Future of Electrification

Caitlin Murphy

April 17, 2023
CalPlug Workshop Series #21

Study sponsored by U.S. DOE-EERE Office of Strategic Analysis
The Electrification Futures Study explored 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?
• **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**
  – Did not consider electrification of air transport, petroleum refining and mining, CHP, outdoor cooking
How might electrification impact electricity demand and use patterns?

**Example for light-duty vehicles**

Sales shares determined from a combination of expert judgment based on current trends & consumer choice models (e.g., NREL ADOPT model for LDVs)

**EnergyPATHWAYS** model used for stock rollover and detailed energy accounting

**Principles:** technology-rich assessment, bottom-up accounting, cross-sectoral breadth, national scope with state-level detail
Transportation electrification insights

- The greatest opportunities lie in **light-duty plug-in electric cars and trucks**, in part because fully electric vehicles accounted for <1% of the on-road LDV fleet in 2021
- **Electric freight trucks** can play a major role, particularly for short-haul applications and in more transformational scenarios
- **Transit buses** are prime candidates for electrification
- The High electrification scenario requires significant infrastructure investment, with 138,000 DCFC stations (447,000 plugs) and 10 million non-residential L2 plugs

Source: Mai et al. 2018
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)

Building electrification insights

- Electricity already powers a significant share of buildings end-use services.
- Electrification opportunities in buildings are most significant for **space and water heating**.
- Air-source **heat pumps** are the key buildings electrification technologies: electric equipment provides up to 61% of space heating, 52% of water heating, and 94% of cooking services in the combined commercial and residential building sectors by 2050 (**High** scenario).

Source: Mai et al. 2018
Electric space heating has the most pronounced impact on the timing and magnitude of peak demand.

Note: Summer = June-August, Fall = September-November, Winter = December-February, Spring = March-May
Demand growth drives the expansion of renewable energy resources, energy storage, and long-distance transmission capacity.

Murphy et al. (2021), https://www.nrel.gov/docs/fy21osti/72330.pdf
Demand growth drives the expansion of renewable energy and energy storage capacity.

- 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
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*

---

**Value of Electric Vehicle Managed Charging**

<table>
<thead>
<tr>
<th>Benefit</th>
<th>Cost/Benefit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduce Bulk Power Systems Investment Costs</td>
<td>20–1350 $/EV/year</td>
</tr>
<tr>
<td>Reduce Bulk Power Systems Operating Costs</td>
<td>15–360 $/EV/year</td>
</tr>
<tr>
<td>Reduce Renewable Energy Curtailment</td>
<td>23–2400 kWh/EV/year</td>
</tr>
<tr>
<td>Reduce Distribution Systems Investment Costs</td>
<td>5–1090 $/EV/year</td>
</tr>
<tr>
<td>Increase Distribution Systems EV Hosting Capacity</td>
<td>30–450%</td>
</tr>
</tbody>
</table>

Anwar et al., 2021. “Assessing the value of electric vehicle managed charging: a review of methodologies and results.” *Energy & Environmental Science*
Available EFS Resources and Results

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
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 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.
Scenario Planner: Analysis Architecture

Key Sources

- U.S. Energy Information Administration Data
  - Natural Gas Demand (Annual)
  - Electricity Demand (Hourly/Annual)
  - Other Fuels

- Electrification Futures Study
  - Electrification Levels (EnergyPATHWAYS)

- NREL Models
  - ResStock*
  - ComStock
  - TEMPO

- Scenario Planner Strategies from Standard Scenarios
  - Grid Decarbonization Trajectories (ReEDS, dGen)*
  - Transmission Expansion Availability (ReEDS)*

SLOPE Scenario Planner

- Outcomes for 25 Unique Scenario Strategy Combinations
  - County-level energy consumption through 2050
  - County-level CO2 emissions through 2050
  - State-level system cost impacts through 2050
  - Annual, State-Level Planning Metrics

*Previous R&D 100 winners

Represents 74% of U.S. primary energy demand in 2015
Explore Supply and Demand Scenarios across Energy System Metrics

