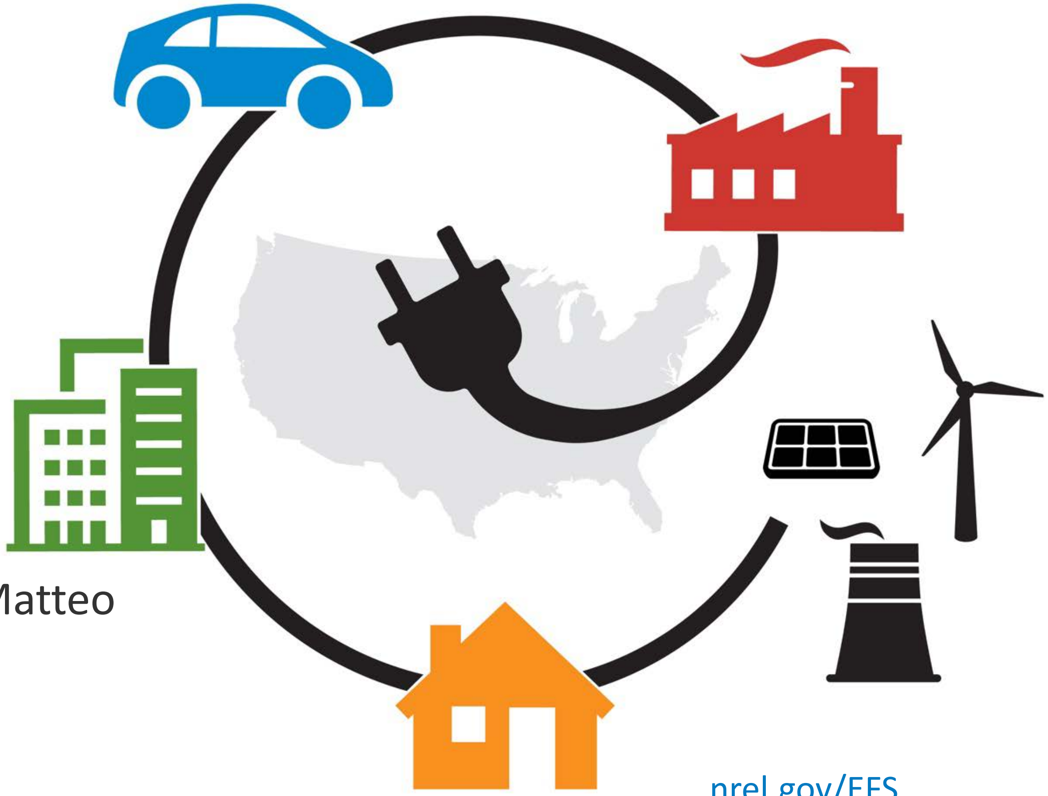
NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Electrification Futures Study



Caitlin Murphy, Trieu Mai, Ella Zhou, Matteo Muratori, and Paige Jadun

September 13, 2022
Electrify the Big Sky
Missoula, Montana

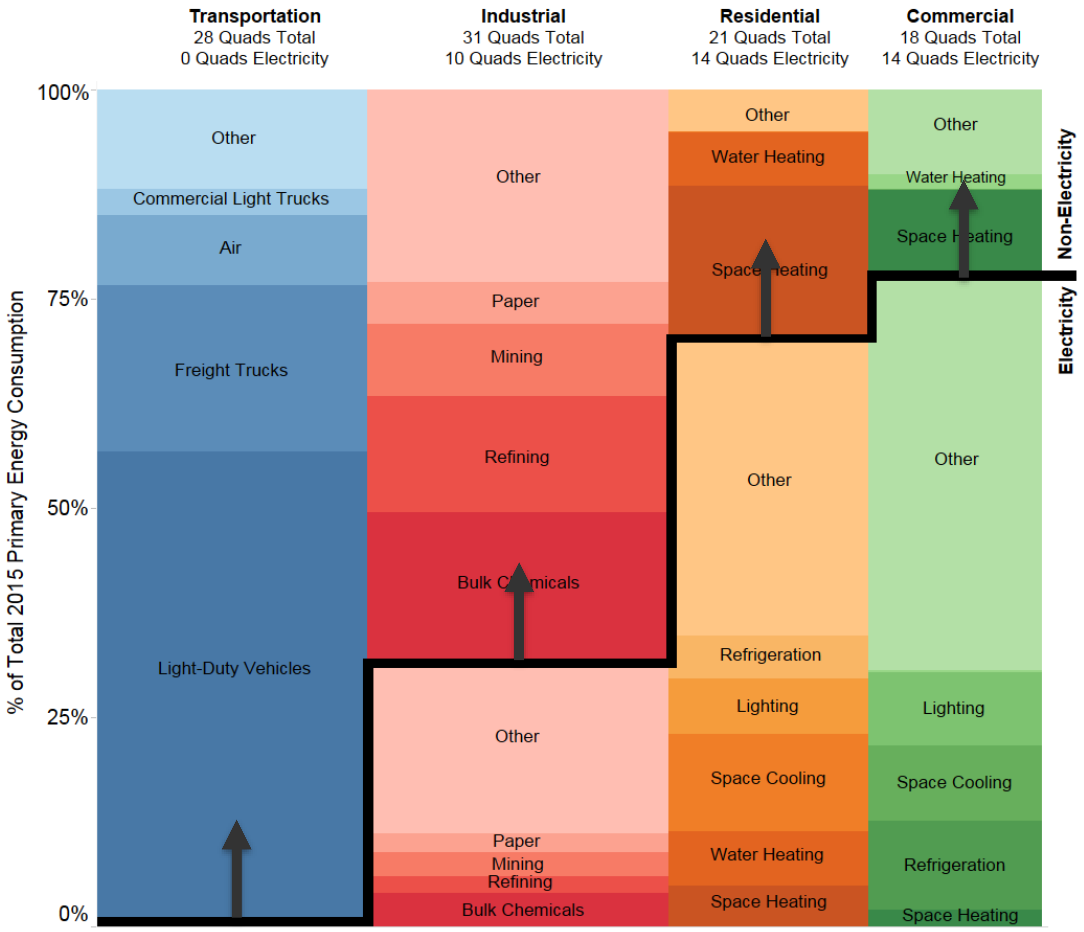
nrel.gov/EFS

Study sponsored by U.S. DOE-EERE Office of Strategic Programs

Electrification: Scope and Definitions

- **Electrification**: the shift from any non-electric source of energy to electricity at the point of final consumption
  - Direct electric technologies only
  - Not exploring new sources of demand

- **Contiguous U.S. energy system**, including transportation, residential and commercial buildings, industry
  - Sectors cover **74% of primary energy in 2015**
  - Excludes air transport, petroleum refining and mining, CHP, outdoor cooking



Today, we will explore 5 crucial questions:

Load

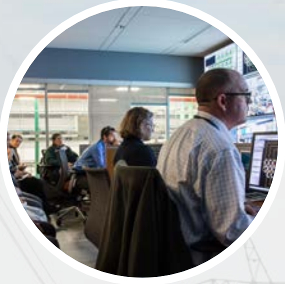
How might electrification impact electricity **demand** and **use patterns**?

Capacity

How would the electricity system need to **transform** to meet changes in demand?

Operation

How would the system operate, with high levels of electrification, to meet **reliability** needs in 2050?



Flexibility

What role might **demand-side flexibility** play to support reliable operations?

Impacts

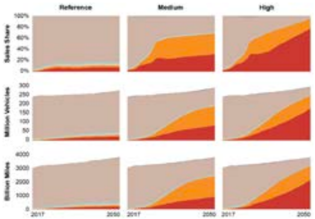
What are the potential **costs, benefits, and impacts** of widespread electrification?

