Impacts of PHEVs on Electricity Demand

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Explanations from Dr. McCalley

• Slide 9: Annual energy demand increase as a function of number of PHEVs on the road, parameterized by "Frac" which is the "electricity fraction of PHEV miles," i.e., it is the percentage of PHEV vehicle miles that are supplied from the grid. Since this plot is given as a function of PHEVs on the road, it can be applied to any geographical region (e.g., US or Iowa) for which one might develop a prediction for how the number of PHEVs on the road will grow in the future.

• Slide 10: Annual energy demand increase as a % PHEV penetration, parameterized by "Frac" (which is the same parameter described above). This plot depends on geographical location and is given for the US and for the state of Iowa. The plots are obtained under assumption that the number of registered vehicles remains the same as given in the 2005 data from State transportation statistic 2006).

• Slide 12: Number of PHEVs in the road in the US as a function of time, through 2030. This is a forecast and depends on the information given in Slide 11 which includes a forecast of vehicles and of PHEV market share. NOTE THERE IS MUCH UNCERTAINTY IN THESE FORECASTS!!!!

• Slide 13: Annual energy demand increase as a function of time, through 2030. This is also a forecast and depends on the information given in Slide 12.
Objectives

1. Increase in electricity demand vs. PHEV number
2. Increase in electricity demand vs. PHEV penetration\(^1\)
3. Increase in electricity demand vs. year

Relate 2 to 1:

\[(\text{PHEV penetration}) \times (\text{total number of LDV}) \rightarrow \text{number of PHEVs}\]

Relate 3 to 1:

Calculate PHEV number for the given year

Only need to solve 1:

Load increase as a function of PHEV number-\(L(N)\)

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\(^1\)PHEV penetration: \[
\frac{\text{number of PHEV on-road}}{\text{number of LDV on-road}}
\]
Load increase as a function of PHEV number-$L(N)$

$L(N) = a \text{ kWh/mile} \times b \text{ mile/day} \times 365 \text{ day/year} \times N$

• Rough estimation:
  \(a\): 0.35 (kWh/mile)
  \(b\): 33 (mile/day)

\[ \Rightarrow L(N) = 4.2 \text{ MWh/year} \times N \]

How are \(a\) and \(b\) obtained?
Electricity consumption per mile

<table>
<thead>
<tr>
<th>Vehicle Class</th>
<th>Compact sedan</th>
<th>Mid-size sedan</th>
<th>Mid-size SUV</th>
<th>Full-size SUV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy Requirements(^2) (-a_i) (kWh/mile)</td>
<td>0.26</td>
<td>0.30</td>
<td>0.38</td>
<td>0.46</td>
</tr>
<tr>
<td>Mix of LDV (-p_i)</td>
<td>Case1 25%</td>
<td>25%</td>
<td>25%</td>
<td>25%</td>
</tr>
<tr>
<td></td>
<td>Case 2 30%</td>
<td>30%</td>
<td>20%</td>
<td>20%</td>
</tr>
</tbody>
</table>

\[
a = \sum_{i=1}^{4} a_i p_i
\]

Average Energy Requirement:

Case 1: 0.35 kWh/mile  
Case 2: 0.336 kWh/mile

\(^2\)The data are from M. K. Meyer et al., “Impacts Assessment of Plug-in Hybrid Vehicles on Electric Utilities and Regional U.S. Power Grids”.

\[\text{a: Electricity consumption per mile} \]

\[\text{Compact sedan} \quad \text{Mid-size sedan} \quad \text{Mid-size SUV} \quad \text{Full-size SUV} \]

\[
a = \sum_{i=1}^{4} a_i p_i
\]

Average Energy Requirement:

Case 1: 0.35 kWh/mile  
Case 2: 0.336 kWh/mile

\[\text{Case 1: 0.35 kWh/mile} \quad \text{Case 2: 0.336 kWh/mile} \]
**b: Average Daily Vehicle Miles Traveled (VMT)**

