Evaluating future emissions from electric vehicles across the United States with a changing electric grid mix under the Clean Power Plan

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Overview

In the United States, the transportation sector consumes approximately five billion barrels of oil annually and accounts for nearly a third of greenhouse gas emissions. The potential climate impacts of the transportation sector has led to a transition towards cleaner, alternative fuel vehicles such as electric vehicles (EVs)—touted as "zero-emission" vehicles. The transition has been accelerated by policy such as the Zero Emissions Vehicle (ZEV) mandate in California and incentives such as the federal Plug-In Electric Vehicle Credit (IRC 30D). However, if the ultimate goal of the transition is to create a cleaner transportation system, a proper accounting of emissions is necessary to understand the true impact of EVs. A nationwide electricity dispatch model was constructed based on outputs from the Environmental Protection Agency's (EPA) Integrated Planning Model (IPM) used in the assessment of the Clean Power Plan (CPP). Using future projections of EV sales as well as a number of scenarios for charging behavior, a profile of electric vehicle emissions can be captured on sub-state level and importantly across a lengthy time span from 2016 through 2050. The time periods being captured are significant due to the lack of existing literature on EV emissions as the electric grid changes and cleaner sources of electric capacity are developed.

Methods

A simple economic dispatch model is constructed using the EPA's Power Sector Modeling Platform. The inputs for the model are from their National Electric Energy Data System (NEEDS) v.5.15 as well as their Integrated Planning Model (IPM) used for the impact assessment for the Clean Power Plan. The operation of all electric generators can be modelled by minimizing the total system cost to the operator as follows:

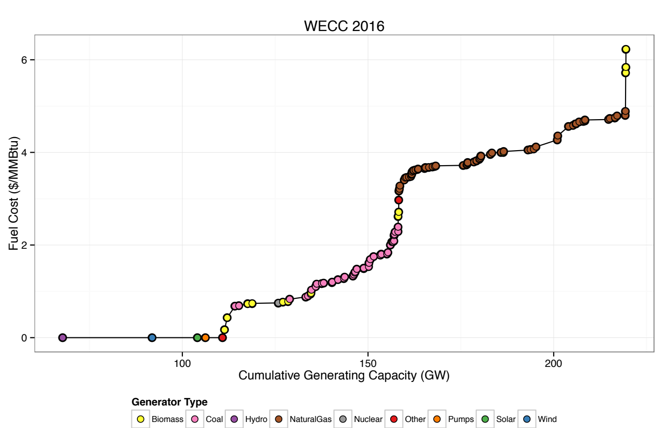
$$\min_{x_{gt}^{\text{gen}},\, x_{rto}^{\text{trans}}} \sum_{gt} \left(x_{gt}^{\text{gen}} c_{g}^{\text{cost}} + \sum_{rto} x_{rto}^{\text{trans}} c_{ro}^{\text{transcost}} \right)$$

Subject to constraints:

$$\sum_{g} x_{gt}^{\text{gen}} + \left(\sum_{o} x_{otr}^{\text{trans}} c^{\text{transloss}} - \sum_{p} x_{rtp}^{\text{trans}} \right) - c_{tr}^{\text{load}} = 0, \forall tr$$

$$c_{ro}^{\text{transCap}} - \sum_{t} x_{rto}^{\text{trans}} \geq 0, \forall rto$$

where g represents the set of generators, t represents the set of time periods (8760 hours in a year), $\{r, o, p\}$ are aliases of a set representing regions. The decision variables of the program are xgen which represents how much electricity a particular generator produces in a single time period and x^{trans} which represents the amount of electricity transmitted from one region to another in a single time period. Parameters include ccost (cost to generate a MWh of electricity), $c^{\text{transcost}}$ (cost to transmit a MWh of electricity across a specific transmission line), c^{load} (electric demand load), and c^{transCap} (maximum amount of electricity that can travel across a specific transmission line).



