NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Electrification Opportunities in the Transportation Sector and Impact of Residential Charging

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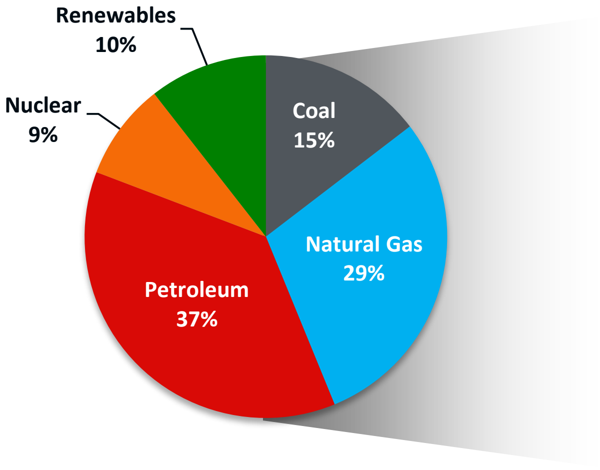
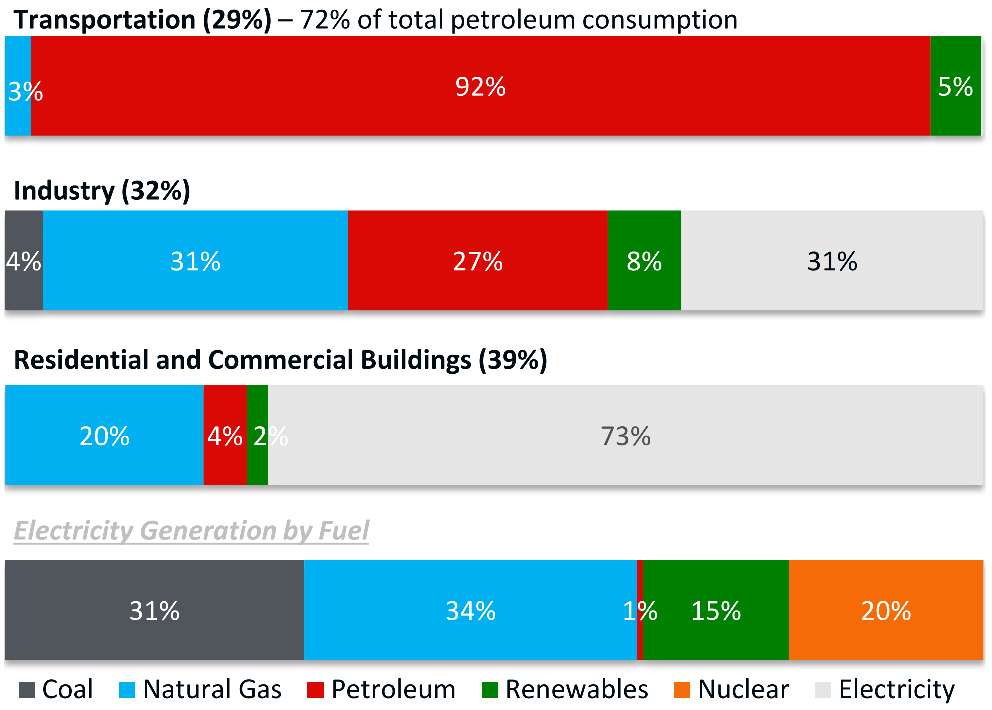
Electric Power Research Institute
Energy and Environment Program Advisory Meeting

Status Quo

U.S. Primary Energy By Fuel (2016)



U.S. Energy Consumption by Sector and Fuel (2016)



Source: NREL. Data from U.S. Energy Information Administration Annual Energy Review

U.S. Transportation Sector

The **U.S. transportation sector:**

- Accounts for **one-third of total energy** use and greenhouse gas emissions
- Accounts for **more than 70% of total petroleum** consumption
- Is the **least diversified sector**, with minor multi-sectoral synergies

Alternative fuel vehicles have long been proposed to:

- Reduce oil dependency and increase **energy security**
- Reduce **environmental impact** (local air quality and climate change)
- Stimulate **economic growth and job creation**

Changing Landscape

Ford plans **$11 billion investment,** 40 electrified vehicles by 2022
– Reuters Business News

Tesla's electric semi truck: Elon Musk unveils his new freight vehicle
– Tesla

LG Chem Expects Chevrolet Bolt Sales to Exceed **30,000 in 2017**
– Inside EVs

Investments in electrified vehicles announced to date (Jan 2018) include at least **$19 billion by automakers in the U.S., $21 billion in China and $52 billion in Germany**.
– Reuters

Tesla puts pedal to the metal, **500,000 cars planned in 2018**
– Reuters Business News

General Motors believes the **future is all-electric** and announced 20 fully electric models by 2023
– Wired

