global GHG emissions in 2019 [2]
- **Goal:** independently estimate road transportation emissions at a global scale (e.g., using AI/ML, satellite imagery, and other widely available data sources)





U.S. Greenhouse Gas Emissions Allocated to Economic Sectors*



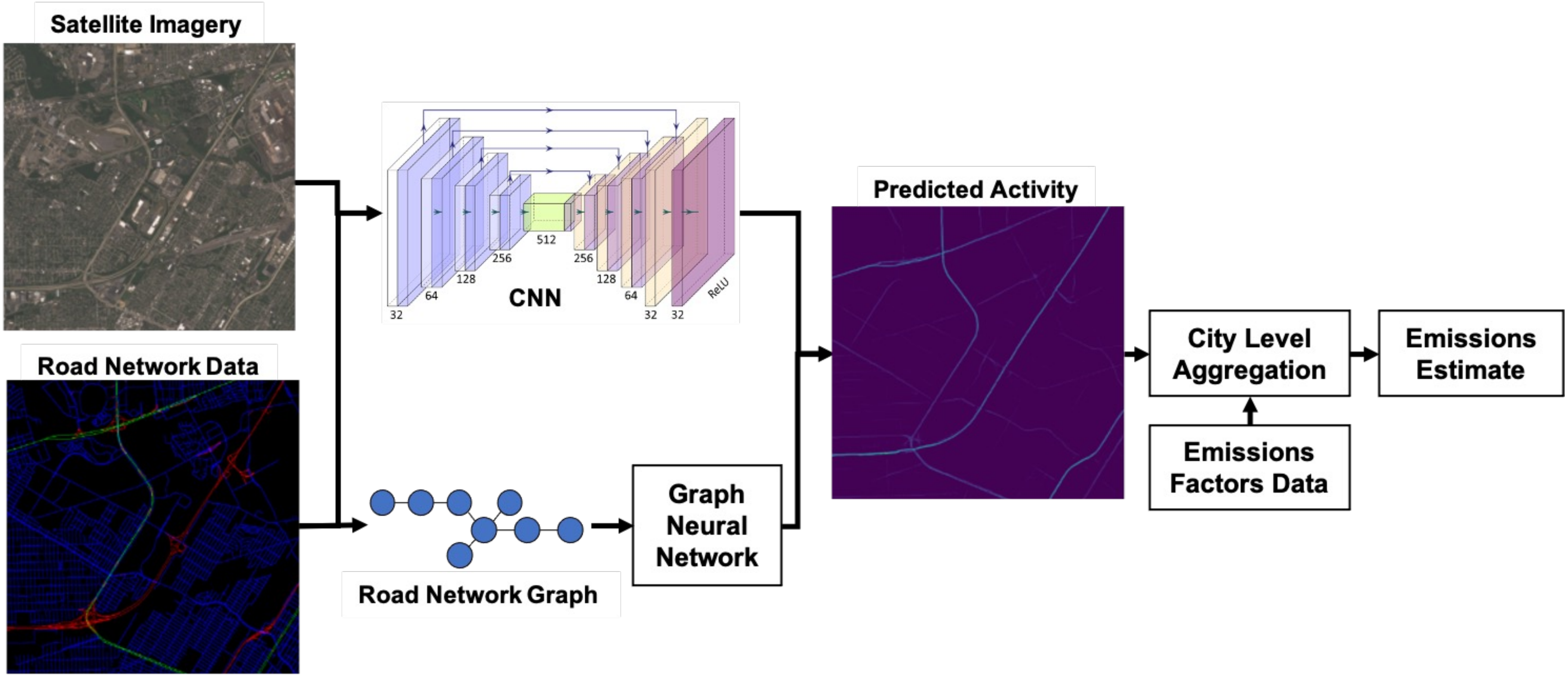
*Land use sinks and U.S. territories are excluded from this figure.

