EV Infrastructure and Grid Impacts

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Infrastructure

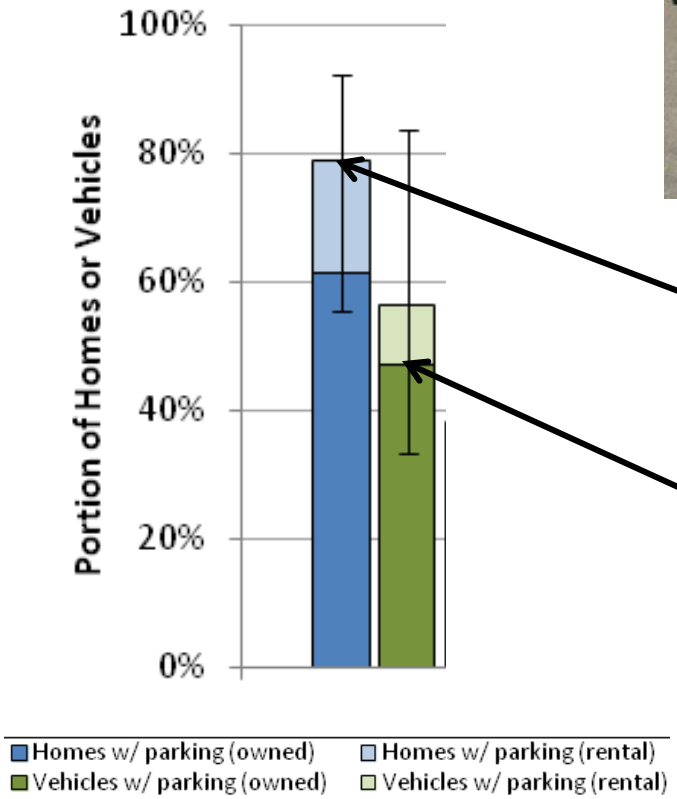
Public Infrastructure Needs

- US public charging infrastructure lags behind other countries, even if the infrastructure bill is realized
- This doesn't immediately imply a problem, since we have more off-street parking than most (most BEVs will leave home with a full tank of electricity on most days), but…

	Chargers per 100 EVs
World	13
China	18
EU	9
US	6

Source: IEA Global EV Outlook 2021

BEV Adoption is Limited by Parking



Most US **households** have some off-street parking

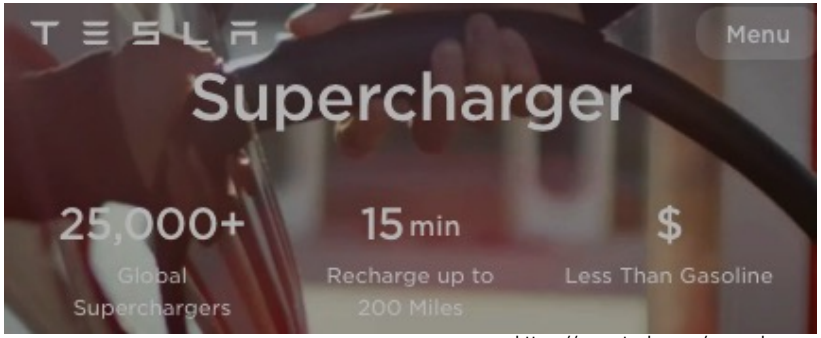
But only ~half of US **vehicles** have reliable off-street parking at an owned residence

So, a complete fleet transition is likely unrealistic without major infrastructure changes

