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Pathways for Climate Sustainability with the Accelerated Deployment of Electric Vehicles

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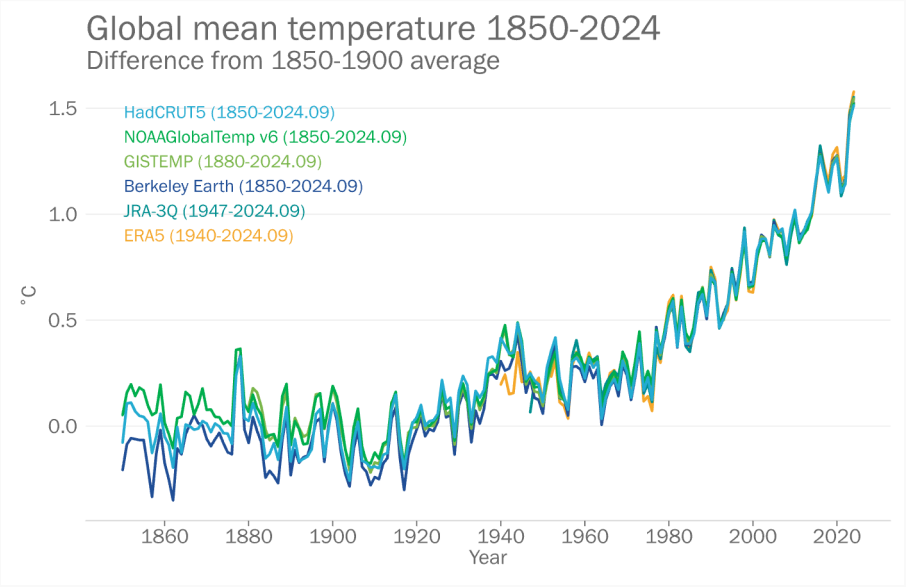
Global Temp Rise, Renewables and EV



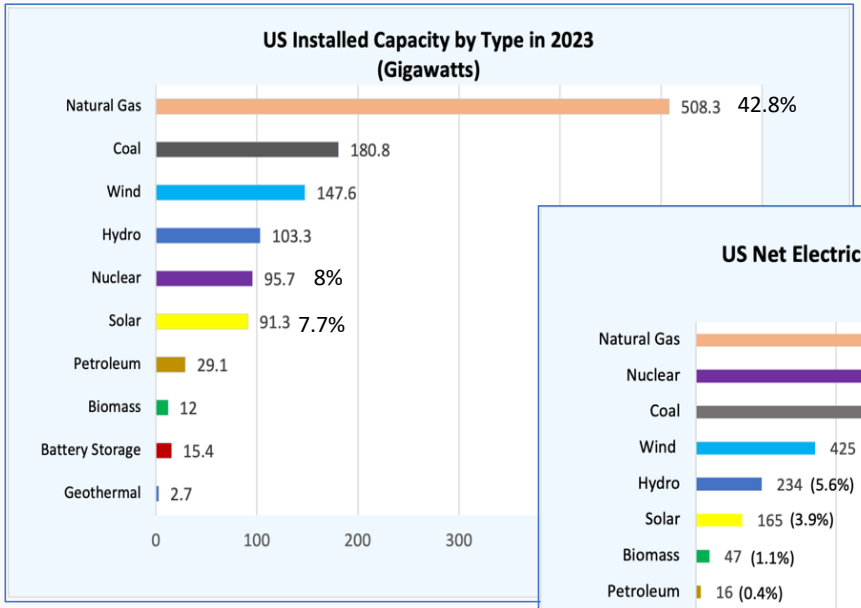
The Urgency of Climate Action

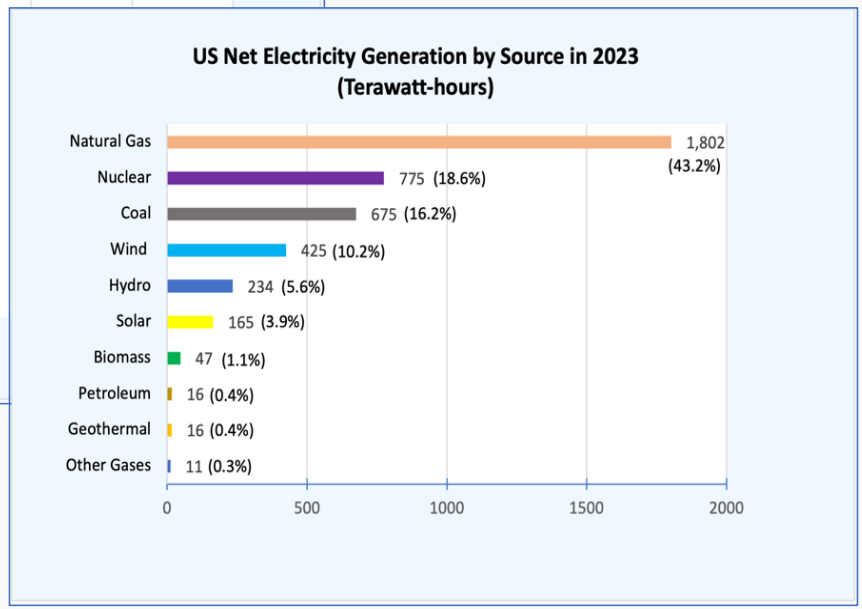
- The world faces an urgent climate crisis and existential threat driven by greenhouse gas emissions. The United States has committed to reducing emissions by 50% by 2030 and achieving net-zero emissions by 2050 as part of a global concerted effort.