https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks-1990-2018

Approach

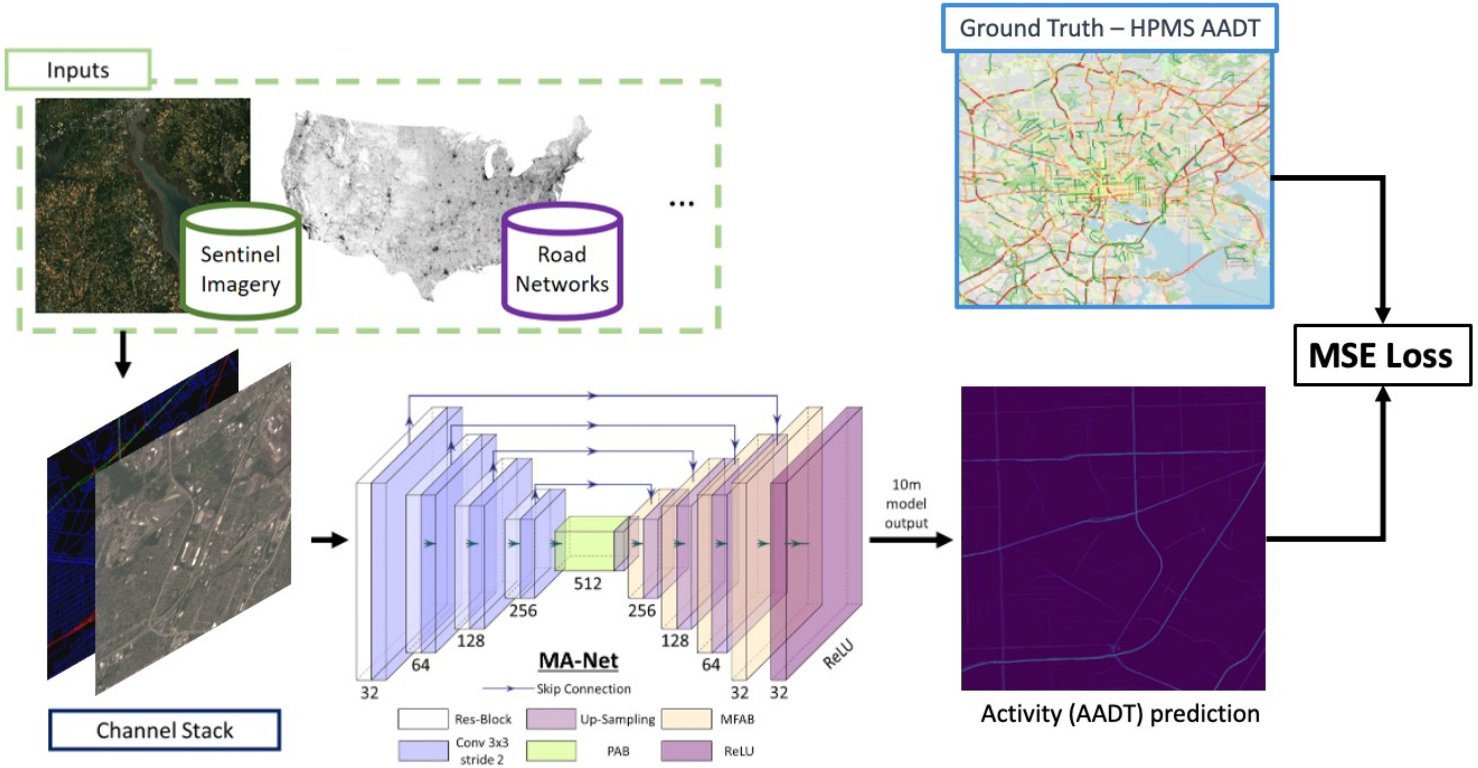

Estimated
ASSET EMISSIONS
=
Estimated
ASSET CAPACITY BY TYPE
X
Estimated
ASSET ACTIVITY
X
Estimated
EMISSION FACTORS

Machine Learning Approach



Data & Model Training

- Ground truth data: U.S. Highway Performance Monitoring System Average Annual Daily Traffic (AADT) data set from 2017 [3]
- OpenStreetMap (OSM) [4] road network data used for both CNN and GNN models
- **CNN models:** Sentinel-2 [5] or PlanetScope [6] satellite imagery used in combination with OSM
- **GNN models:** Graph attention network v2 (GATv2) [7] architecture