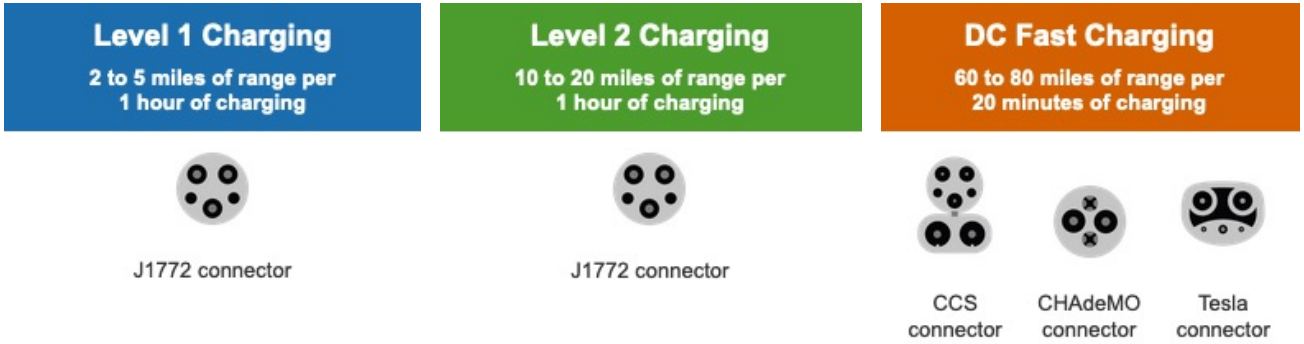
Traut, E., C. Cherng, C. Hendrickson, and J.J. Michalek (2013) "U.S. residential charging potential for electric vehicles," Transportation Research Part D v25 p139-145.

Public Infrastructure Needs

- For those who depend on public chargers, level 2 chargers in retail parking lots aren't going to cut it
- Even the highest speed charging may create long queues at service stations



https://www.tesla.com/supercharger



https://afdc.energy.gov/fuels/electricity_infrastructure.html

Public Infrastructure Priorities

1. High speed charging along **interstates** to enable long distance BEV travel
   - Many charge points eventually needed (more than gas pumps) to manage queuing during peak travel holidays
   - Many will go underutilized during other periods
2. High speed charging in **neighborhoods** where households depend on public chargers
   - Renters and dense areas
   - But, high speed charging creates challenges for the grid
   - Partial vehicle automation could make slower charging more realistic for queuing and juggling vehicles

Impact

Life Cycle Assessment

- What are the emissions impacts of EV charging?
- Why do different studies produce different answers?

Some major reasons

1. They answer different questions (attributional / consequential)
2. They take on different scopes (emission sources, types, …)