- The transportation sector, responsible for over a third of U.S. emissions, presents both challenges and opportunities.

US Electricity Generation Mix (2023)

- U.S. power grid relies heavily on fossil fuels, with coal and natural gas accounting for 60% of the total electricity generation of about 4,200 TWH.
- Of the total 1,186 GW installed capacity, only 39% comes from non-GHG sources like nuclear, wind, hydro, and solar.





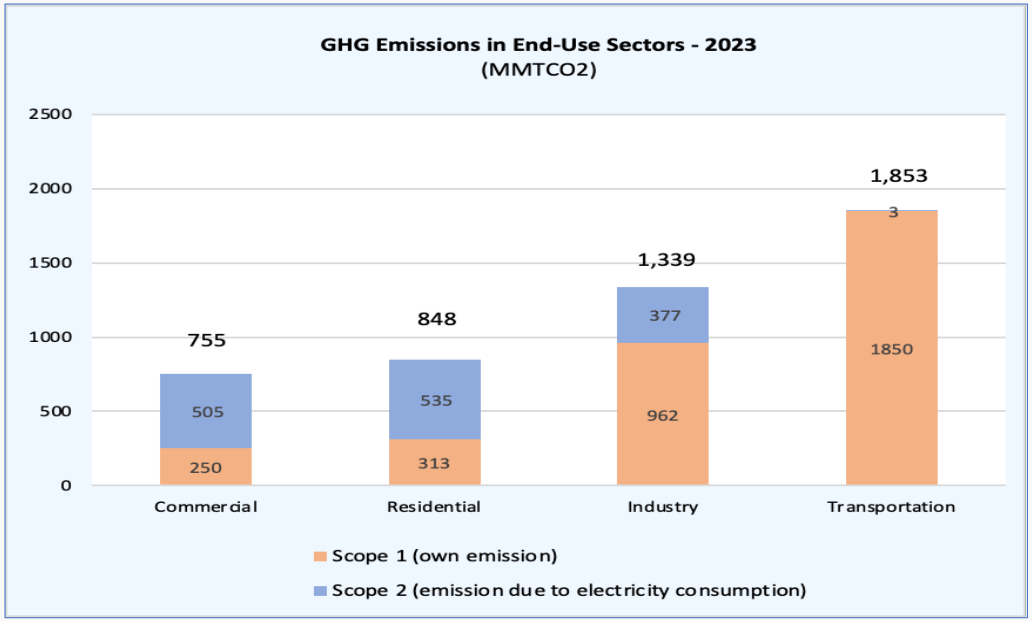
Source: US Energy Information Administration (EIA), October 2024 Monthly Energy Review, DOE/EIA-0035(2024/10)

US GHG Emissions by Sector (2023)

- The transportation sector is the largest contributor to US GHG emissions, accounting for about 39%, followed by the electricity sector at 30%.
- Light-duty vehicles (cars and SUVs) account for nearly half of the emissions in the transportation sector, while medium and heavy-duty vehicles add another significant portion.
- Likewise in the electricity sector, 99% of the GHG emissions are due to the burning of coal and natural gas.
- The emissions of the electricity sector is allocated to the other economic sectors in proportion to their electricity consumption.

Residential	Commercial	Industry	Transportation	Total
1,455 (37.7%)	1,375 (35.6%)	1,025 (26.5%)	7 (0.2%)	3,862 TWH