Modeling Methods

End-Use Technology Adoption:

Demand-Side Scenarios

- EnergyPATHWAYS stock turnover and energy accounting model
- ADOPT vehicle choice model



2016 – 2050 demand

Power System Evolution:

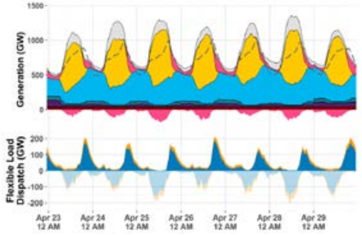
Supply-Side Scenarios

- ReEDS capacity expansion model
- dGen rooftop photovoltaic adoption model

2050 capacity

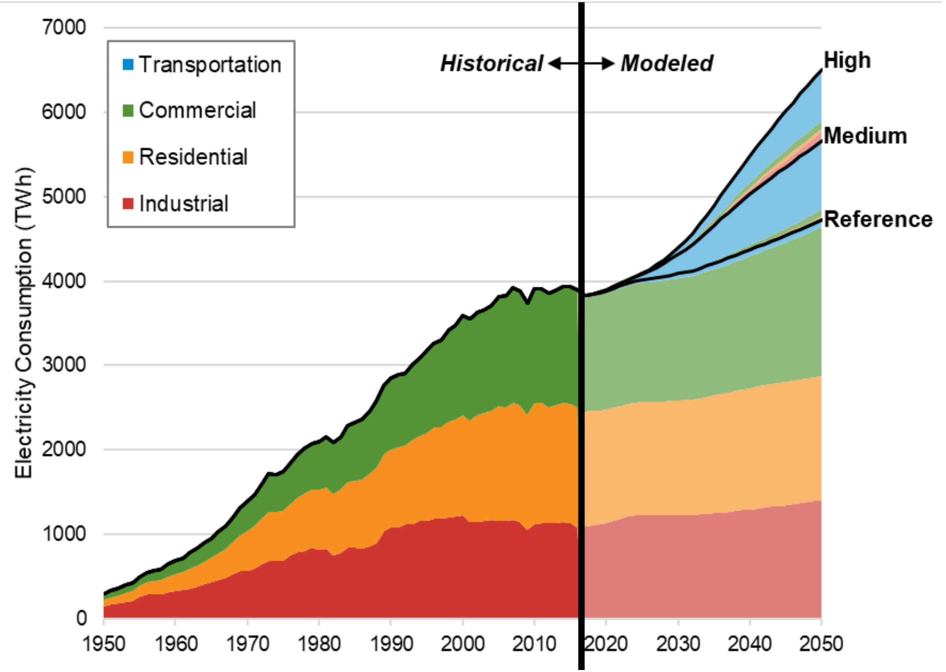
2050 Grid Operation Analysis

- PLEXOS production cost model

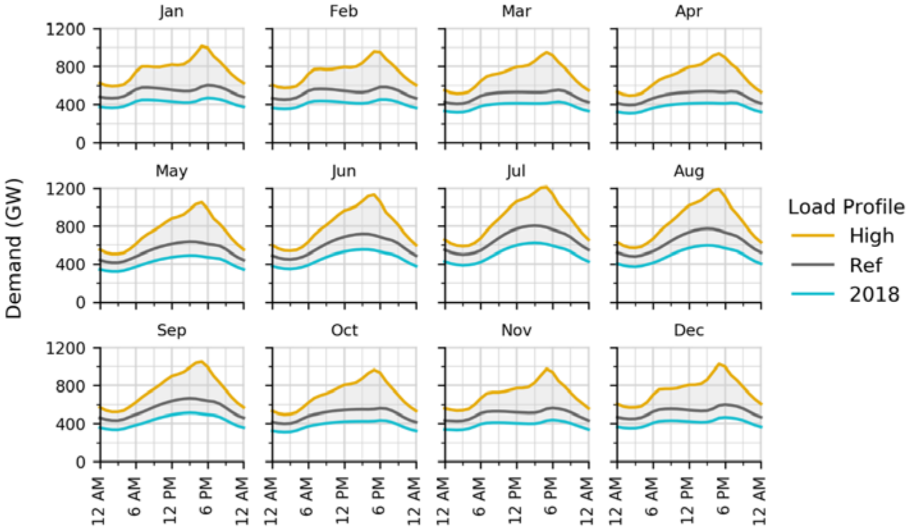


View reports at www.nrel.gov/efs

Vehicle electrification dominates incremental growth in *annual* electricity demand



Greater electricity consumption



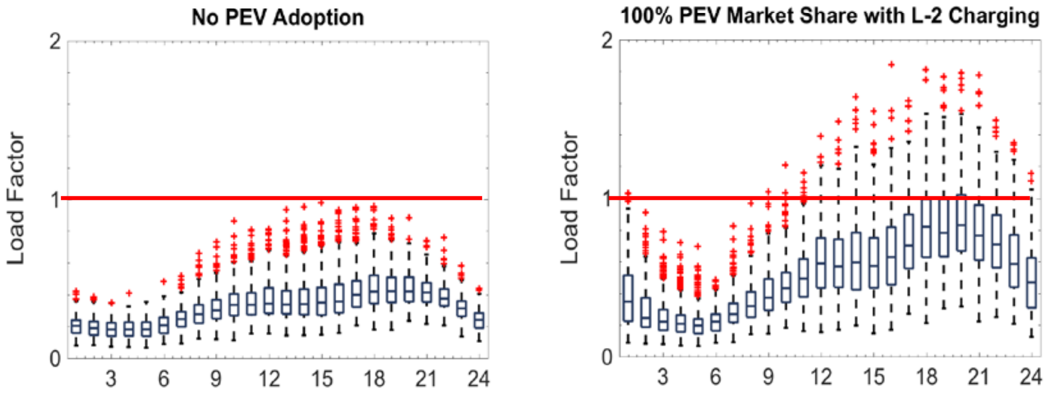
Possibly higher, sharper, and more frequent peaks in 2050
(in the absence of demand flexibility)

Source: Mai et al. 2018, Murphy et al. 2021, Sun et al. 2020, Zhou and Mai. 2021

Residential EV charging represents a significant increase in household electricity consumption

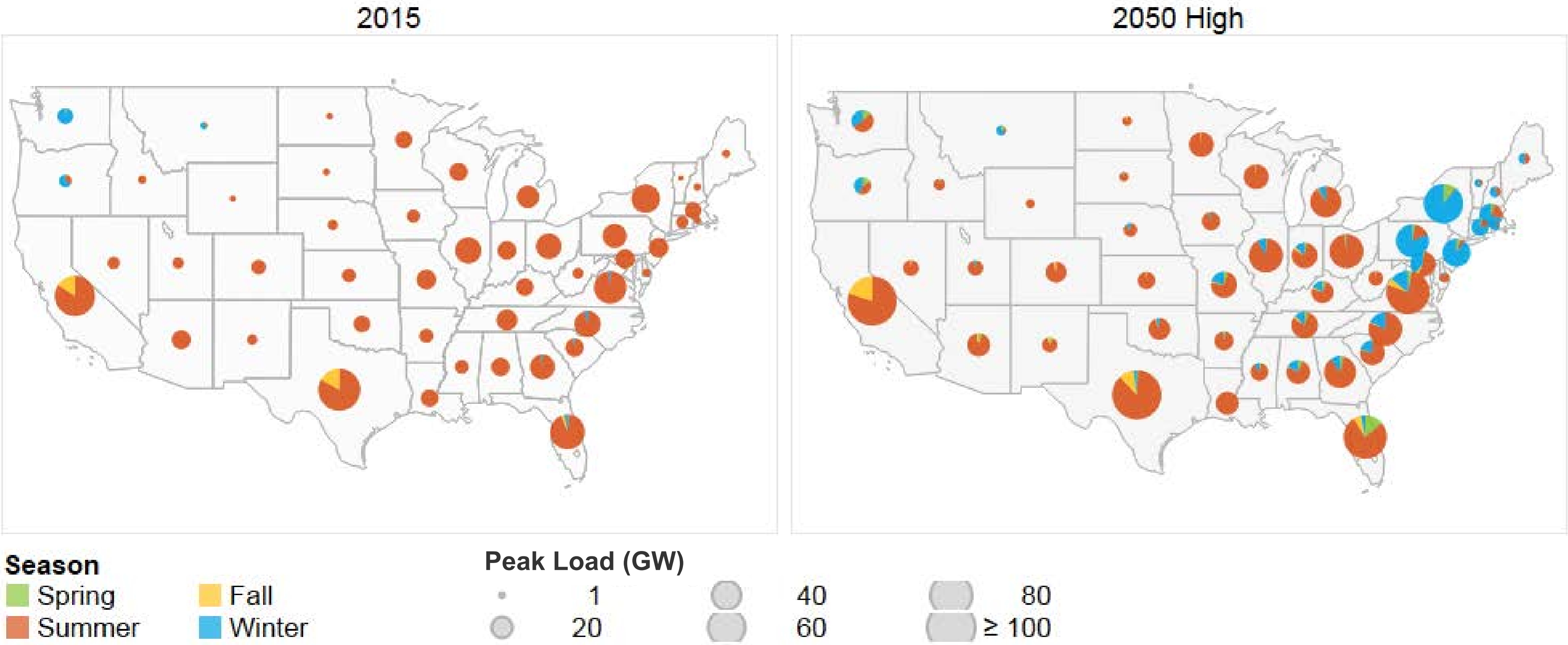
It can require upgrades of the household electrical system and unless properly managed it may lead to exceeding the maximum power that can be supported by distribution systems, especially for legacy infrastructure and during high demand times.