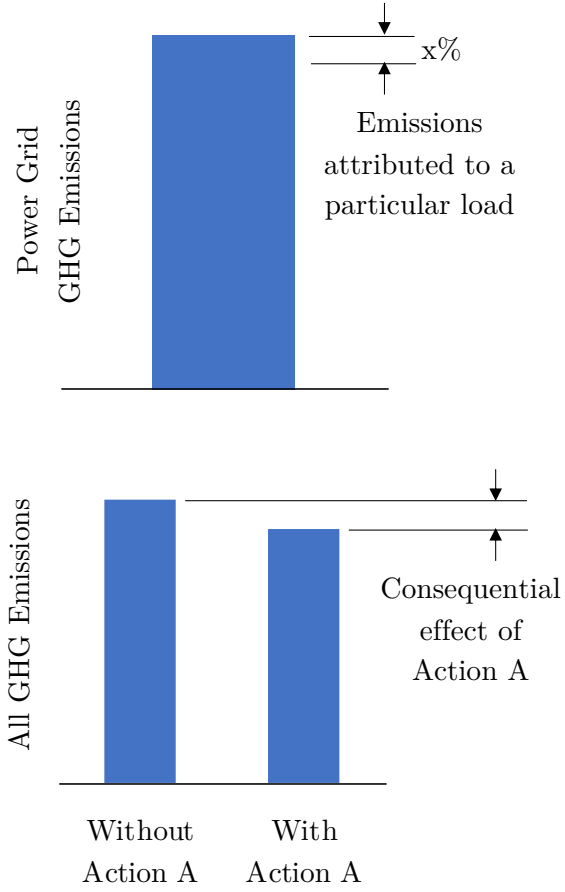
Study	Vehicle types	Regional resolution	Life cycle scope	Electricity source and emissions	Utility factor or VMT pattern	Driving conditions	Temperature
Onat *et al* (2015) [6]	ICV, HEV, PHEV, BEV	13 NERC subregions	**Life Cycle**	**Consequential** Marginal emissions from Thomas (2012) [19] which is based on ORCED model	**Regional** State based utility factors	**Homogeneous** EPA combined	**Ignored**
Tamayao *et al* (2015) [2]	ICV, HEV, PHEV, BEV	NERC region	**Life Cycle**	**Consequential** Compares Graff Zivin *et al* (2014) and Siler-Evans *et al* (2012) marginal emission factors by NERC region and average state, eGRID subregion, and NERC emission factors	**Homogeneous** US NHTS (2009) national distribution	**Homogeneous** EPA combined	**Ignored**
Yuksel and Michalek (2015) [11]	BEV	NERC region	**Partial Use Phase** Electricity generation; gasoline combustion	**Consequential** Compares Graff Zivin *et al* (2014) and Siler-Evans *et al* (2012) marginal emission factors by NERC region.	**Homogeneous** US NHTS (2009) national distribution	**Homogeneous** Efficiency based on FleetCarma on-road data [28]	**Regional** Based on FleetCarma data for Nissan Leaf and regional temperature data
Nealer *et al* (2015) [18]	BEV	eGRID subregions	**Life Cycle**	**Attributional** Average emission rate for generators located in each subregion.	**Homogeneous**	**Homogeneous** EPA combined city/highway	**Ignored**
Archsmith *et al* (2015) [20]	ICV, BEV	NERC regions	**Life Cycle**	**Consequential** Regression-based marginal emission estimates for current, average emission rates for future	**Regional** Based on regional NHTS data	**Homogeneous** Based on GREET	**Regional** Based on data from [26–27]

…

Yuksel, T., M. Tamayao, C. Hendrickson, I. Azevedo and J.J. Michalek (2016) "Effect of regional grid mix, driving patterns and climate on the comparative carbon footprint of electric and gasoline vehicles," *Environmental Research Letters*, v11 n4 044007.