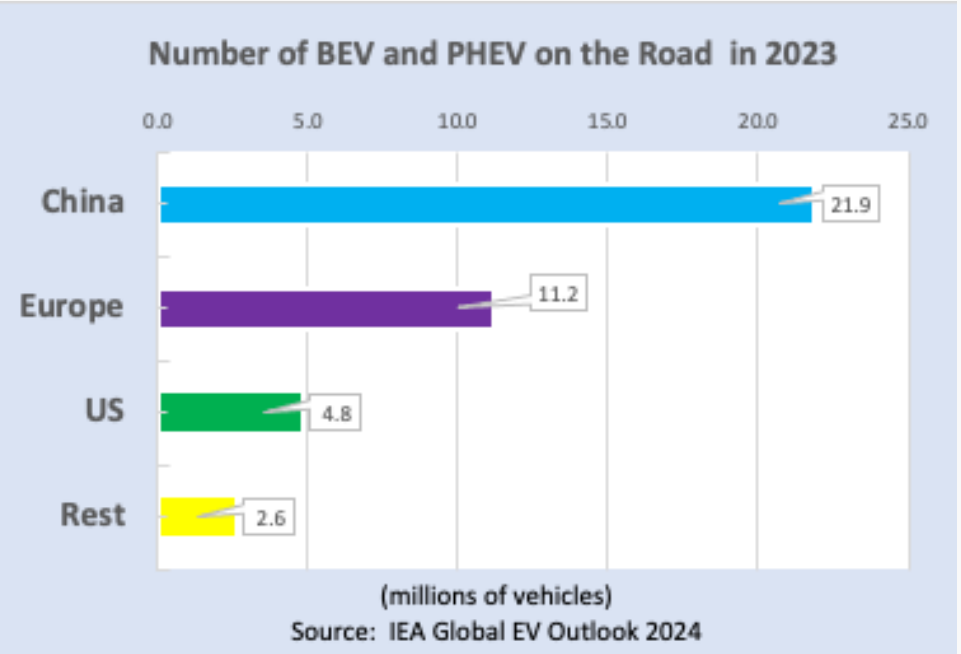
Electricity Consumption by End-use Sectors in 2023 (TWH and % of Total)



Source: US Energy Information Administration (EIA), October 2024 Monthly Energy Review, DOE/EIA-0035(2024/10)

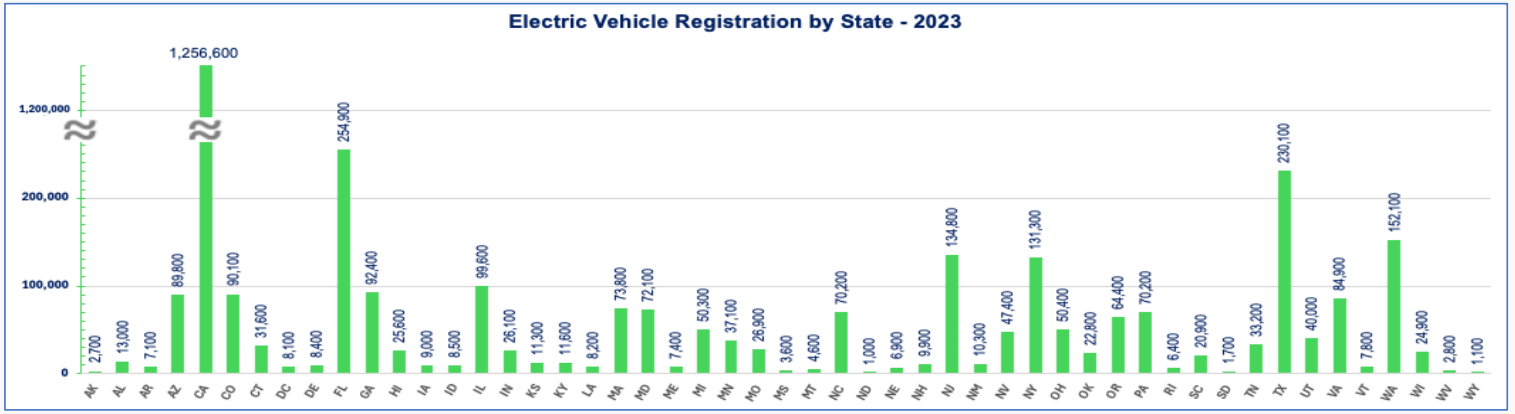
Where the U.S. Stands in EV Adoption (2024)