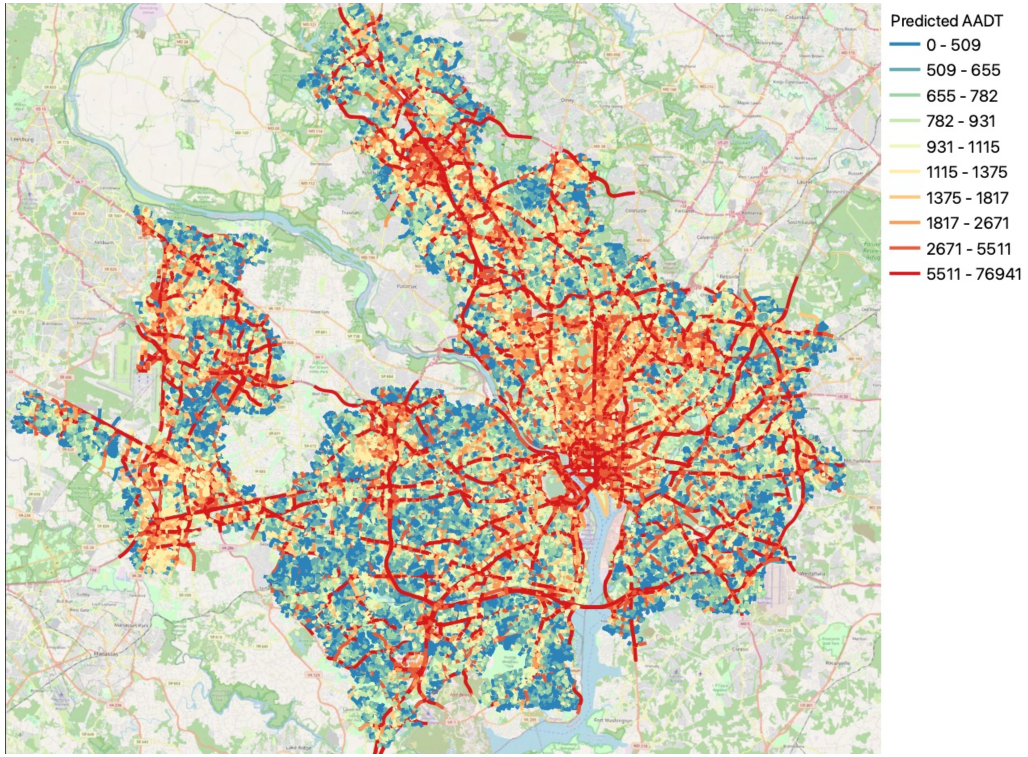
AADT Validation

AADT error metrics for 14 U.S. hold out cities. RMSE is in units of vehicles per day.

Method	RMSE	MAPE	MPE	Pearson's ρ
S2+OSM	4823.6	116.3%	**-39.3%**	0.58
S2+OSM Ensemble	5249.5	**102.3%**	-71.74%	0.58
Planet+OSM	**3329.9**	159.9%	41.01%	0.60
GNN OSM	4470.0	137.6%	103.3%	0.87
GNN OSM+GHSL	4384.9	143.3%	110.6%	0.87
GNN OSM+CNN	4415.3	135.0%	99.27%	**0.88**
GNN OSM Ensemble	4307.3	142.3%	113.0%	**0.88**

AADT error metrics for international cities: 26 cities in the UK [8], Buenos Aires [9], and Paris [10]. RMSE is in units of vehicles per day.