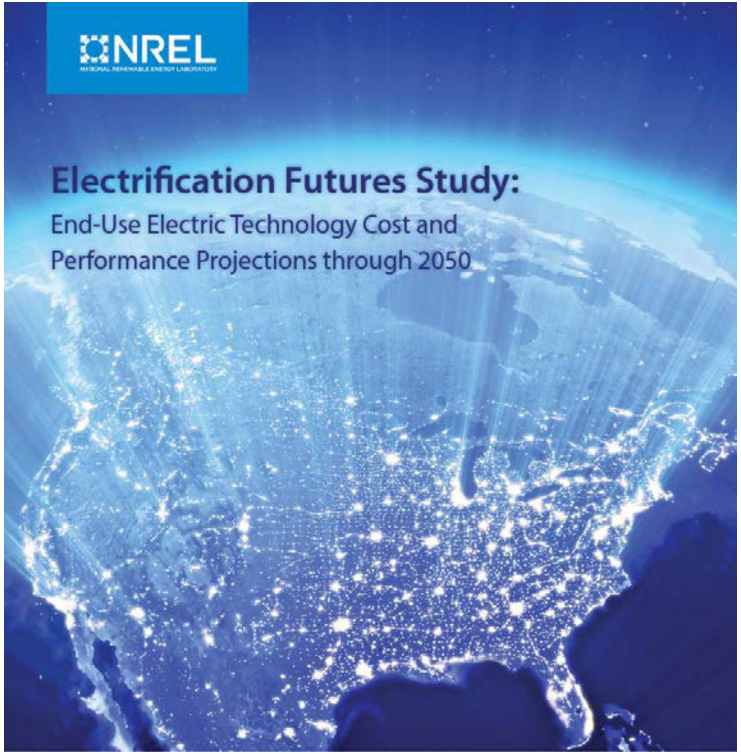
Volvo Cars announces new target of **1 million electrified cars sold by 2025**
– Volvo Car Group

NREL’s Electrification Futures Study

Through the **Electrification Futures Study**, the National Renewable Energy Laboratory (NREL) is exploring scenarios with and impacts of widespread electrification in the United States:

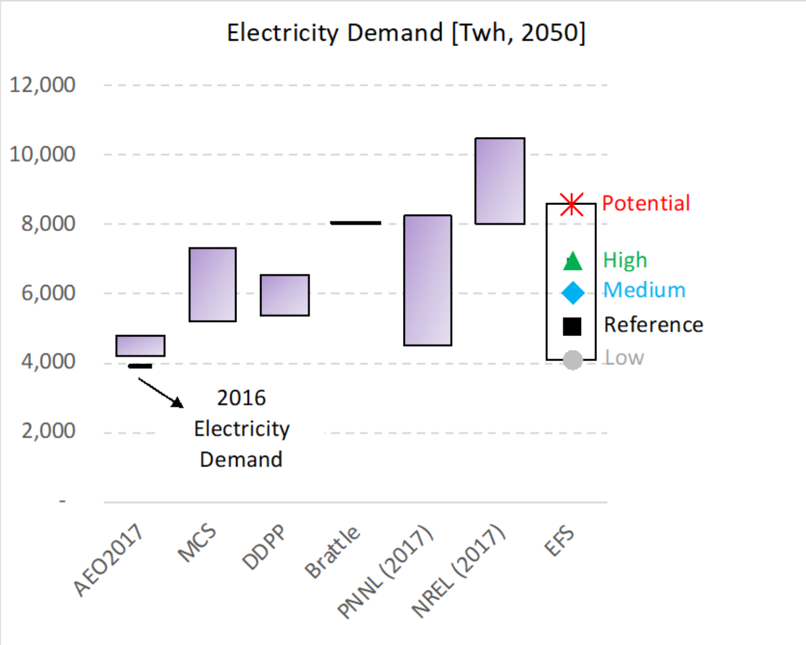
- How might widespread electrification impact **national and regional electricity demand?**
- How would the U.S. **electricity system need to transform**?