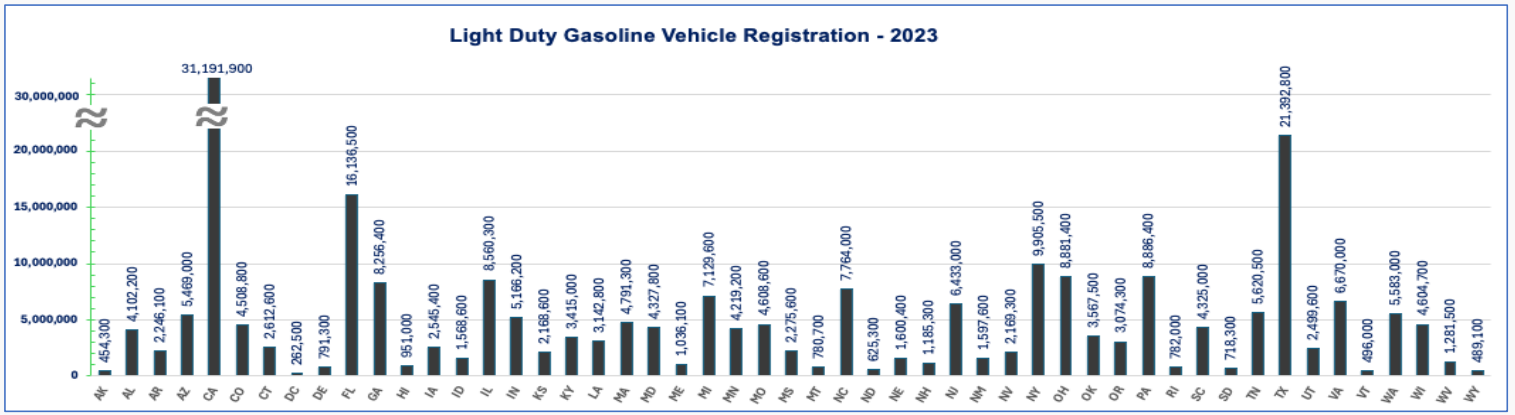
- The US lags behind global EV leaders such as China and the European Union, with only 4.8 million EVs on the road compared to China's 22 million and EU's 11.2 million.
- The market share of light-duty electric vehicles in the US, which was 6% in 2022, is projected to attain 13%-29% range depending on the price of oil during 2030-2050 period. Projections indicate that by 2030, over 26.5 million or 10% of the vehicles on US roads will be light duty electric vehicles.



Light Duty Vehicle Registration by Type and State -2023

- California, Texas, and Florida were the States with the largest number of gasoline vehicles at over 31, 21 and 16 million units, respectively.
- Wyoming, Alaska, and D.C. were the States with the lowest numbers of gasoline vehicles registered at 489, 454 and 262 thousand units, respectively.
- California, Florida, and Texas had the most EVs registered at over 1.256, 0.254 and 0.230 million unit, respectively.
- South Dakota, Wyoming and North Dakota registered the fewest number of EVs at 1700, 1100, and 1,000 units, respectively.





Are EVs Truly Clean?

- EVs themselves do not produce emissions, but the electricity used to charge them leaves a carbon footprint depending on the mix of the sources used in generating it.
- A vehicle charged in Vermont, where clean energy plays a major role, results in far fewer emissions than one charged in coal-reliant West Virginia. The overall impact of EVs must be evaluated not just by the number on the road, but also by the carbon intensity of the electricity they consume.

Assumptions Used in Calculating Emissions of EVs and Light Duty Gasoline Vehicles

ELECTRIC VEHICLE	
Vehicle Miles Traveled Annually (VMT) [1]	11,579 miles
Average Energy Consumption [2]	34.6 KWH/100 miles
Annual Consumption/Vehicle	4,006 KWH

1. Average annual vehicle miles traveled for light duty vehicles 2019, Transportation Energy Data Book, Edition 39, 2020
2. Based on the average consumption of 231 light-duty EVs produced during 2000-2022 and tracked by EPA's fueleconomy.gov.

GASOLINE VEHICLE	
Vehicle Miles Traveled Annually (VMT) [1]	11,579 miles
Average Tailpipe CO_2 Emission [2]	0.4 KG/mile
Annual CO_2 Emission/Vehicle	4,632 KG

1. Average annual vehicle miles traveled for light duty vehicles 2019, Transportation Energy Data Book, Edition 39, 2020
2. EPA estimates, Tailpipe Greenhouse Gas Emissions from a Typical Passenger Vehicle, https://www.epa.gov/greenvehicles/greenhouse-gas-emissions-typical-passenger-vehicle

Estimating Emissions of EVs and Light Duty Gasoline Vehicles

EMISSIONS due to CHARGING ELECTRIC VEHICLES from the GRID

$$CO_2 \text{ Emissions} = (\text{Annual Energy Consumption/EV}) \times (CO_2 \text{ Output Emission Rate for the State})^{1} \times (\text{No. of EVs Registered in the State})$$

1. The CO_2 Output Emission Rate is the amount of CO_2 generated in producing a unit of energy using the generation mix of the power plants in each State. https://www.epa.gov/egrid/data-explorer.