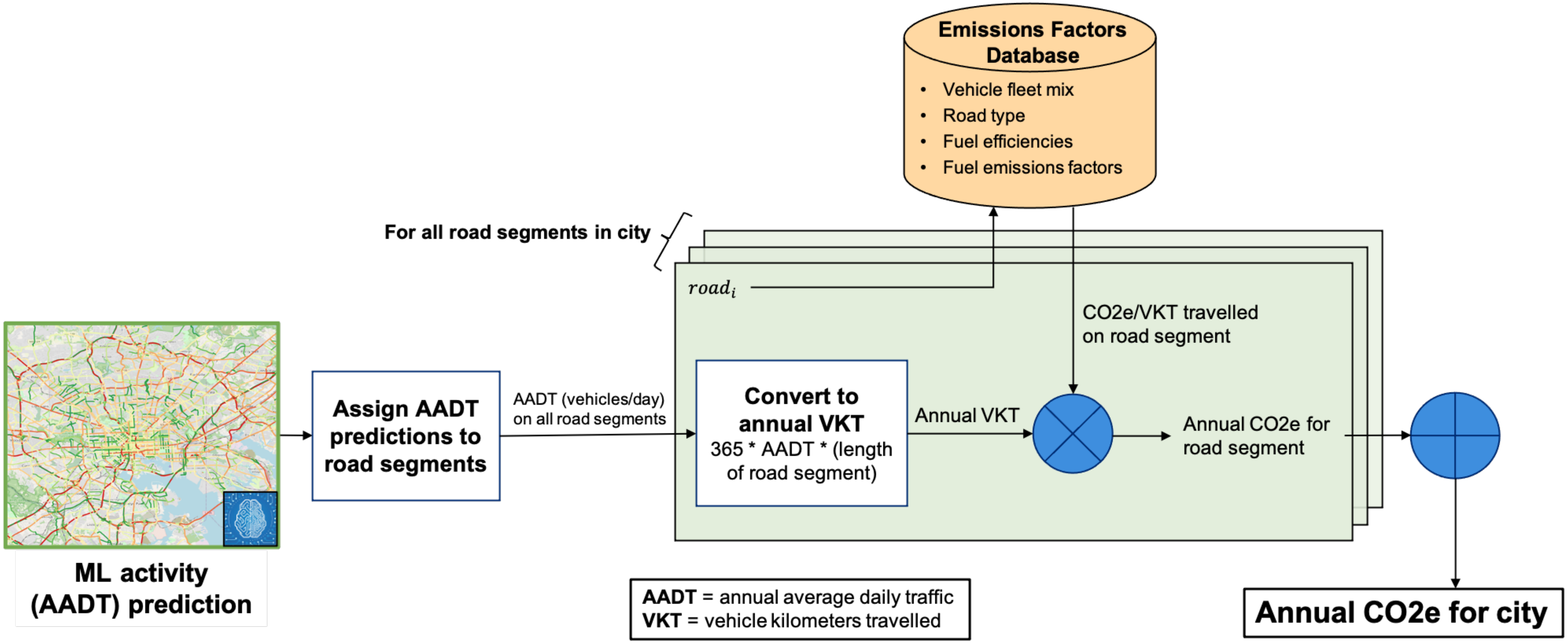
Region	RMSE	MAPE	MPE	Pearson's ρ
U.K. 26 (2018)	3804.6	119.5%	49.2%	0.69
U.K. 26 (2019)	3177.2	130.9%	63.0%	0.73
U.K. 26 (2020)	3447.0	84.7%	20.6%	0.69
Buenos Aires (2017)	8750.2	74.3%	71.8%	0.66
Paris (2021)	9467.9	96.3%	20.4%	0.79