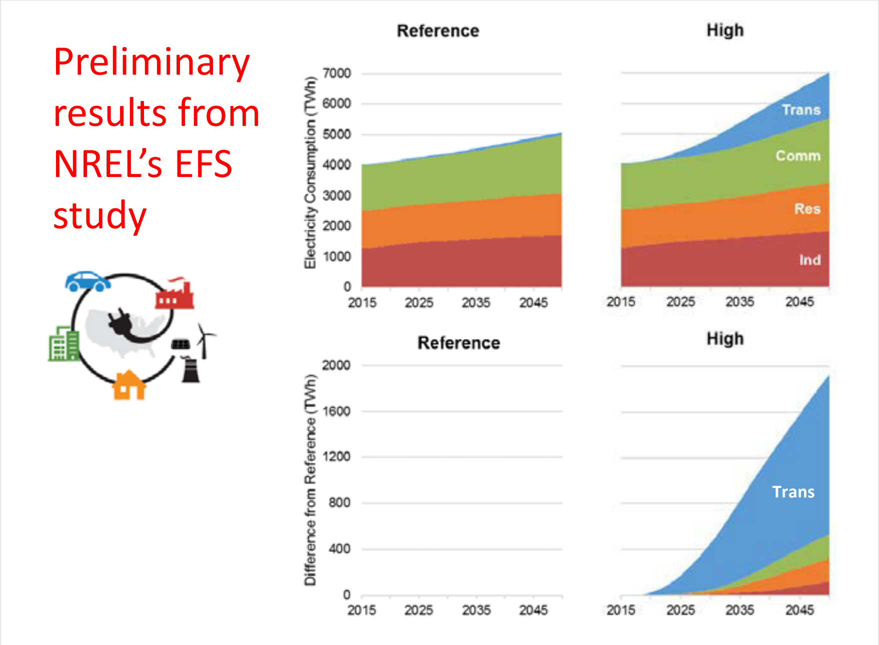
https://www.nrel.gov/analysis/electrification-futures.html



U.S. Scenarios of Electrification

Several **energy system transformation scenarios** assume a great degree of future electrification, especially for transportation





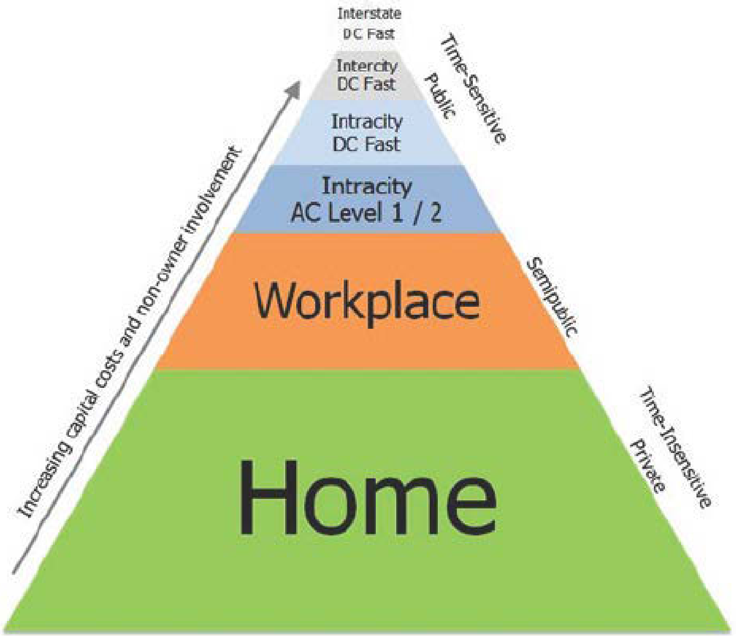
Source: https://www.nrel.gov/analysis/electrification-futures.html

Charging Requirements

While the majority of plug-in electric vehicle (PEV) charging is expected to come from residential plugs, a network of **non-residential chargers** is still required to:

- Support adopters that cannot reliably charge at home
- Enable long-distance travel
- Cope with range anxiety (safety net)

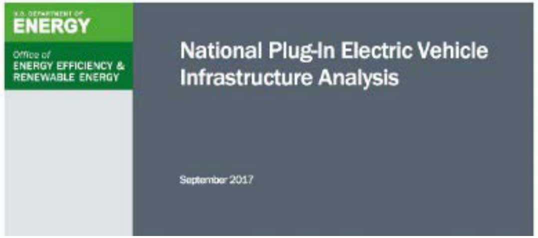
Infrastructure plays a big role in enabling and supporting PEV adoption (dynamic charging or battery swapping also have big infrastructure components)