- **Clustering effects** in EV adoption and **higher power** charging exacerbates these issues
- Effective planning, smart EV charging, and distributed energy storage systems can help to mitigate these potential issues.
- Key to **consider EVs in system upgrades**



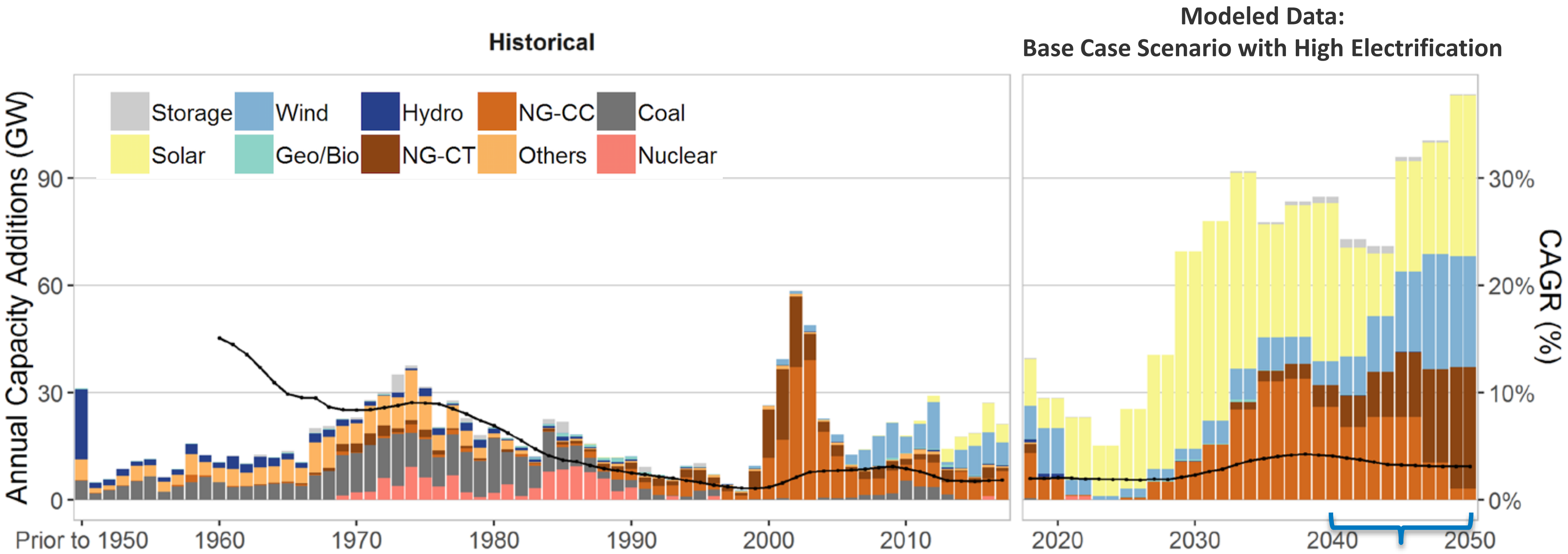
Source: Muratori, M., 2018. Impact of uncoordinated plug-in electric vehicle charging on residential power demand. Nature Energy, 3(3), pp.193-201.

Electric space heating also impacts the timing and magnitude of peak demand



Note: Summer = June-August, Fall = September-November, Winter = December-February, Spring = March-May

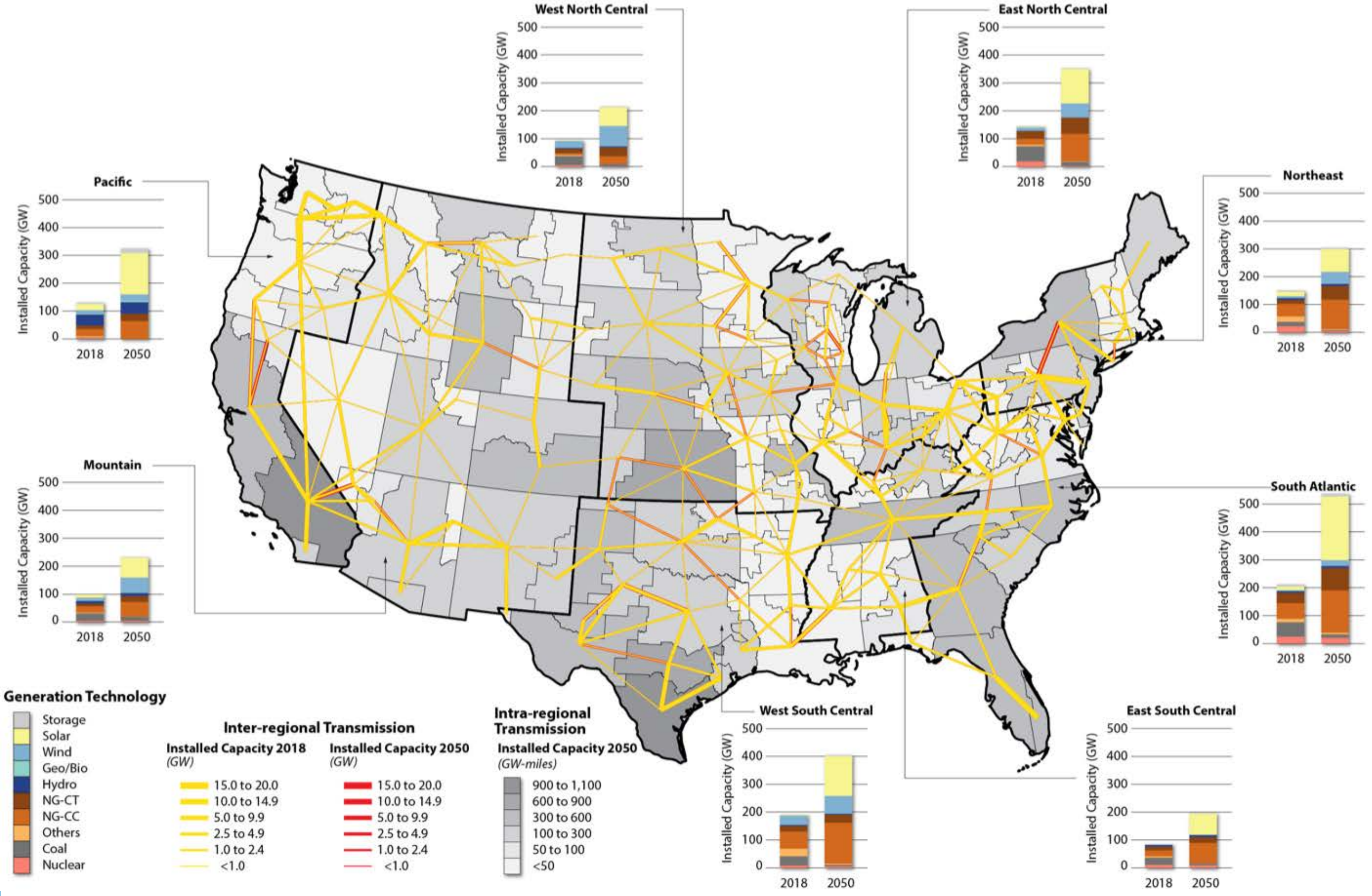
Electrification drives total installed capacity in 2050 to be 58% greater than 2018 levels