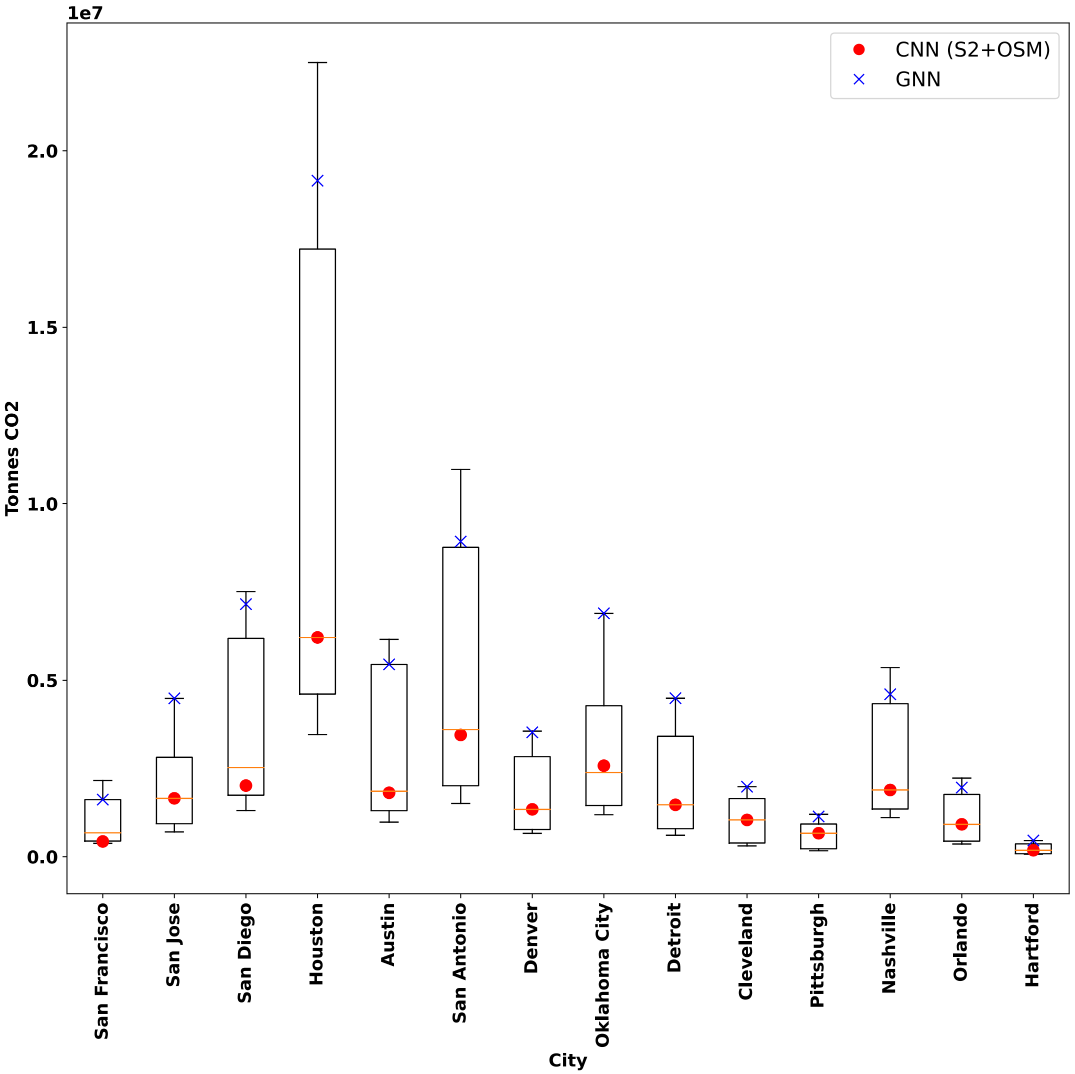
Example ensembled AADT predictions for the greater Washington D.C. area

Activity to Emissions

Leverage **region-specific** emissions factors data to translate ML-predicted activity to total emissions.