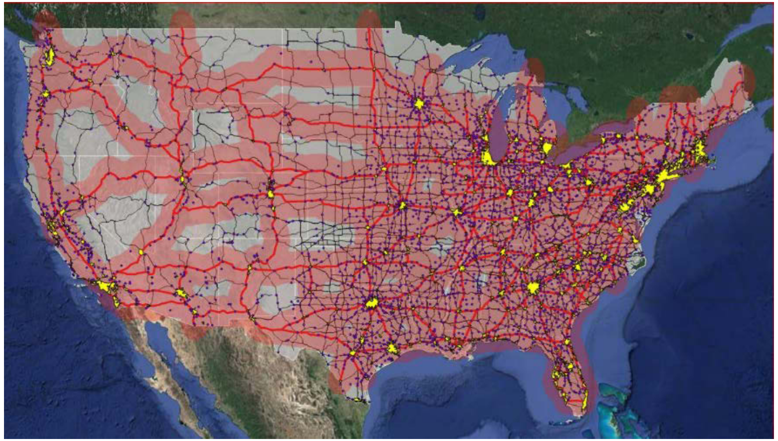


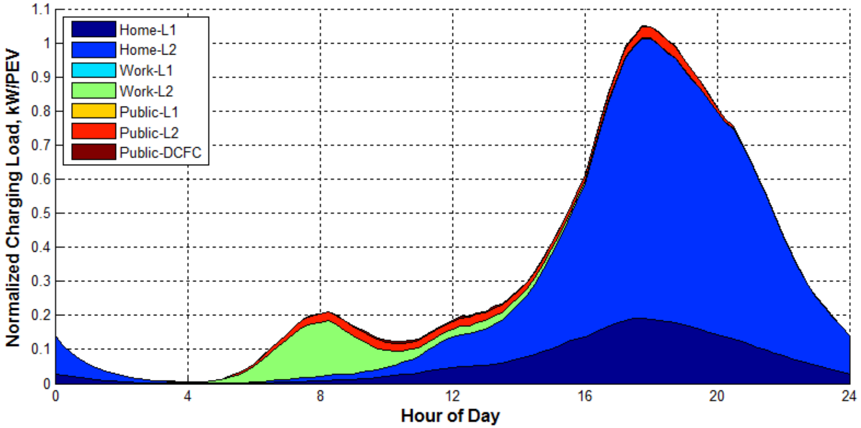
Source: National Research Council. *Overcoming barriers to deployment of plug-in electric vehicles*. National Academies Press, 2015.

NREL's Infrastructure Analysis

NREL analyzes c**harging behavior and infrastructure requirements** to support PEV adoption, including estimating PEV supply equipment counts, location, use, and resulting hourly load profiles







Source: Wood et al. 2017. Model: NREL's EVI-Pro

Impact of Residential Charging

Given the projected adoption of PEVs (primarily being charged at home), the **impact on residential power demand** needs to be carefully assessed

Nature Energy | Articles (Jan 2018)
doi:10.1038/s41560-017-0074-z
Impact of uncoordinated plug-in electric vehicle charging on residential power demand | **Matteo Muratori**

Integrating PEVs creates **load growth opportunities** for electric utilities but also poses **new challenges** in a system of growing complexity

PEVs change the electricity demand in two ways:

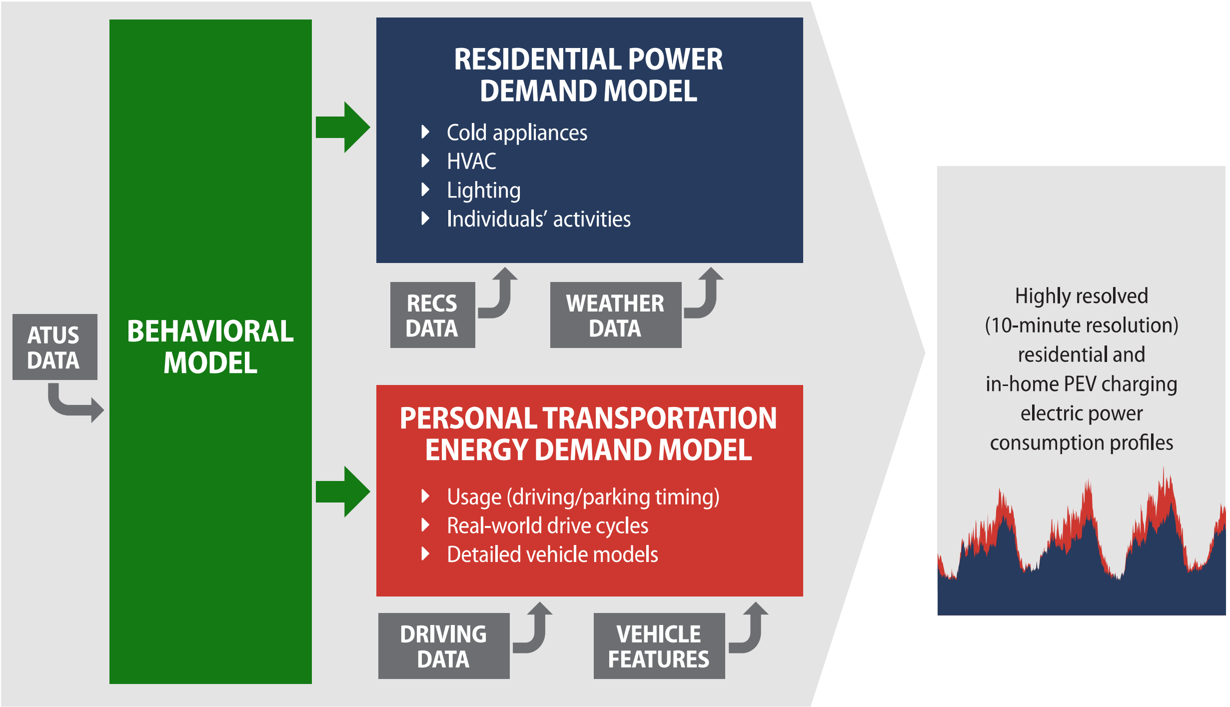
- Overall **demand increases**, given that an additional load is introduced
- The **shape** of the demand is modified