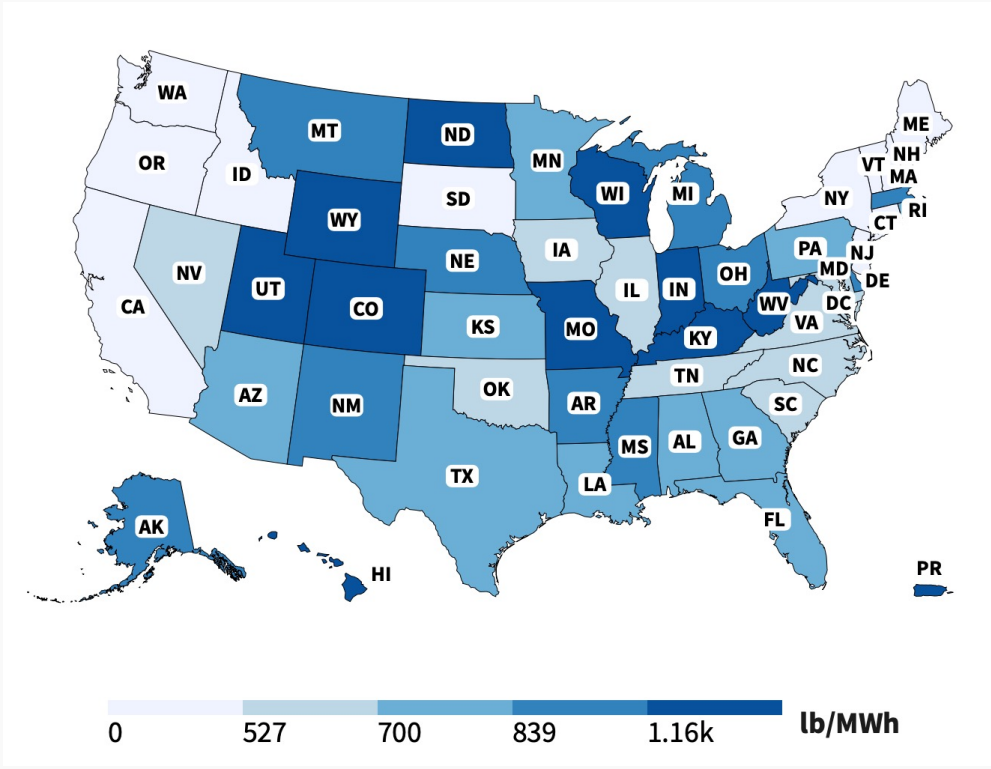
EMISSIONS due to TAILPIPE EMISSIONS from GASOLINE VEHICLES

$$CO_2 \text{ Emissions} = (\text{Annual Tailpipe Emission/vehicle}) \times (\text{No. of GVs Registered in the State})$$

CO_2 Total Output Emission Rate by State - 2022 (lb/MWh)

CO_2 Emission Rates depend on the generation mix of each State. States with more fossil-fueled generation emit more CO_2.

ALABAMA	787.66
ALASKA	912.71
ARIZONA	709.12
ARKANSAS	1,056
CALIFORNIA	455.94
COLORADO	1,166
CONNECTICUT	520.86
DELAWARE	899.25
DISTRICT OF COLUMBIA	553.98
FLORIDA	815.57
GEORGIA	737.19
HAWAII	1,453
IDAHO	247.85
ILLINOIS	588.41
INDIANA	1,567
IOWA	617.35
KANSAS	820.17
KENTUCKY	1,720
LOUISIANA	818.06
MAINE	336.61
MARYLAND	637.05
MASSACHUSETTS	851.74
MICHIGAN	1,009
MINNESOTA	768.24
MISSISSIPPI	886.21
MISSOURI	1,506