U.S. Emissions Validation

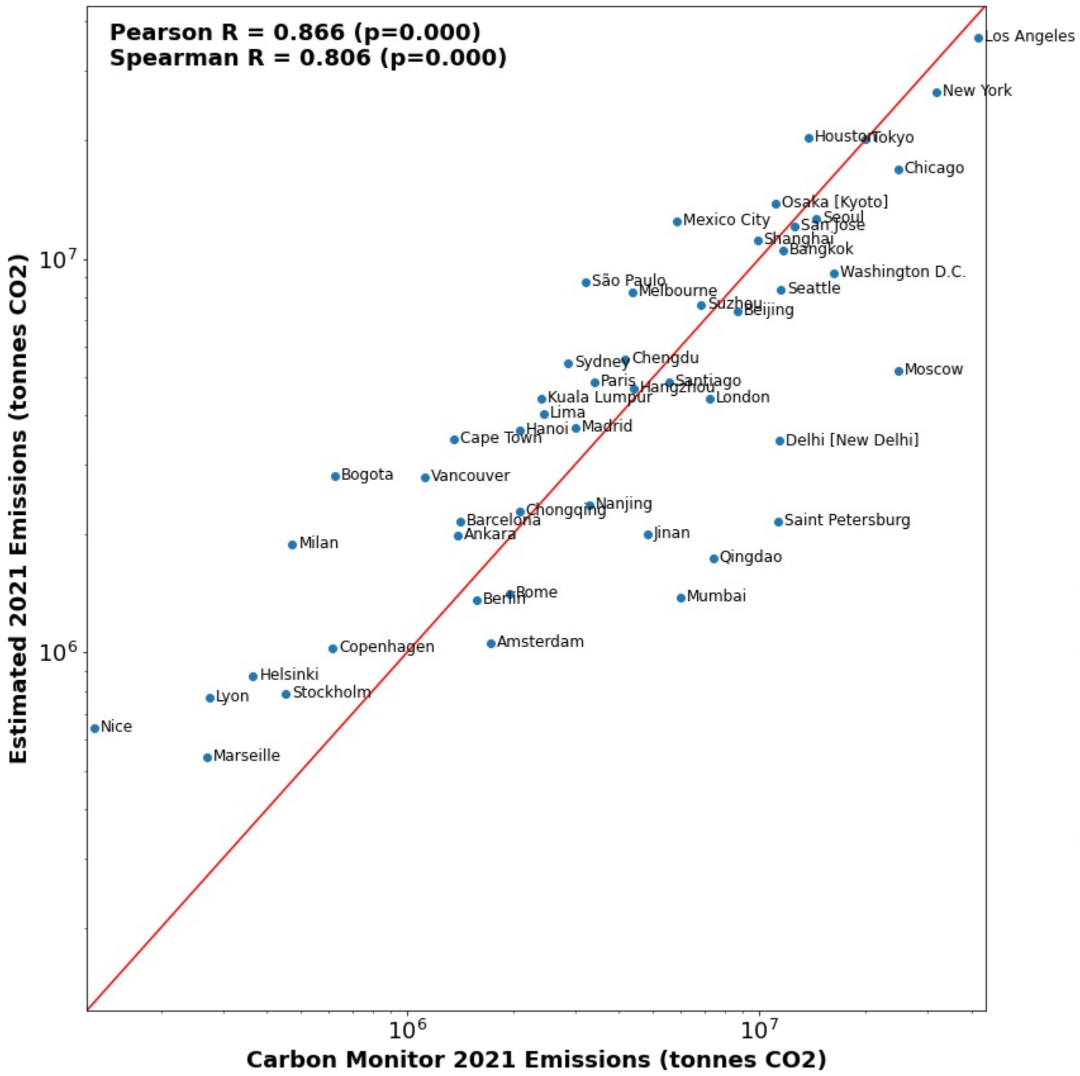


- Emissions estimates compared against other major emissions inventories [11,12,13] for 14 hold out U.S. cities
- **Strong correlation** between our estimates and others
- Range of values highlights **uncertainties** and **discrepancies** between various methods

	CNN				GNN			
Emissions Dataset	RMSE	Mean Error	MAPE	ρ	RMSE	Mean Error	MAPE	ρ
EIE_v1_2018	544,225	407,997	77.3%	0.94	3,706,827	3,706,827	321.5%	0.95
EIE_v2_2018	1,180,437	-1,153,065	36.1%	0.94	2,223,303	2,145,764	71.3%	0.96
DARTE_2015	2,606,389	-2,606,389	53.6%	0.98	708,514	692,440	19.8%	0.99
DARTE_2017	3,505,472	-3,505,472	59.5%	0.98	875,254	-206,642	17.2%	0.99
VULCAN_lo_2015	912,134	912,134	124.8%	0.98	4,210,964	4,210,964	473.2%	0.99
VULCAN_mn_2015	761,213	759,672	93.3%	0.98	4,058,502	4,058,502	391.8%	0.99
VULCAN_hi_2015	617,740	607,210	71%	0.98	3,906,040	3,906,040	330.7%	0.99