Approach and Key Assumptions

- **Literature gaps**:
  - Building load models don’t consider PEVs
  - PEV impact studies usually assume ubiquitously ‘smart’ charging, and most studies rely on average statistics to estimate PEV charging loads
- **This paper:**
  - Highly resolved modeling of residential power demand and PEV use—based on a bottom-up approach that quantifies consumer behavior
  - Assumes 100% residential uncoordinated charging

➢ **Objective: Assess aggregate and local impact of uncoordinated PEV charging for different adoption levels and EVSE types**

Methods

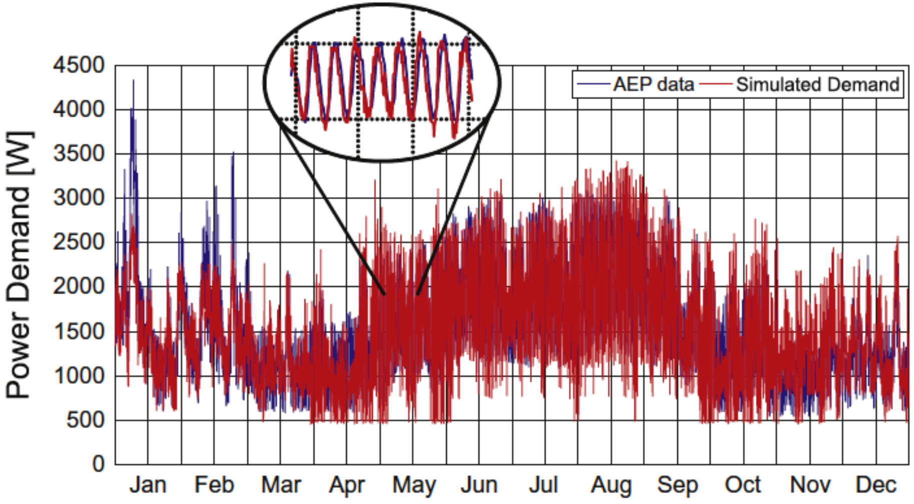


Source: Muratori 2018

Aggregate Impact

Aggregate load profile from 200 residential households in the Midwest is used as a proxy for the aggregate residential load to assess PEV charging impact

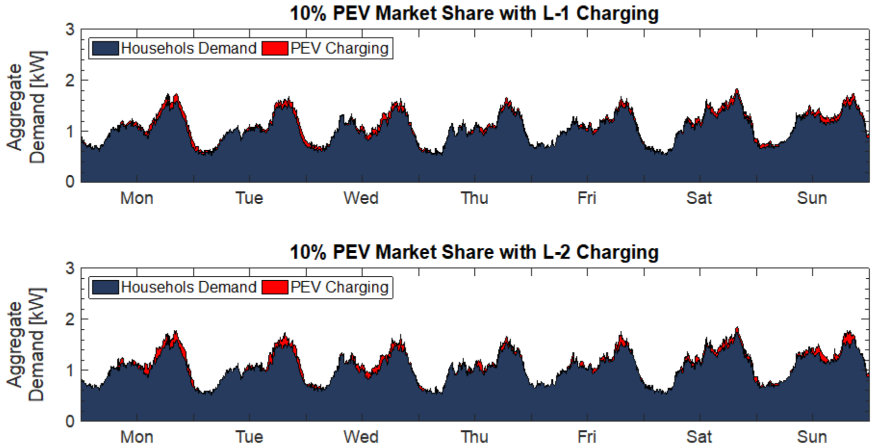
- Capture seasonal and diurnal fluctuations
- **Validated against AEP metered data**



Source: Muratori et al. 2013

Aggregate Impact (Results 1)

- PEVs are an additional load that increases total electricity demand and changes its shape
- **Impact on the overall energy consumption increase is limited** (e.g., 10% PEV market share → demand increase of 5%)



Source: Muratori 2018

- The **shape of the aggregate residential power demand is more affected by the introduction of PEVs**—especially for Level 2 charging

Aggregate Impact (Results 2)

The **increase in peak demand is less than linear compared with the number of PEVs:** that not all PEVs are charged at the same time (vehicle charging timing is predicted by the model), and vehicle charging does not always correspond with residential peak demand

Table 2 | Maximum share of PEVs simultaneously recharged for at least one 10-min time interval during the simulated year for an aggregate of 200 sampled households

PEV market share	3%		10%		25%		50%		100%	
Charging level	**L1**	**L2**	**L1**	**L2**	**L1**	**L2**	**L1**	**L2**	**L1**	**L2**
PEVs simultaneously charged per total PEVs	8/10	5/10	20/35	11/35	39/87	19/87	74/174	36/174	139/348	63/348
Share of PEVs simultaneously charged (%)	80	50	57	31	45	22	43	21	40	18
Average per-household incremental peak demand (W)	9	32	85	121	257	394	497	856	949	1,615

L1 and L2 denote Level 1 and 2 PEV charging.