Location
Search for a state or county
Sarasota, FL County

Energy System Metrics
- Energy Consumption
- CO₂ Emissions
- System Costs (state only)

Scenario Selections
Electricity Supply Scenarios
- Reference Case
- 95% grid decarbonization by 2035
- 95% grid decarbonization by 2050
- Transmission Constraints

Energy Demand Scenarios
Level of Electrification
- Reference
- Medium
- High

Level of Building Energy Efficiency
(Coming April 2022)
- Reference
- High

Level of Demand-Side Flexibility
- Reference
- Enhanced
The Scenario Planner delivers planning metrics to inform next steps for clean energy transitions

Scenario 1: Reference Case

CO₂ Emissions - Sarasota, Florida

<table>
<thead>
<tr>
<th>Details for Year 2045</th>
<th>Residential</th>
<th>Commercial</th>
<th>Industrial</th>
<th>Transportation</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity - CO₂ Million Metric Tons (MMT)</td>
<td>0.7101</td>
<td>0.6146</td>
<td>0.1628</td>
<td>0.04207</td>
<td>1.530</td>
</tr>
<tr>
<td>Non-Electricity - CO₂ Million Metric Tons (MMT)</td>
<td>0.1202</td>
<td>0.1357</td>
<td>0.1732</td>
<td>2.356</td>
<td>2.803</td>
</tr>
<tr>
<td>Total - CO₂ Million Metric Tons (MMT)</td>
<td>0.8303</td>
<td>0.7683</td>
<td>0.3360</td>
<td>2.398</td>
<td>4.332</td>
</tr>
</tbody>
</table>

Planning Metrics
State-level data only

- Share of Space Heating Services Supplied by Electricity (%): 46.81%
- BEV and PHEV Share of Light-Duty Vehicles (%): 10.97%
- Share of Electricity Provided by Renewable Energy (%): 28.80%
- Reduction in Energy-Related CO₂ Emissions from 2005 (%): 22.55%
- Net Change in System Cost from Reference Scenario (Billions 2020 $): $0.00

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

CO₂ Emissions - Sarasota, Florida

<table>
<thead>
<tr>
<th>Details for Year 2045</th>
<th>Residential</th>
<th>Commercial</th>
<th>Industrial</th>
<th>Transportation</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity - CO₂ Million Metric Tons (MMT)</td>
<td>0.2055</td>
<td>0.2016</td>
<td>0.05046</td>
<td>0.1621</td>
<td>0.6196</td>
</tr>
<tr>
<td>Non-Electricity - CO₂ Million Metric Tons (MMT)</td>
<td>0.07491</td>
<td>0.1059</td>
<td>0.1732</td>
<td>0.9175</td>
<td>1.272</td>
</tr>
<tr>
<td>Total - CO₂ Million Metric Tons (MMT)</td>
<td>0.2804</td>
<td>0.3075</td>
<td>0.2236</td>
<td>1.080</td>
<td>1.891</td>
</tr>
</tbody>
</table>

Planning Metrics
State-level data only

- Share of Space Heating Services Supplied by Electricity (%): 80.25%
- BEV and PHEV Share of Light-Duty Vehicles (%): 75.54%
- Share of Electricity Provided by Renewable Energy (%): 72.05%
- Reduction in Energy-Related CO₂ Emissions from 2005 (%): 65.89%
- Net Change in System Cost from Reference Scenario (Billions 2020 $): -$3.217
Scenario Planner reveals for the first time changes in state-level system costs, including investment and savings tradeoffs.

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

Change in System Costs Relative to Reference Scenario (Billions of 2020$) - Florida

Data Filters
- Electricity Supply: T&D (Wires)
- Demand: Fuel Consumption and O&M
- Electricity Supply: Fuel and O&M
- Net System Cost
- Demand: Equipment Capital
- Demand: Fuel Infrastructure
- Electricity Supply: Generation and Storage
Thank you!

caitlin.murphy@nrel.gov

www.nrel.gov

NREL/PR-6A20-85911