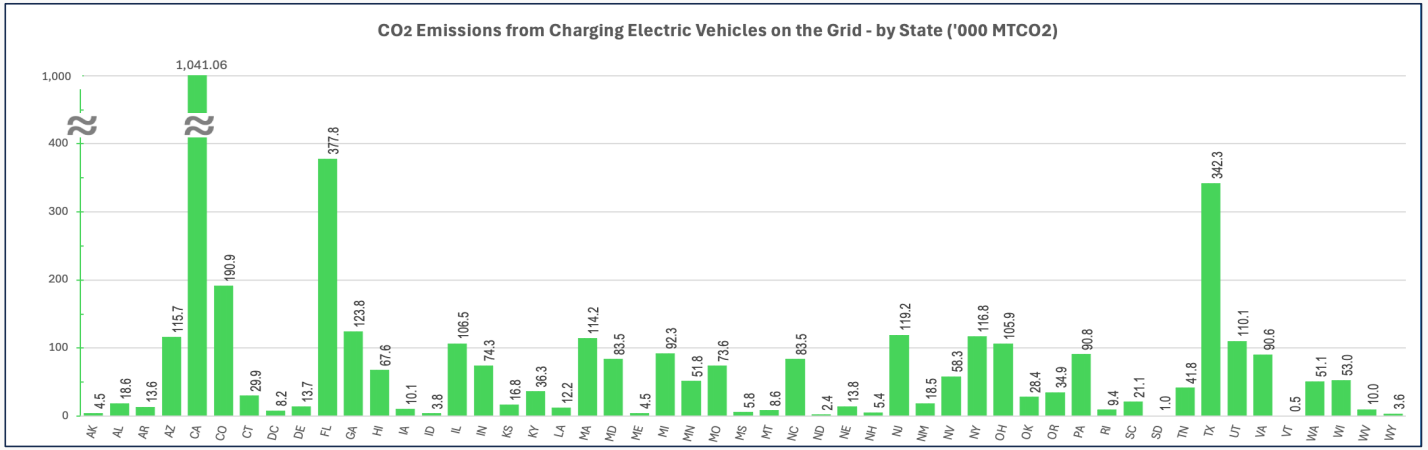


MONTANA	1,023
NEBRASKA	1,097
NEVADA	676.96
NEW HAMPSHIRE	302.93
NEW JERSEY	486.63
NEW MEXICO	985.81
NEW YORK	489.71
NORTH CAROLINA	654.57
NORTH DAKOTA	1,311
OHIO	1,156
OKLAHOMA	686.63
OREGON	298.21
PENNSYLVANIA	711.37
PUERTO RICO	1,593
RHODE ISLAND	811.32
SOUTH CAROLINA	556.74
SOUTH DAKOTA	325.11
TENNESSEE	693.63
TEXAS	818.54
UTAH	1,514
VERMONT	35.63
VIRGINIA	587.45
WASHINGTON	184.81
WEST VIRGINIA	1,959
WISCONSIN	1,171
WYOMING	1,804

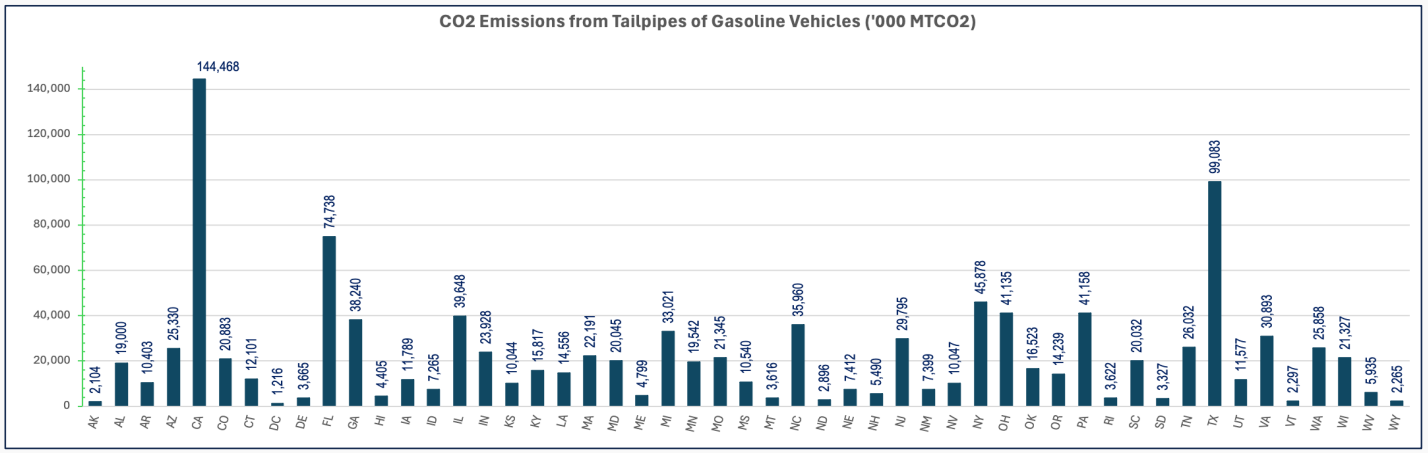
Source: EPA eGRid Data
https://www.epa.gov/egrid/data-explorer

CO_2 Total Emission by State – 2022 ('000 MTCO2)