Solar: ~30-45 GW/yr
Natural Gas: ~35 GW/yr
Wind: ~20 GW/yr
even higher rates in some scenarios

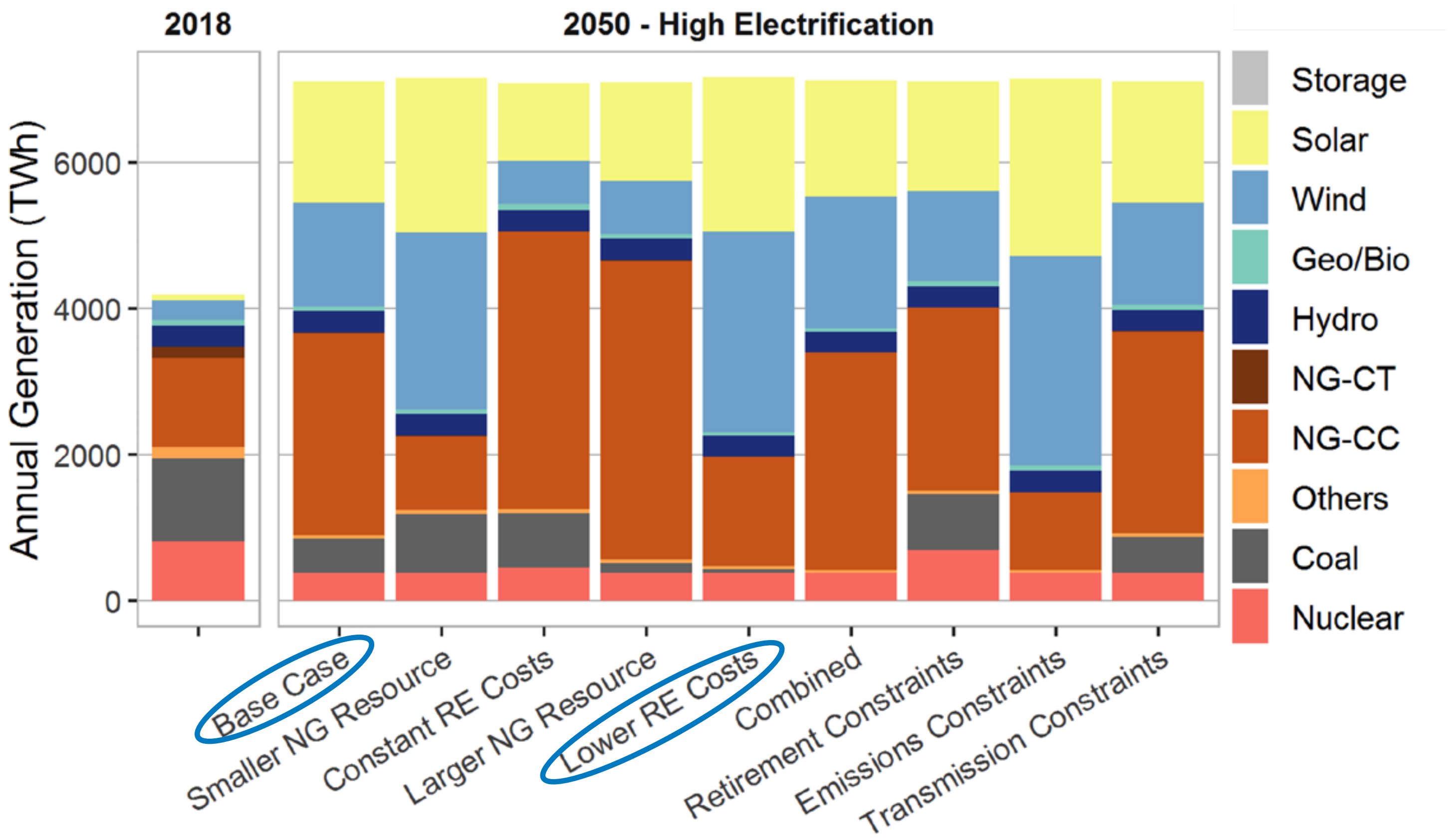
Murphy et al. (2021), https://www.nrel.gov/docs/fy21osti/72330.pdf

Expansion of long-distance transmission capacity is correlated with growth in renewable energy sources



Murphy et al. (2021), https://www.nrel.gov/docs/fy21osti/72330.pdf

Future electricity supply mix depends on uncertain technology, market, and policy conditions



We modeled the hourly operation in 2050 of:

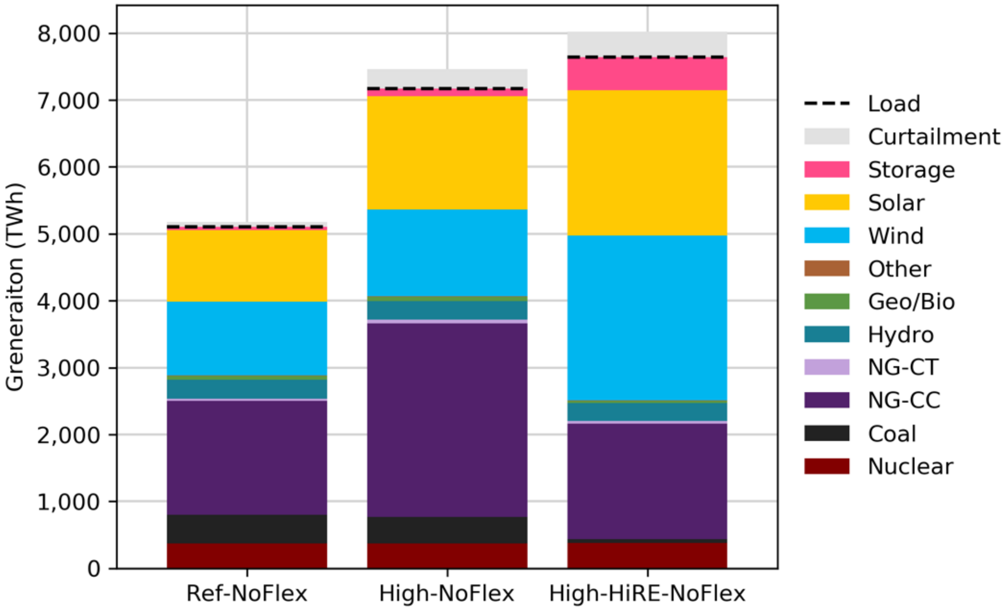
- Reference Electrification (**Ref**)
- High Electrification Base Case (**High**)
- High Electrification Lower RE Costs (**High-HiRE**)

with varying levels of demand-side flexibility

Murphy et al. (2020), *Electricity Journal,* https://doi.org/10.1016/j.tej.2020.106878

Modeled portfolios are resource adequate

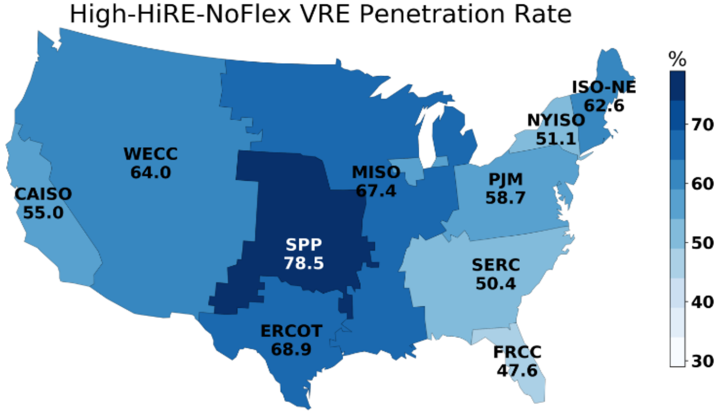
2050 Annual Generation for Scenarios without Demand-Side Flexibility