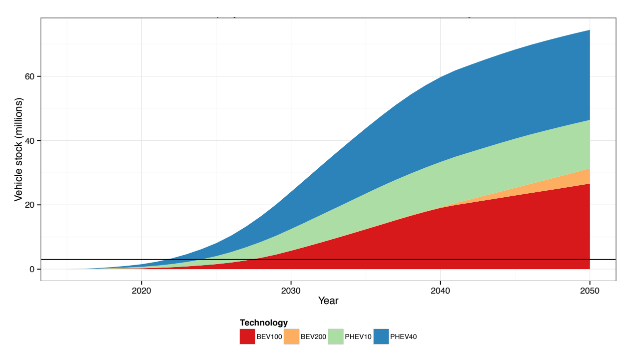
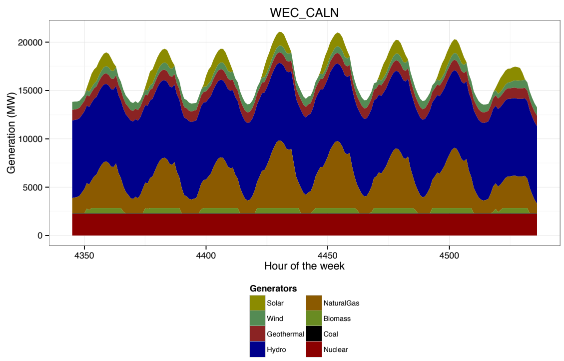


Figure 1a (left): Dispatch order of generators for the Western interconnect balancing area in 2016.
Figure 1b (right): National Academies forecast of electric vehicle adoption through 2050

Several projections of electric vehicles are employed as scenarios for future adoption through 2050 (see example in Fig 1b). The vehicles are then distributed into the different regions of measurement and their daily driving and charging patterns are simulated via data from the California Household Travel Survey administered by CalTrans. The electricity demand isolated to electric vehicle charging is then added to the baseload demand and the dispatch model is run with and without this additional demand in order to determine the difference in electricity and emissions generation.

Results



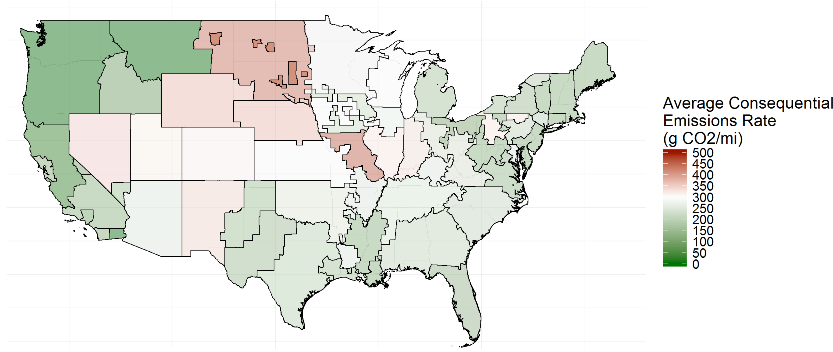


Figure 2a (left): Example dispatch output for one week in July of 2016 in Northern California
Figure 2b (right): Average consequential emissions of electric vehicle by region in 2016

Fig 2a demonstrates the output of the dispatch model over a small time window in Northern California but the model itself is currently fully functional for the entire country for select years from 2016 through 2050. Fig 2b shows the average emissions associated with electric vehicles across the US in the EPA Integrated Planning Model regions. The figure shows consequential emissions, that is the emissions associated with the addition of all electric vehicles in the United States.

Conclusions

The development of this model is the first academic attempt at understanding how emissions of electric vehicles will differ both spatially *and* temporally across the US far into the future. The ability to use IPM results from the Clean Power Plan ensures the use of a plausible scenario of future electric grid since those results are modeled to ensure future compliance of all states. The results provide insights into how electric vehicles contribute, both marginally and in total, to emissions throughout the United States. Across scenarios of electric vehicle adoption and charging patterns, the model will output the expected consequential emissions of electric vehicles in the Clean Power Plan framework. The results indicate to what extent the cleaning of the power system will lead to decreased emissions from electric vehicles—and importantly the relative locational benefits of this transition. The work has important implications for government stakeholders as it may influence policy makers (especially in dirtier regions of the country's electric grid) that are considering ZEV-like policies or other policies affecting the adoption of electric vehicles.

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