Source: Muratori 2018

Local Impact

A residential **distribution transformer connected to six households** is considered to evaluate the local impact of uncoordinated in-home PEV charging on the electric power distribution infrastructure

- Household characteristics taken from **RECS**
- 19 residents, 11 vehicles

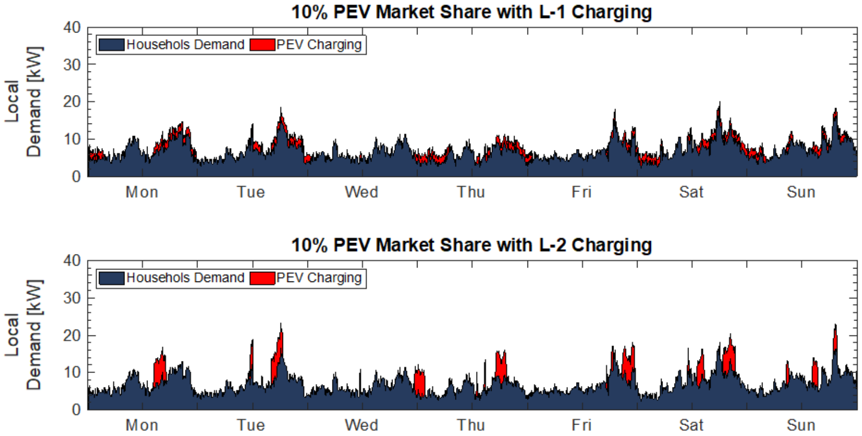
Table 3 | Households considered to assess the local impact of PEV charging on residential power demand

Household	Number of residents	House size (m^2)	Number of passenger vehicles
Household 1	6	254	3
Household 2	1	773	1
Household 3	2	133	1
Household 4	4	91	2
Household 5	4	337	2
Household 6	2	106	2
Total	19	1,694	11

Source: Muratori 2018

Local Impact (Results 1)

- At the local level, **clustering effects** in PEV adoption exacerbate the impact
- The introduction of PEVs—even considering L1 charging—leads to significant increases in peak demand at the transformer



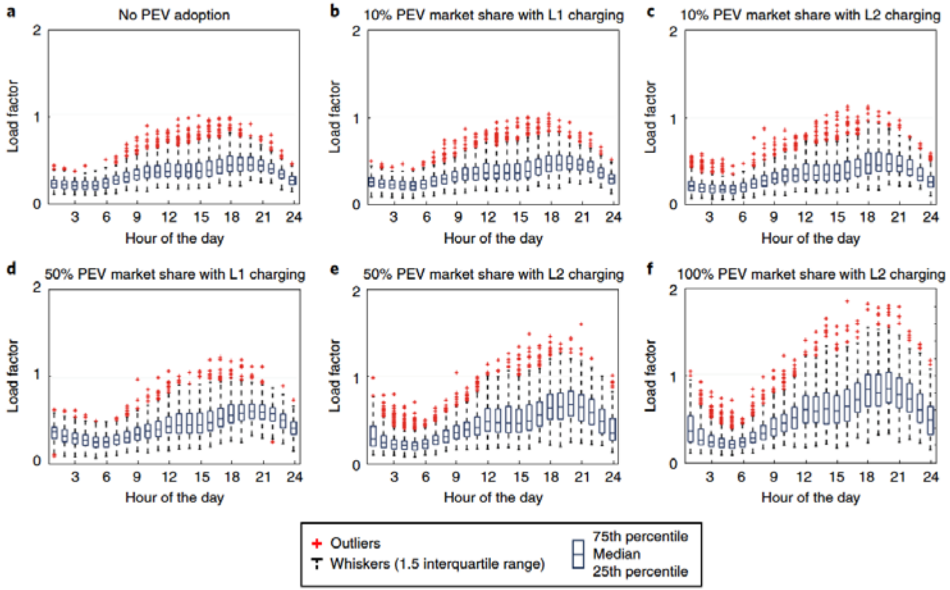
Source: Muratori 2018

- **Level 2 charging significantly aggravates the impact of PEVs on the residential distribution infrastructure**, since charging events are shorter but steeper

Local Impact (Results 2)

When no PEV is connected to the transformer the load factor is always lower than 1

As more PEVs are introduced and higher charging power is adopted, PEV charging **increases the stress on the distribution infrastructure** that might no longer reliably support the local electricity demand