Geo/Bio = geothermal/bioenergy
NG = natural gas

CT = combustion turbine
CC = combined cycle

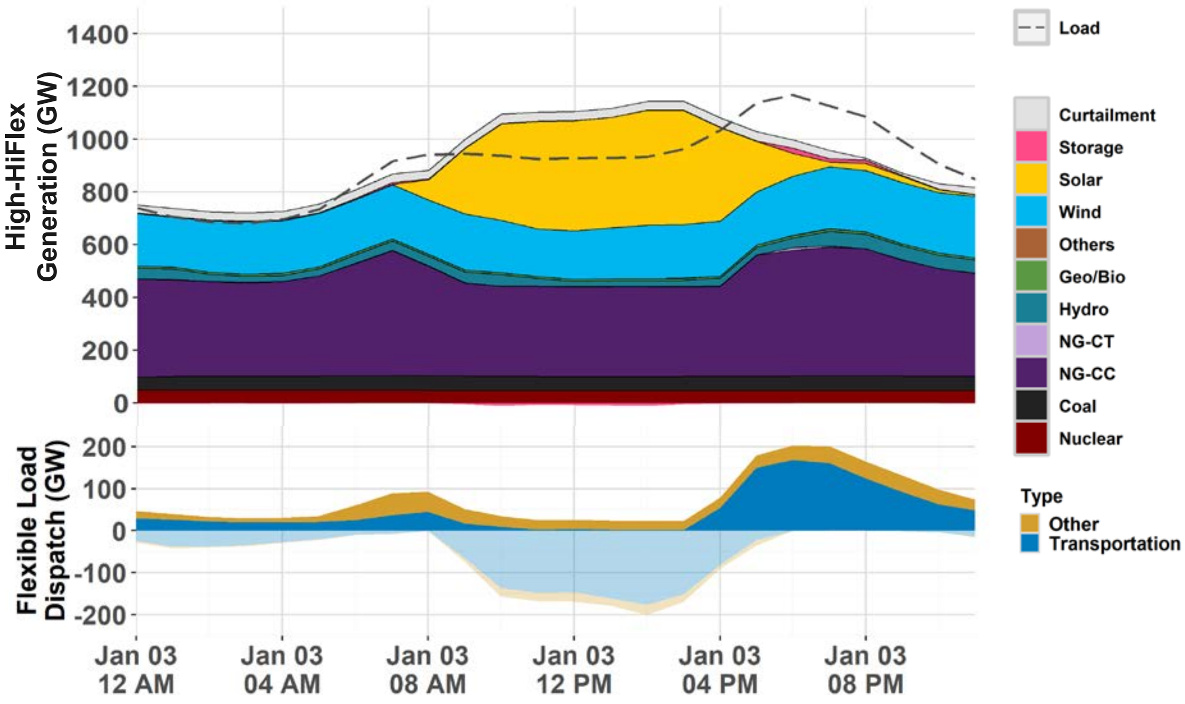
The system serves **more than 99.99% of the load and 99.96% of the operating reserves** in hourly simulations of all 2050 scenarios



Demand-side flexibility benefits system operation through energy shifting and reserves

Top: Simulated dispatch on Jan. 3 in High-HiFlex (highest net load ramp day in High-NoFlex)

Bottom: Zoom-in of DSF dispatch for the same time period. Positive generation indicates reduced consumption.



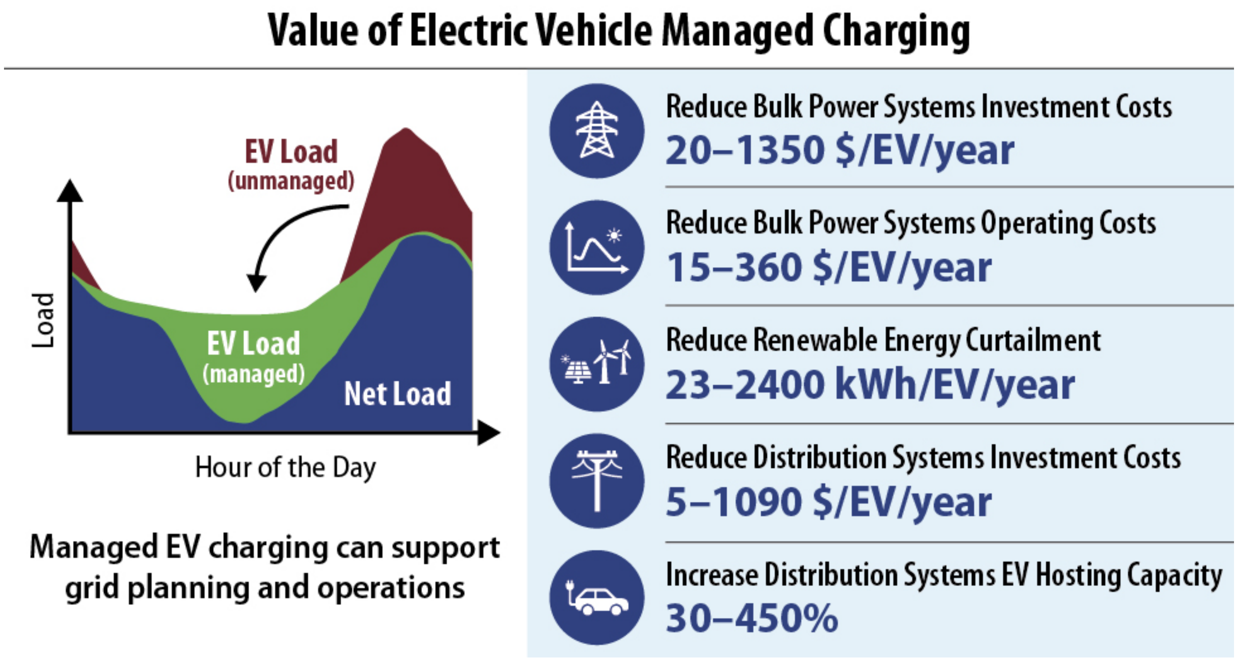
Dotted line shows original static load from High-NoFlex

Flexible loads provide value by mitigating power sector **infrastructure** needs, systems costs, and price volatility

Electrification Futures Study analysis indicates that flexible loads:

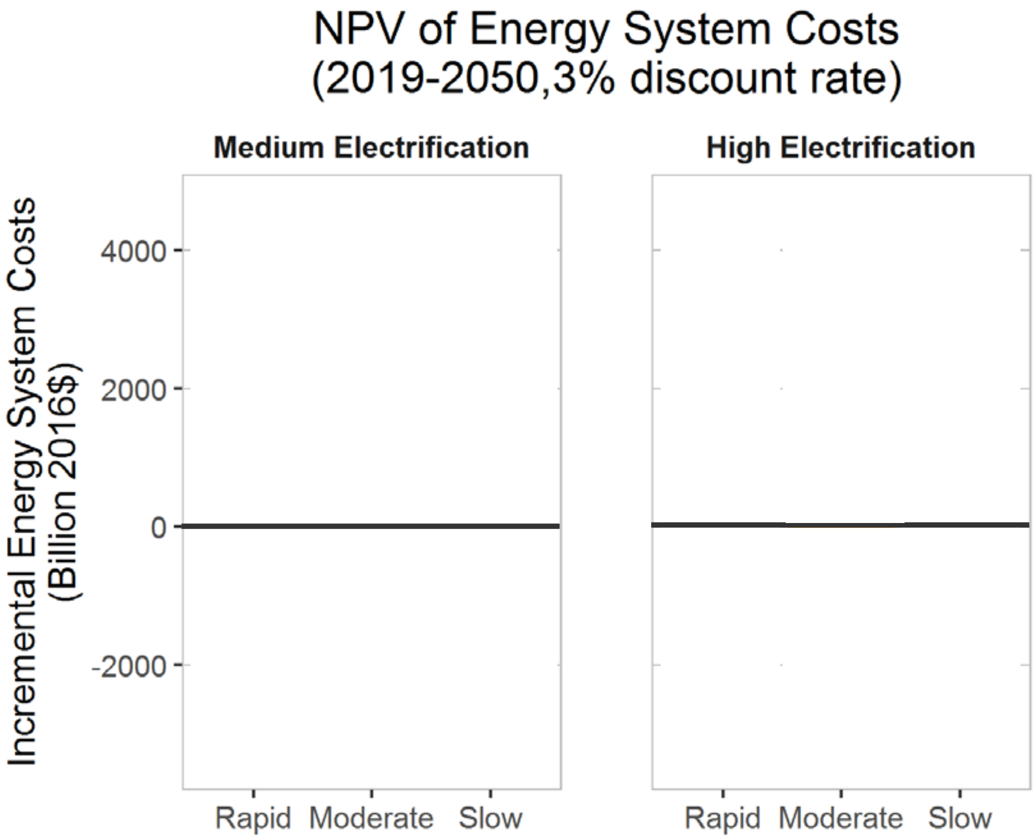
- **Reduce bulk electric system costs** in all scenarios
- **Mitigate** some electrification-induced **investments**
- **Reduce operational costs by up to 10%**
- Enhance the ability of electrification to decarbonize the energy sector by **reducing VRE curtailment**
- **Reduce price volatility**

Caveat: no incremental cost to implement load shifting considered



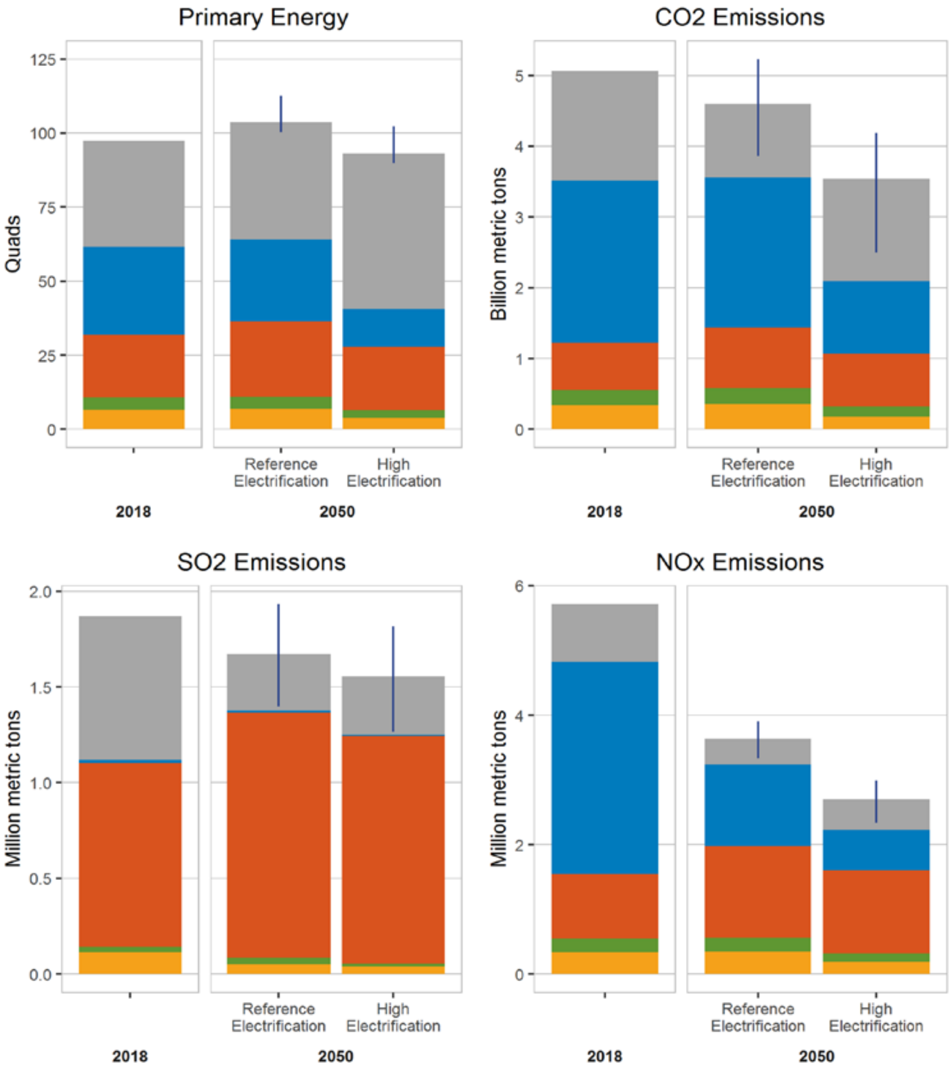
Anwar et al., 2021. "Assessing the value of electric vehicle managed charging: a review of methodologies and results." *Energy & Environmental Science*

Net cost of electrification depends on future advancements in the cost & efficiency of electric end-use technologies



Murphy et al. (2021), https://www.nrel.gov/docs/fy21osti/72330.pdf

High electrification results in 1.1 billion metric ton (or 23%) CO2 reduction in the energy sector in 2050, relative to Reference electrification



Murphy et al. (2021), https://www.nrel.gov/docs/fy21osti/72330.pdf

Related research and data sources at NREL

- See the www.nrel.gov/efs for more information
  - Hourly demand data
  - Scenario data viewer
- Standard Scenarios: www.nrel.gov/analysis/standard-scenarios.html
- Annual Technology Baseline (Electricity and Transportation): atb.nrel.gov
- Demand-side grid (dsgrid): www.nrel.gov/analysis/dsgrid.html
- Transportation Energy & Mobility Pathway Options (TEMPO): www.nrel.gov/transportation/tempo-model.html
- State and Local Planning for Energy (SLOPE): https://maps.nrel.gov/slope

Best-in-Class Tool: SLOPE Scenario Planner

Helping communities visualize energy futures through 2050

How can various energy strategies help my community achieve our energy goals?