Emission due to EV Charging



Emission from Tailpipes of Gasoline Vehicles

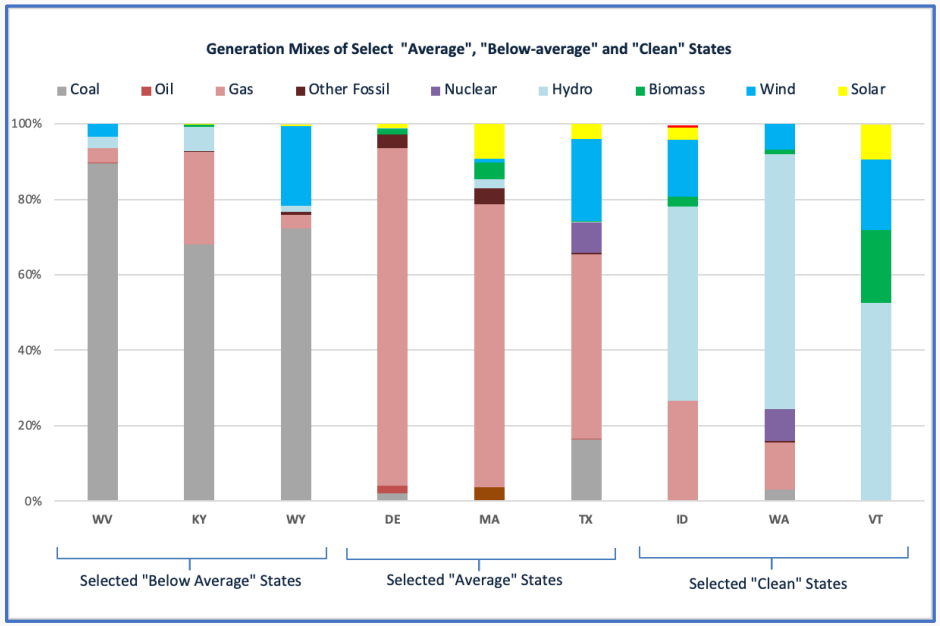


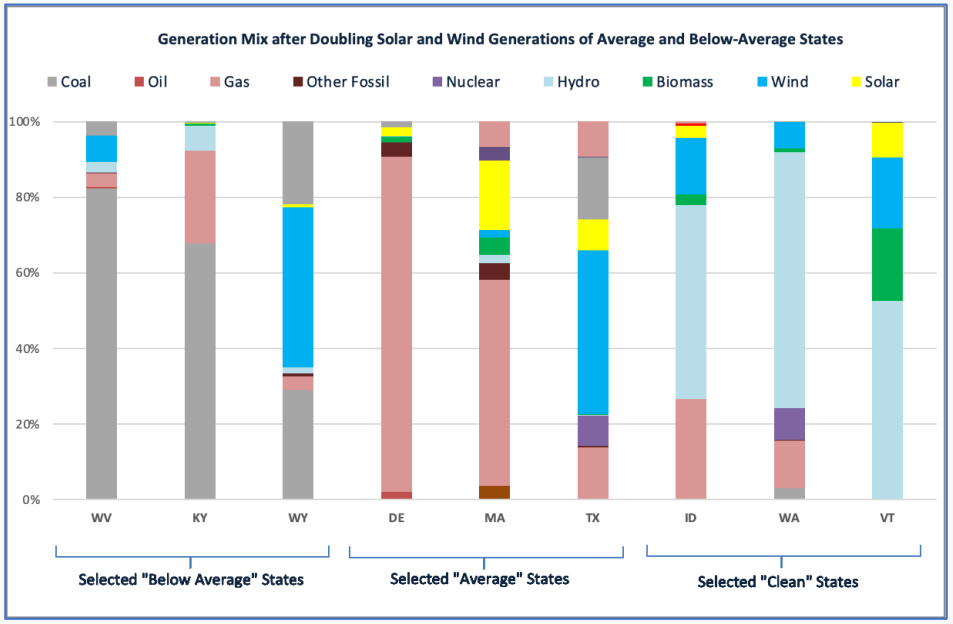
What-if Analyses on Alternatives to Reduce CO_2 Emissions

- A few States were selected and categorized in three groups for the analyses based on their CO_2 Output Emission Rates centered around the US average (0.401 kg/KWH).
- Three states were selected in each category as shown below:

Below-average (States with high emission rates)	**Average** (States with moderate emission rates)	**Clean** (States with low emission rates)
West Virginia (0.889 kg/kWh)	Delaware (0.408 kg/kWh)	Idaho (0.112 kg/kWh)
Wyoming (0.819 kg/kWh)	Texas (0.371 kg/kWh)	Washington (0.084 kg/kWh)
Kentucky (0.780 kg/kWh)	Massachusetts (0.386 kg/kWh)	Vermont (0.016 kg/kWh)

Generation Mix of Selected States in each Category (2022)





- Generation mix in "Below-Average" States is dominated by coal-fired power plants with some natural gas and wind energy generation.
- Generation mix in "Average" States is predominantly natural gas powered with some solar and wind energy generation.
- "Clean" States generate most of their electricity from hydro with some solar, wind and nuclear generation.

- The Solar and Wind components of the generation mixes of "Below-Average" and "Average" States were doubled at the expense of the dominant fossil-fuels, i.e., Coal and Natural Gas.
- Wyoming and Texas had the most impact from doubling their wind energy generation, followed by impact of solar PV in the generation mixes of Massachusetts and Texas.
- Generation mixes of the "Clean States" were left unchanged.