Source: Muratori 2018

$$Load\ factor = \frac{hourly\ power\ consumption}{transformer\ nominal\ power}$$

Overall Results

- A 3% PEV market share, which translates to about **7.5 million vehicles on the road**—a number far above the current 0.6 million PEVs deployed—**does not seem to significantly impact the aggregate residential power demand** under either charging level considered

- The introduction of **one single PEV** in a residential distribution network consisting of six households **can potentially increase the peak load** factor of the distribution transformers if **Level 2 charging** (6.6 kW) is adopted

- All residential and PEV load profiles (10-minute resolution) are available for **download**: https://data.nrel.gov/submissions/69

Conclusions

- Future research should focus more heavily on understanding **consumer driving and charging behavior** (to better estimate charging requirements) and the nuances determining the **choice of PEV charging infrastructure** (*e.g.*, use of Level 1 versus Level 2 residential charging)

- Future studies could leverage the approach and data presented in this paper to explore **opportunities related to controlled charging** as well as vehicle-to-grid opportunities

Future Research and Collaboration Opportunities

Future research planned at NREL:

- Assess opportunities to **leverage PEV charging flexibility** to support grid operation and facilitate renewable integration (demand response assessment)
- Assess the **impact of non-residential PEV charging** on the power system, especially DC fast charging
- Better capture the **infrastructure implications of transportation electrification**, including:
  - The "**PEV adoption–EVSE availability**" nexus for light-duty vehicles
  - Electrification strategies for different **medium- and heavy-duty vocations**

Acknowledgements

I'd like to acknowledge Trieu Mai (lead of the EFS project), Eric Wood (lead of the national infrastructure assessment study), Maggie Mann, and Jeff Logan for useful discussion and comments.

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Thank you

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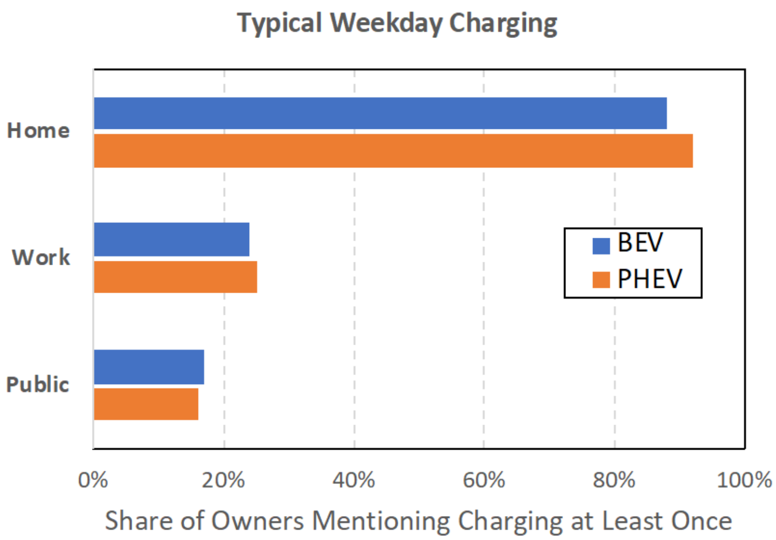
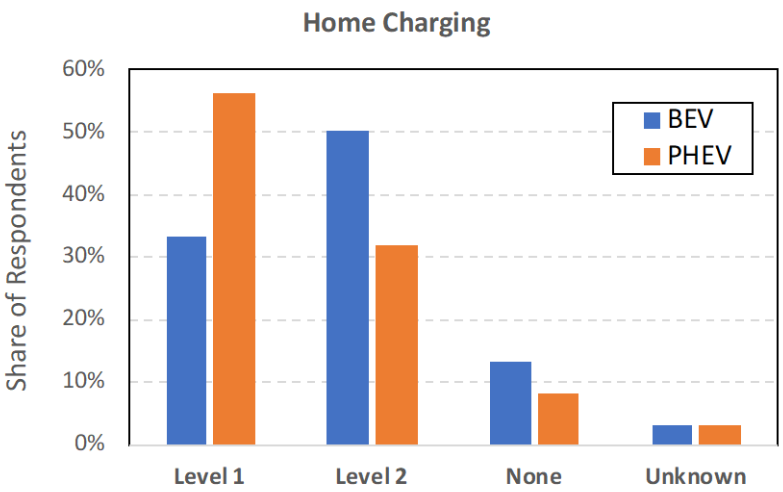
L1 vs. L2 Charging

With 12% of the population of the United States, California has 24% of the public PEV charging stations and 30% of the outlets for charging PEVs .