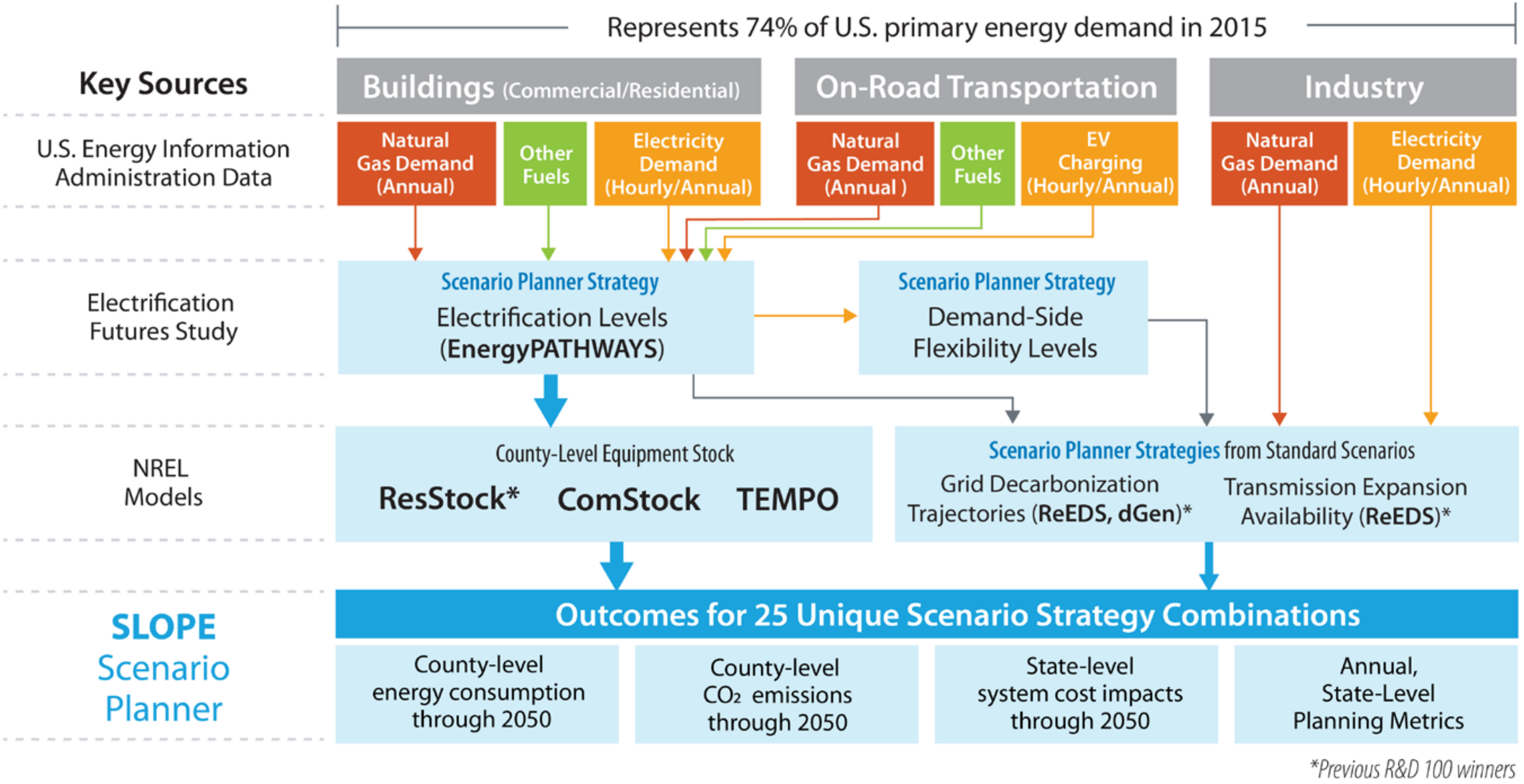
- Build, view, and compare pre-defined future energy scenarios and their associated costs, emissions, and consumption levels
- Explore energy supply and demand scenarios at very high spatial resolution.

How do system cost and emission impacts of various energy strategies compare?

- See energy and carbon emissions implications of electricity decarbonization, building and transportation electrification, and (soon) energy efficiency scenarios down to the county level
- Model how combining strategies can result in emissions and cost reduction tradeoffs or synergies.

maps.nrel.gov/slope/scenarios

Scenario Planner: Analysis Architecture



The Scenario Planner delivers planning metrics to inform next steps for clean energy transitions

Scenario 1: Reference Case

CO_2 Emissions - Sarasota, Florida

Details for Year 2045

	Residential	Commercial	Industrial	Transportation	Total
Electricity - CO_2 Million Metric Tons (MMT)	0.7101	0.6146	0.1628	0.04207	1.530
Non-Electricity - CO_2 Million Metric Tons (MMT)	0.1202	0.1537	0.1732	2.356	2.803
Total - CO_2 Million Metric Tons (MMT)	0.8303	0.7683	0.3360	2.398	4.332

Planning Metrics ⓘ

State-level data only

46.81%	10.97%	28.80%	22.55%	$0.000
Share of Space Heating Services Supplied by Electricity (%)	BEV and PHEV Share of Light-Duty Vehicles (%)	Share of Electricity Provided by Renewable Energy (%)	Reduction in Energy-Related CO2 Emissions from 2005 (%)	Net Change in System Cost from Reference Scenario (Billions 2020 $)

Scenario 2: 95% Grid Decarbonization by 2050 & Widespread Electrification

CO_2 Emissions - Sarasota, Florida

Details for Year 2045

	Residential	Commercial	Industrial	Transportation	Total
Electricity - CO_2 Million Metric Tons (MMT)	0.2055	0.2016	0.05046	0.1621	0.6196
Non-Electricity - CO_2 Million Metric Tons (MMT)	0.07491	0.1059	0.1732	0.9175	1.272
Total - CO_2 Million Metric Tons (MMT)	0.2804	0.3075	0.2236	1.080	1.891

Planning Metrics ⓘ

State-level data only

80.25%	75.54%	72.05%	65.89%	$-3.217
Share of Space Heating Services Supplied by Electricity (%)	BEV and PHEV Share of Light-Duty Vehicles (%)	Share of Electricity Provided by Renewable Energy (%)	Reduction in Energy-Related CO2 Emissions from 2005 (%)	Net Change in System Cost from Reference Scenario (Billions 2020 $)

Available EFS Resources and Results

NATIONAL RENEWABLE ENERGY LABORATORY

EVOLVED ENERGY RESEARCH

NORTHERN ARIZONA UNIVERSITY

OAK RIDGE National Laboratory

U.S. DEPARTMENT OF ENERGY

- Technology cost and performance (December 2017)
- Demand-side adoption scenarios (June 2018)
- dsgrid model documentation (August 2018)
- Methodological approaches (July 2020)
- Supply-side evolution scenarios (January 2021)
- Power system operation with flexible loads (May 2021)

Study sponsored by U.S. DOE-EERE Office of Strategic Programs

Thank you!

Caitlin.murphy@nrel.gov

www.nrel.gov/efs

NREL/PR-6A20-80971

NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.

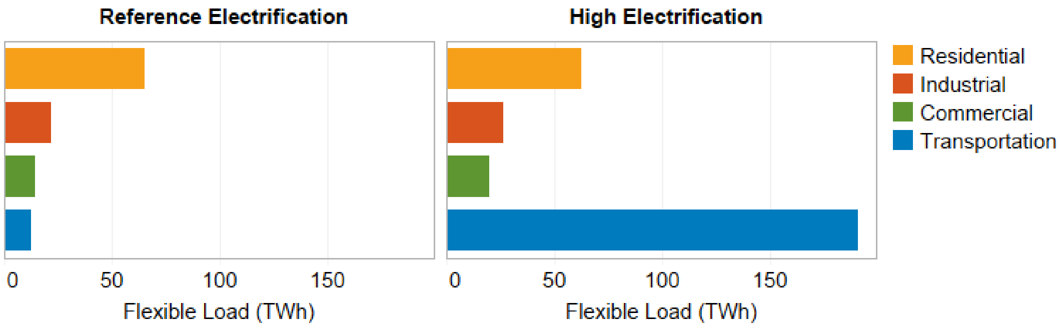
NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Modeling demand-side flexibility (DSM)

- 14 types of shiftable DSM across commercial, residential buildings, industrial, and transportation sectors are modeled for each modeled BA
- Parameterized by **timing, duration, participation, and capacity to increase and decrease**
- Amount and nature of flexibility depends on electrification, with greater potential for flexibility primarily from **optimized EV** charging but also managed **building and industrial** loads

% of total 2050 load that is flexible:

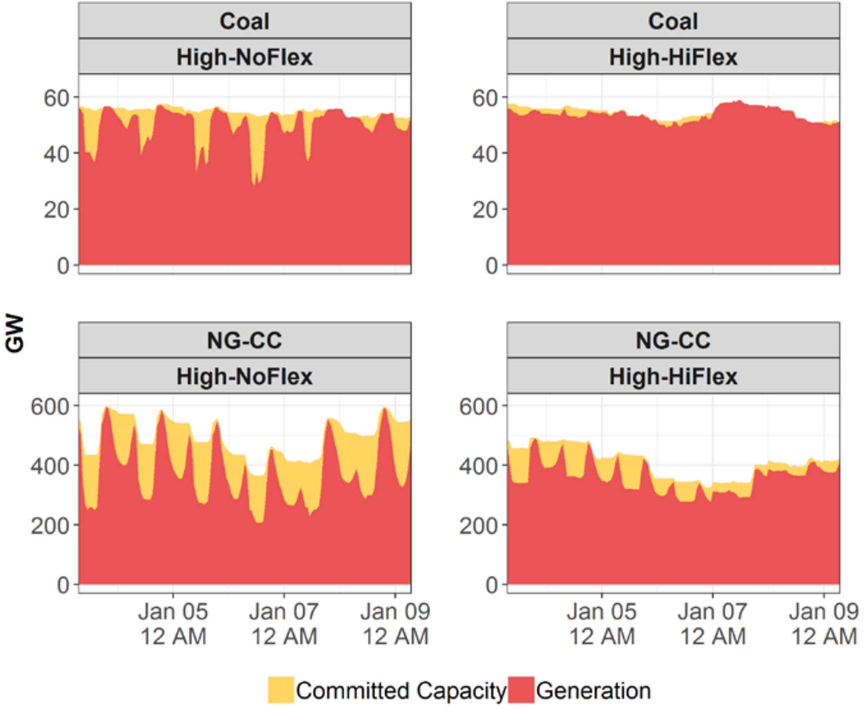
0% Ref-NoFlex	0% High-NoFlex | High-HiRE-NoFlex
2% Ref-LoFlex	4% High-LoFlex | High-HiRE-LoFlex
7% Ref-HiFlex	17% High-HiFlex | High-HiRE-HiFlex

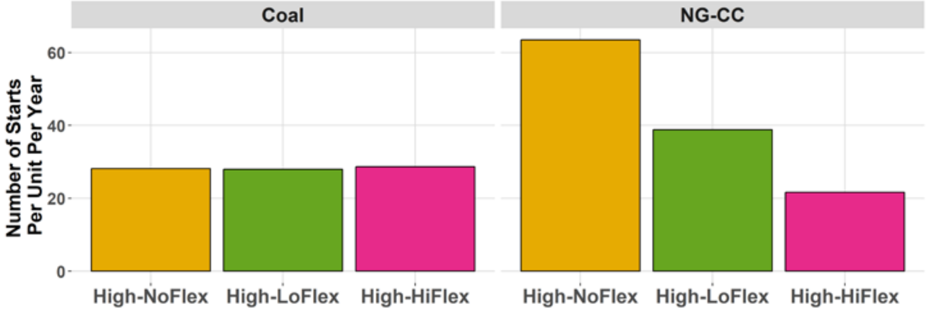


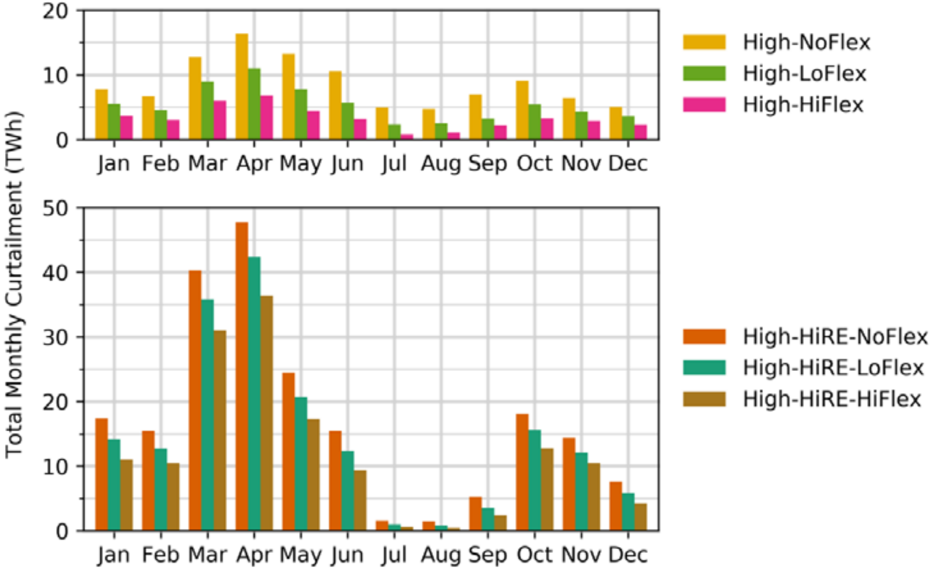
Murphy et al. (2021), https://www.nrel.gov/docs/fy21osti/72330.pdf

Demand-side flexibility reduces thermal plant cycling and VRE curtailment

Committed capacity and generation from coal and natural gas in a sample week in January

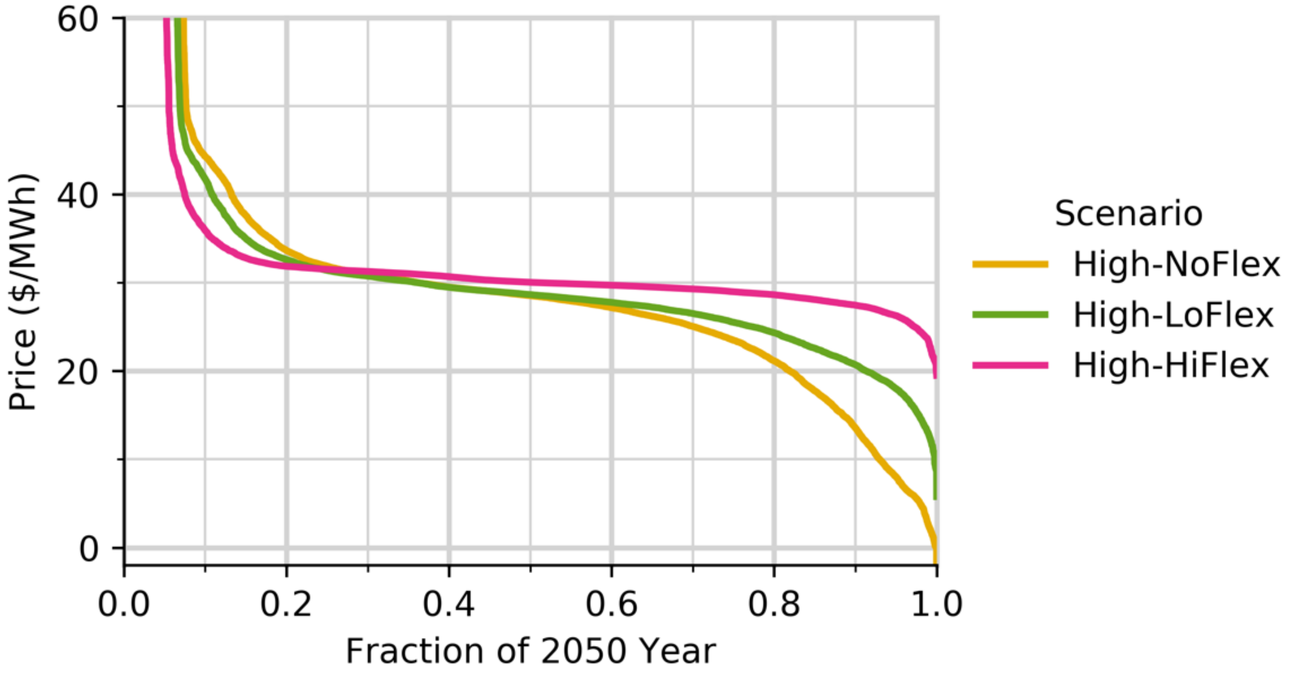






Demand-side flexibility reduces price volatility

Duration Curve for the National Average Marginal Hourly Price from Each Balancing Area, Weighted by Load



Scenario Planner Unique Features

INTEGRATION OF MODELS AND ANALYSES

Leverages and integrates state-of-the-art NREL tools and impactful analyses.

FLEXIBLE SCENARIO OPTIONS

Presents energy, emissions, and economic metrics for a wide range of options for energy transformation.

SECTORAL INTERACTIONS

Captures how energy demand and supply sectors interact and respond to key strategies such as widespread electrification.

LOCALIZED RESULTS

Translates the results of impactful national studies to the local level for community decision makers.

ACCESSIBLE USER INTERFACE

Presents complex scenario results in an accessible way for a wide range of decision makers to use and share.