MAE and Mean Error are in units of tonnes CO_2

Global Emissions Validation



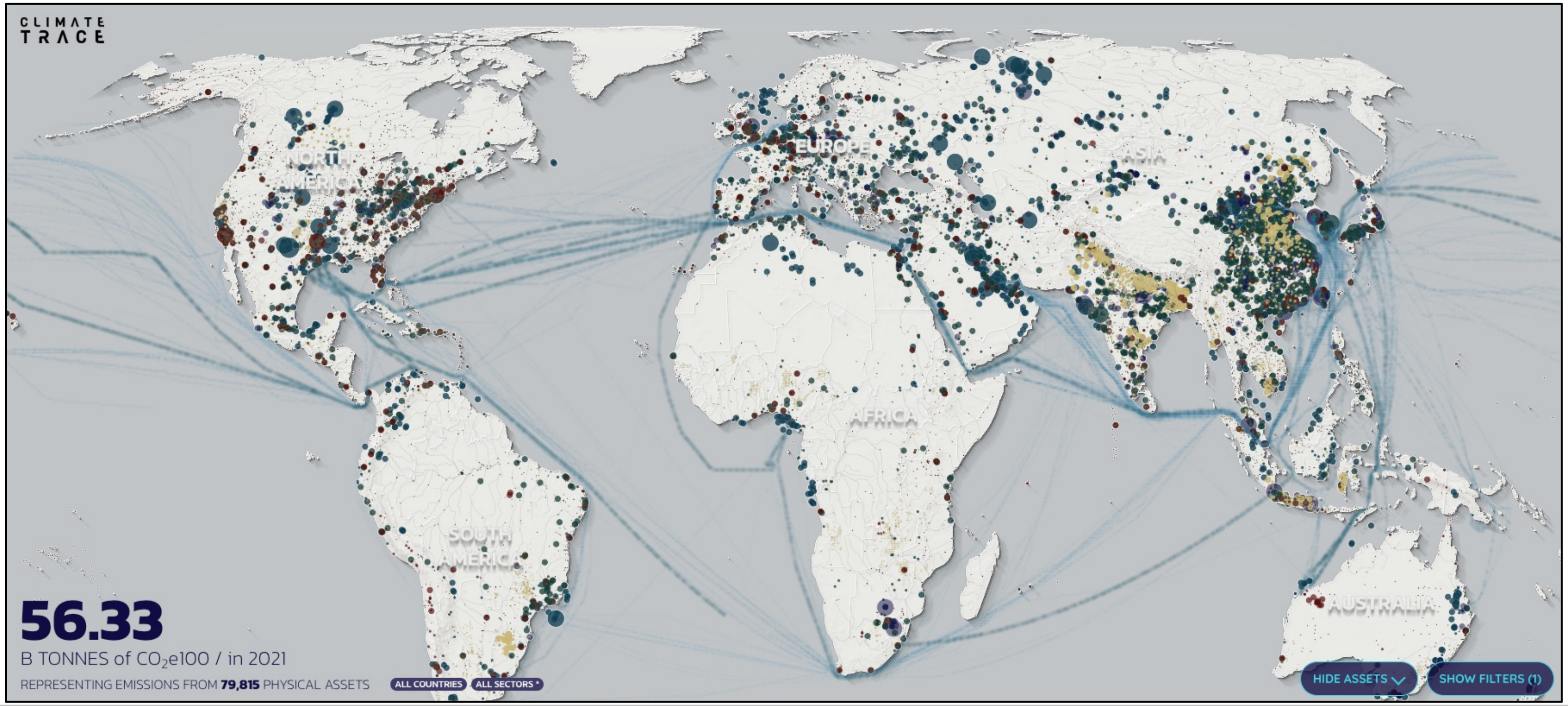
- Emissions estimates compared against other global emissions inventories [14,15] for 14 hold out U.S. cities
- **Strong correlation** between our estimates and others
- **Discrepancies** between estimates warrants future investigation