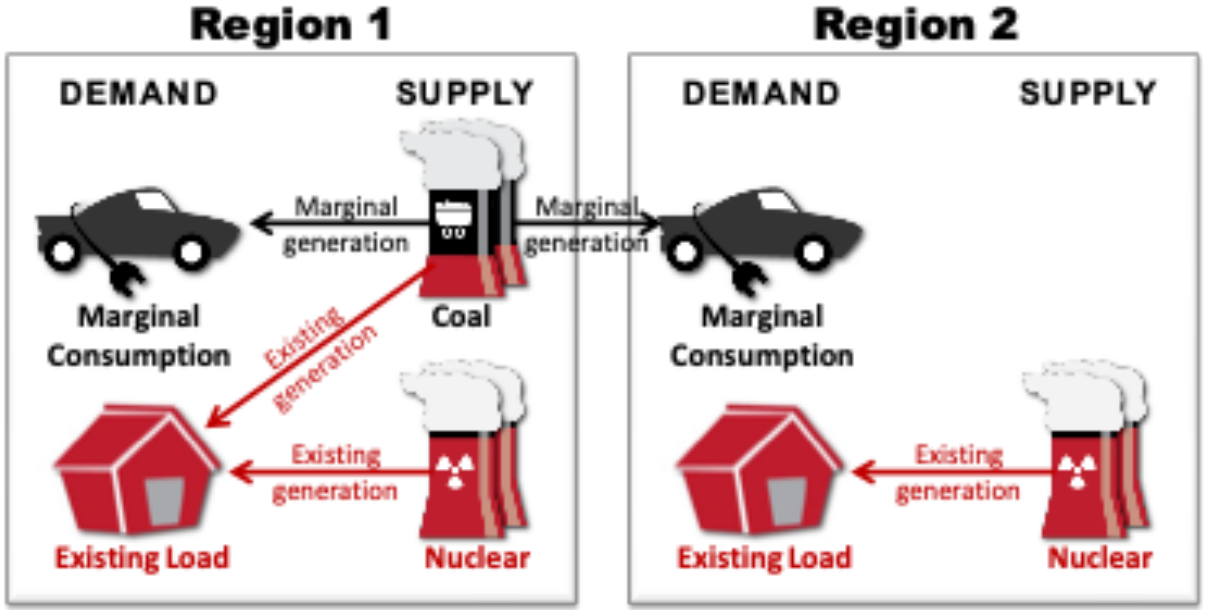
Life Cycle Assessment Questions

- **Attributional**
  - "What emissions are an EV associated with or responsible for?"
  - Requires value judgments: how to assign responsibility?, system boundary, allocation of emissions to co-products
- **Consequential**
  - "How will emissions change if we adopt more EVs or EV policy?"
  - Requires estimating counterfactual scenarios, usually uncertain



Marginal Emission Factors

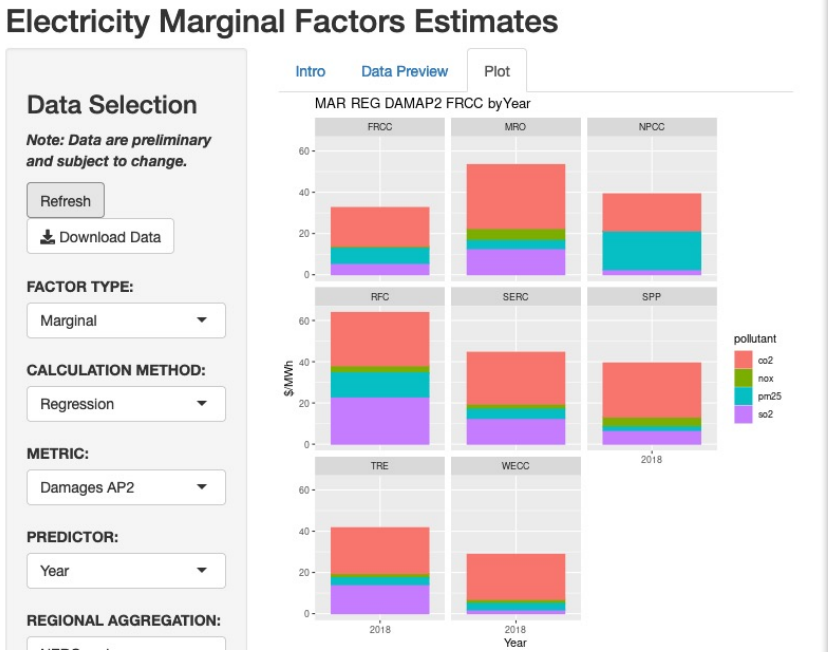
- Marginal emission factors provide a snapshot estimate of consequential emissions from small changes in load



Tamayao, M., J.J. Michalek, C. Hendrickson and I. Azevedo (2015) "Regional variability and uncertainty of electric vehicle life cycle CO_2 emissions across the United States," *Environmental Science & Technology*, v49 n14 p8844-8855.

Consequential Emissions

- **Consequential emissions** are typically the question of interest for policy or adoption – what will be the effect of an action?
- **High uncertainty**: Need to estimate the difference in grid emissions, over time, with vs. without EV adoption or policy
- If the change in load is small, **marginal emission factors** (now widely accessible) provide a snapshot estimate of consequential emissions