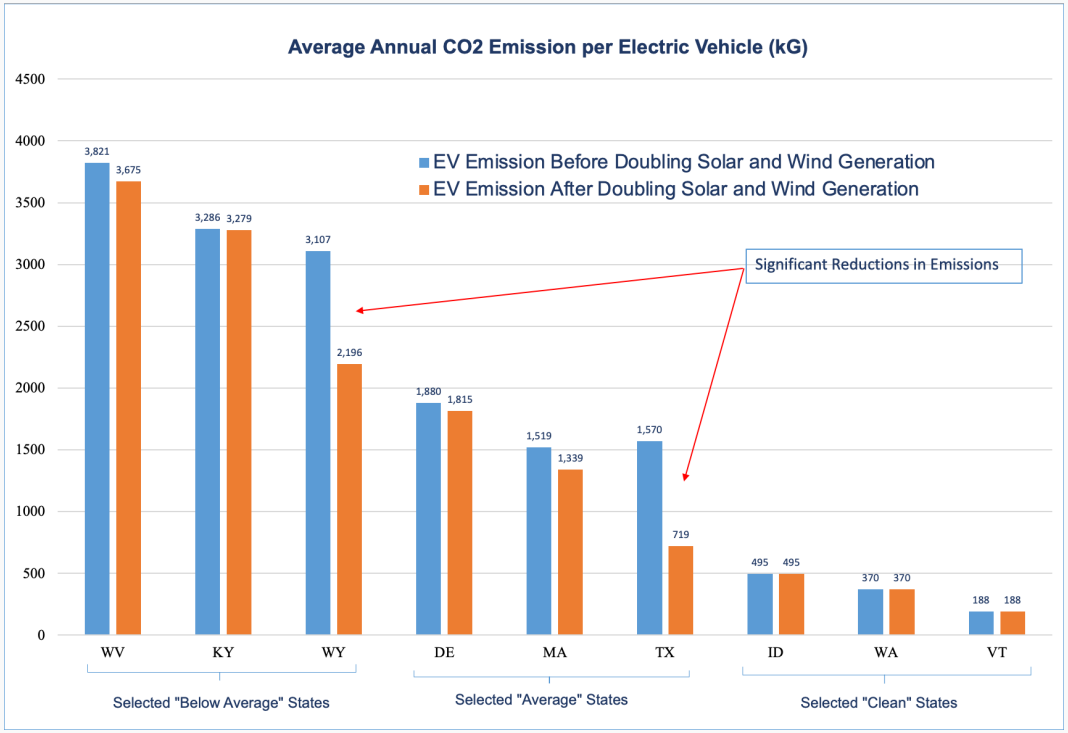
Observations and Findings

- Wyoming and Texas attained significant reductions in their CO2 output emission rates when solar and wind generation were doubled replacing equivalent amounts of coal and natural gas fired generation. This was due to the large wind energy generation (about 20-25%) in their mix.
- Alternatively, West Virginia, with a generation mix composed mostly of coal (89.5%), natural gas (3.7%), wind and solar (3.5%) and hydro (2.9%) was only able to achieve a slight improvement in its CO_2 output emission rate. Although its Wind generation was doubled to 7.0%, it still had a large share of its generation mix based on coal (82.5%).

States	CO_2 Output Emission Rate (Actual Generation Mix)	Estimated CO_2 Output Emission Rate after Doubling Renewables in the Generation Mix
West Virginia	0.889 kg/kWh	0.854 kg/kwh
Wyoming	0.819 kg/kWh	0.579 kg/kwh
Kentucky	0.780 kg/kWh	0.778 kg/kwh
Delaware	0.408 kg/kwh	0.394 kg/kwh
Massachusetts	0.386 kg/kwh	0.341 kg/kwh
Texas	0.371 kg/kwh	0.170 kg/kwh

Observations and Conclusions

- The revised CO_2 output emission rates, resulting from the doubling of Solar and Wind in the generation mix, were used to recalculate the average annual CO_2 emissions that would be incurred in charging an electric vehicle using the grid.
- As expected, electric vehicles in Wyoming and Texas will have a significant reduction in their annual CO2 emissions by 27% and 54%, respectively.
- The contribution of electric vehicles in reducing emissions in states dominated by fossil fuel-based electricity generation may be minimal. Conversely, in states with a more favorable generation mix featuring a higher percentage of Solar and Wind generation, EVs could provide a pivotal role in helping states achieve emissions reduction goals.



Conclusions

- The energy generation mix in many states remains far from carbon-free and is expected to stay that way for the foreseeable future.
- Although electric vehicle registrations are still orders of magnitude lower than those of gasoline vehicles across all states, the market share of EVs is gradually increasing due to growing public acceptance, awareness, incentives, and infrastructure improvements.
- Tailpipe emissions from gasoline vehicles will always exceed the indirect emissions associated with charging an electric vehicle from the grid. Even in West Virginia, the state with the highest CO2 emission rate in the country, gasoline vehicles emit an average of 4,362 kg of CO2 annually, compared to 3,571 kg for electric vehicles. This highlights the clear environmental benefits of transitioning to electric vehicles.

Conclusions-2

- The shift to electric vehicles must go hand in hand with a transition to renewable energy. States with cleaner grids will experience the greatest benefits, while regions still dependent on fossil fuels must prioritize clean electricity to maximize the value of EV in emissions reduction. By electrifying transportation and decarbonizing the energy sector, these regions can build a sustainable, low-carbon future.
- Most importantly, as the adoption of electric vehicles grows, transitioning to a cleaner energy mix will shift emissions from distributed tailpipe sources to centralized point-source emissions at power plants. This change will enable the implementation of the best available technologies for capturing, sequestering, or processing emissions, further enhancing environmental sustainability.