- $f(m)$: distribution probability
- $F(m)$: cumulative probability (the figure above shows a typical pattern$^3$)

\[
f = \frac{dF}{dt} \quad b = \int_{0}^{\infty} f(m) \cdot m \, dm = 34 \text{ (mile/day)}
\]

## Improve the Accuracy of Estimation

Fraction of vehicle miles from electricity

<table>
<thead>
<tr>
<th>Daily Trip</th>
<th>Trip Mileage</th>
<th>All Electric Mileage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>PHEV-20⁴</td>
</tr>
<tr>
<td>Mon</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Tue</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Wed</td>
<td>30</td>
<td>20</td>
</tr>
<tr>
<td>Thu</td>
<td>50</td>
<td>20</td>
</tr>
<tr>
<td>Fri</td>
<td>45</td>
<td>20</td>
</tr>
<tr>
<td>Sat</td>
<td>70</td>
<td>20</td>
</tr>
<tr>
<td>Sun</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>210</strong></td>
<td><strong>95</strong></td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td><strong>30</strong></td>
<td><strong>13.6</strong></td>
</tr>
<tr>
<td><strong>Mileage Weighted Probability (MWP)</strong></td>
<td>0.452</td>
<td>0.786</td>
</tr>
</tbody>
</table>

⁴ A PHEV can be designated by its effective “all-electric” range, e.g., PHEV-20 refers a vehicle that may travel 20 miles without using its internal combustion engine.
All-Electric Operation Fraction

MWP method:

\[
\text{Frac}(x) = \frac{\int_{0}^{x} f(m) \cdot mdm + \int_{x}^{\infty} f(m) \cdot mdm}{\int_{0}^{\infty} f(m) \cdot mdm}
\]

Assumptions:
- PHEV has the same driving pattern as gasoline vehicle (Nationwide Personal Transportation Survey, 1995)
- Charging frequency: once per day
- Start with full-charge every day
- PHEV is operated in depletion-mode\(^5\) for MWP (or blend mode\(^6\) for Utility factor) method

\(^5\)Depletion-mode: drive with charged battery similar to battery electric vehicle (BEV).

\(^6\)Blend mode: drive with charged battery with occasional engine power support.
Load increase vs. PHEV number

\[ L(N) = a \ \text{kWh/mile} \times b \ \text{mile/day} \times 365 \ \text{day/year} \times N \times \text{Frac} \div \eta \]

Frac: account for mix of PHEV, PHEV operation mode, ...
\( \eta \): efficiency - 85% (account for charger and battery losses)
Based on State transportation statistic 2006 data and assume the LDV number remains the same.
PHEV number vs. year

The lifetime of PHEV is assumed to be 10 years.
Load increase vs. year

United State

Iowa

Increase in Electricity Demand (billion kWh)

year

Frac=0.5  Frac=0.7  Frac=0.9

Frac=0.5  Frac=0.7  Frac=0.9
Proposed Research (discussion)

**Accurate** estimation for impacts of PHEVs for the state of Iowa.

**Emissions**
- Emissions from vehicle reduced by using PHEV
- Emissions increased from power plants due to additional PHEV load

**Cost**
- Additional capital cost for PHEV
- Increase the utilization of baseload units and decrease plant cycling (It is also possible to result in new power plant due to PHEV)
- Reduced gas cost (and transportation?) for vehicles
- Increase fuel cost and transportation in power system
- Energy storage system

**Reliability**
- How to deal with or utilize a big amount of PHEV in power system
- Reduce the dependency on foreign oil
- Reserve
Things we must know

1. Forecast of PHEV numbers by classification (PHEV 20 compact sedan, PHEV 40 compact sedan, PHEV 20 mid-size SUV, ...)?
2. Does the driving pattern depend on PHEV types? If so, how the driving pattern will be affected?
3. Charging frequency (how many times per day) and timing (at what time)
4. Charging power rating and efficiency
5. Load profile and mix of generation
6. How to make the dispatch decision (based on fuel and operation cost and emission credit price?)
7. Should possible technology, e.g., smart grid, be included?
...