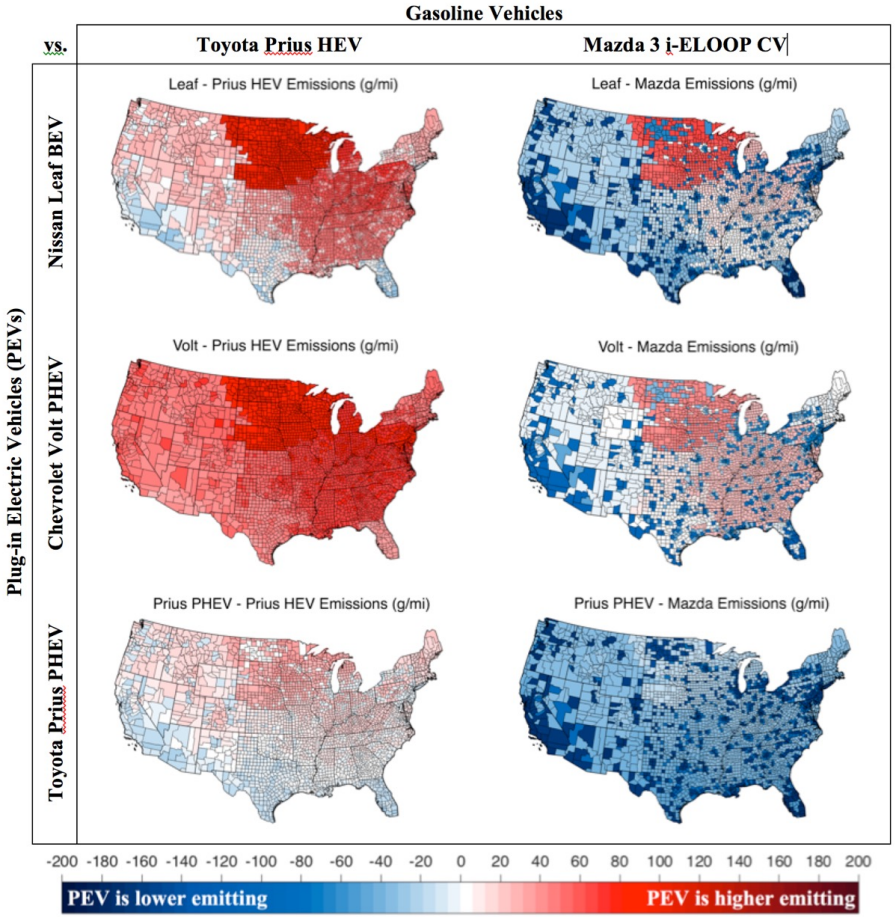
https://cedm.shinyapps.io/MarginalFactors/

Consequential Emissions

- Some modelers prefer to use attributional methods and average emission factors because consequential emissions are uncertain
- This answers a different question and implies a value judgment
- If we want to know the effect of an action (EV adoption or policy) on emissions, the uncertainty is there whether we model it or not – better to estimate it than ignore it

EV Benefits Vary

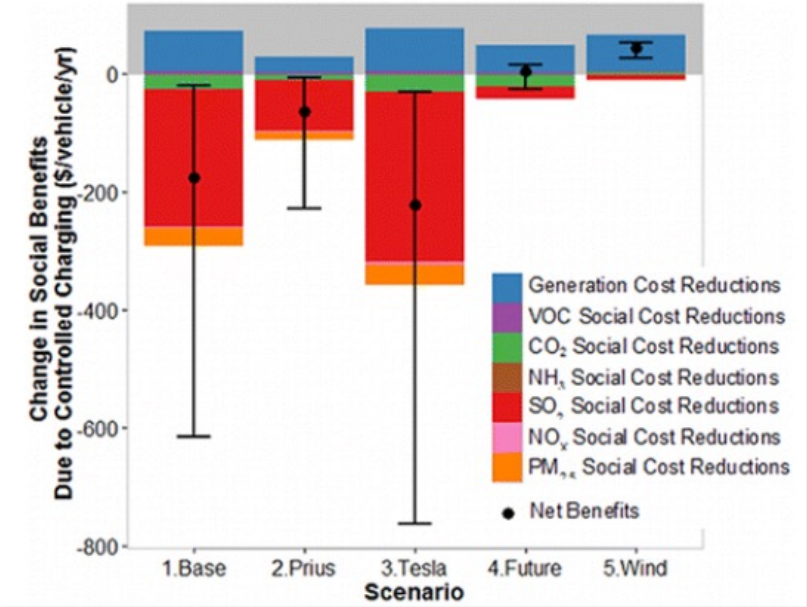
- The relative consequential GHG benefits of EVs depend considerably on:
  - Which specific vehicle designs are compared
  - Regional grid mix
  - Driving patterns
  - Climate