Emissions Dataset	# of Cities	MAE	MAPE	Mean Error	MPE	Pearson's ρ
EDGAR 2015	500	1,158,740	68.80%	248,624	23.60%	0.74
Carbon Monitor 2019	50	2,857,690	72.40%	-844,634	44.40%	0.87
Carbon Monitor 2020	50	2,634,598	83.20%	-317,283	55.70%	0.86
Carbon Monitor 2021	50	2,795,294	73.50%	-781,053	42.40%	0.87

MAE and Mean Error are in units of tonnes CO_2

Discussion and Next Steps

- Hybrid ML + emissions factors method for global road transportation emissions estimation
- Validation performed for both ML activity predictions and derived emission estimates, both within the U.S. and for global cities.
- Plan to explore integration of traffic/mobility data to improve temporal resolution
- Emissions estimates for top 500 global cities included in November 2022 Climate TRACE asset-level release (www.climatetrace.org)



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References

1. Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2020. Tech. rep. U.S. Environmental Protection Agency, 2022.
2. World Resource Institute. *Climate Watch Historical GHG Emissions*. https://www.climatewatchdata.org/ghg-emissions. 2022.
3. US Federal Highway Administration. *Highway Performance Monitoring System (HPMS) Data*. 2017. URL: https://www.fhwa.dot.gov/policyinformation/hpms.
4. Mordechai Haklay and Patrick Weber. “OpenStreetMap: User-Generated Street Maps”. In: *IEEE Pervasive Computing* (2008).
5. Matthias Drusch et al. “Sentinel-2: ESA’s optical high-resolution mission for GMES operational services”. In: *Remote sensing of Environment* (2012).
6. Planet Labs Inc. *Planet imagery product specifications*. 2022. URL: https://assets.planet.com/docs/Planet_Combined_Imagery_Product_Specs_letter_screen.pdf (visited on 09/13/2022).
7. Shaked Brody, Uri Alon, and Eran Yahav. *How Attentive are Graph Attention Networks?* 2021. DOI: 10.48550/ARXIV.2105.14491. URL: https://arxiv.org/abs/2105.14491.
8. Department for Transport. *Road Traffic Statistics*. 2020. URL: https://roadtraffic.dft.gov.uk.
9. Ministry of Transport - National Directorate of Roads. *2017 TMDA data*. 2017. URL: https://datos.transporte.gob.ar/dataset/tmda.
10. Department of Roads and Travel - Service des Déplacements - Poste Central d’Exploitation Lutèce. *Road counting - Traffic data from permanent sensors*. 2021. URL: https://parisdata.opendatasoft.com/explore/dataset/comptages-routiers- permanents.
11. Google. *Environmental Insights Explorer (EIE)*. 2022. URL: https://insights.sustainability.google.
12. C. Gately, L.R. Hutyra, and I.S. Wing. *DARTE Annual On-road CO2 Emissions on a 1-km Grid, Conterminous USA V2, 1980-2017*. en. 2019. DOI: 10.3334/ORNLDAAC/1735. URL: https://daac.ornl.gov/cgi-bin/dsviewer.pl?ds_id=1735.
13. Kevin R Gurney et al. “The Vulcan version 3.0 high-resolution fossil fuel CO2 emissions for the United States”. In: *Journal of Geophysical Research: Atmospheres* (2020).
14. Greet Janssens-Maenhout et al. “EDGAR v4.3.2 Global Atlas of the three major Greenhouse Gas Emissions for the period 1970–2012”. In: *Earth System Science Data Discussions* (2017).
15. Zhu Liu et al. “Carbon Monitor, a near-real-time daily dataset of global CO2 emission from fossil fuel and cement production”. In: *Scientific Data* 7 (Nov. 2020). DOI: 10.1038/s41597-020-00708-7

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