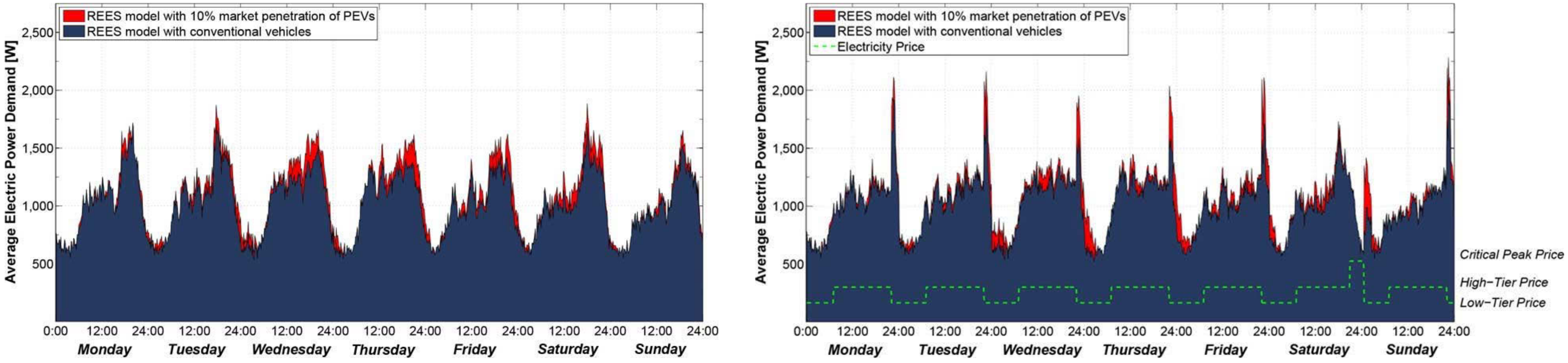
159 BEV owners and 156 PHEV owners responded to questions in the [2016 California Vehicle Survey] about where and when they charged their vehicles on a typical weekday





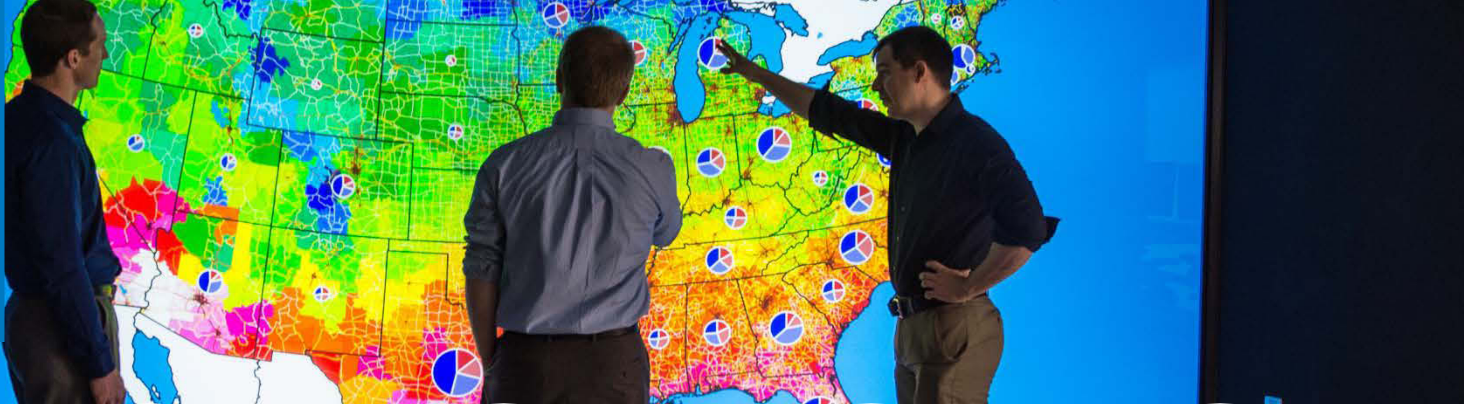
Rebound Peaks

Widespread participation (automated energy management systems) in demand response programs using time-varying electricity pricing (e.g., TOU) might create pronounced rebound peaks.



M. Muratori and G. Rizzoni. 2016. “Residential demand response: dynamic energy management and time-varying electricity pricing”. IEEE Trans. on Power Systems, Vol. 31 (2). 10.1109/TPWRS.2015.2414880

Key Capabilities and Tools



Data

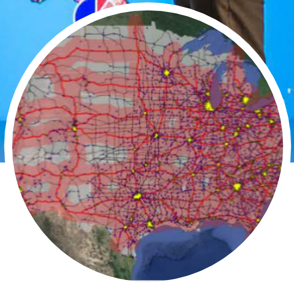
Transportation Secure Data Center & Alternative Fuels Data Center

ADOPT

Vehicle Adoption Modeling

FASTSim

Vehicle Powertrain Modeling



EVI-PRO

Plug-in Electric Vehicle Charging Infrastructure

SERA

Alternative Fuel Infrastructure Supply and Infrastructure