Yuksel, T., M. Tamayao, C. Hendrickson, I. Azevedo and J.J. Michalek (2016) "Effect of regional grid mix, driving patterns and climate on the comparative carbon footprint of electric and gasoline vehicles," *Environmental Research Letters*, v11 n4 044007.

V2G Has Benefits and Costs

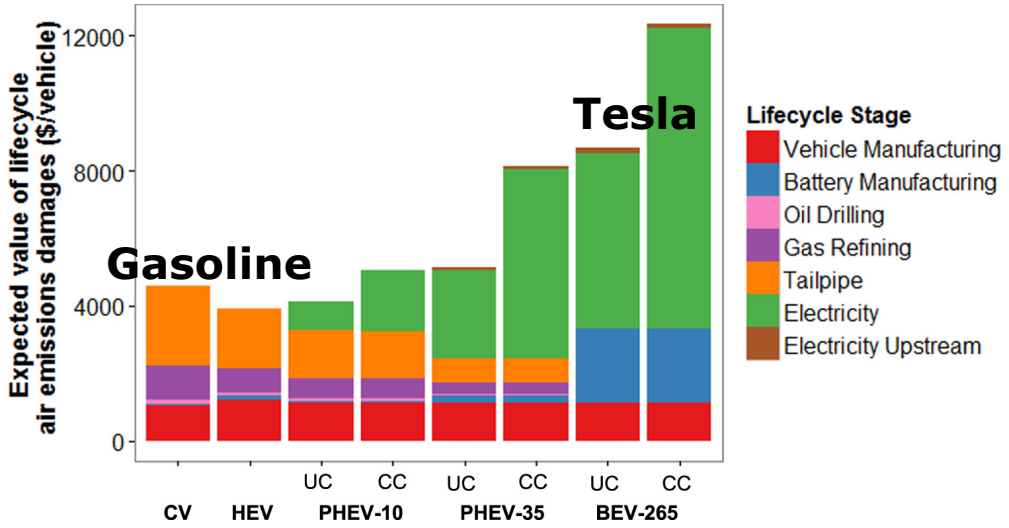
- V2G and utility-controlled charging can reduce costs of electricity generation
- However, it can do so by increasing utilization of coal plants at night, increasing consequential emissions damages
- Public cost of emissions can outweigh generation savings



Weis, A., J.J Michalek, P. Jaramillo and R. Lueken (2015) "Emissions and cost implications of controlled electric vehicle charging in the US PJM interconnection," *Environmental Science & Technology*, v49 n9 p5813-5819.

Coal is Key

- Back in 2016 we estimated that a Tesla in the PJM region created 2-3x the emissions costs of a gasoline vehicle, largely due to SO2 from coal
- We predicted that would change by now due to coal retirement
- We're working on a new study to see if it did



Weis, A., P. Jaramillo and J.J. Michalek (2016) "Consequential life cycle air emissions externalities for plug-in electric vehicles in the PJM interconnection," *Environmental Research Letters*, v11 n2 024009.

Take Away

- Public charging infrastructure strategy should target high speed chargers on interstates and neighborhoods with limited off-street residential parking
- Emissions implications of EVs depend on the question being asked. Consequential analysis is appropriate for policy impact assessment
- Emissions implications of EVs depend substantially on regional factors and vehicle design
- V2G can reduce generation costs, sometimes at the expense of increased health and environmental costs
- Coal retirement is key to EVs being in society's interests