Electric Energy and Power Consumption by Light-Duty Plug-in Electric Vehicles

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NETSCORE21
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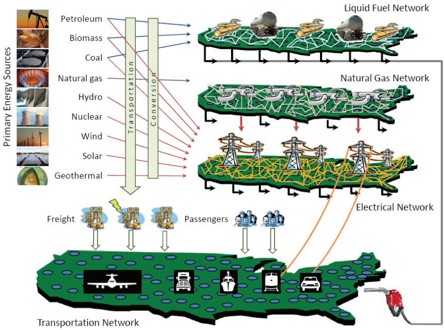
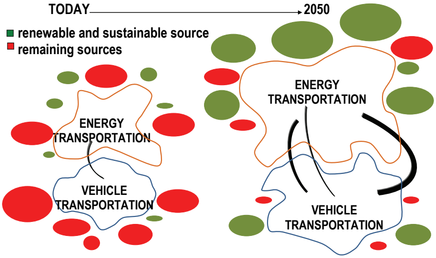
21st Century National Energy and Transportation Infrastructures: Balancing Sustainability, Costs, & Resiliency





Outline

1. Travel pattern
2. PEV operation
3. Analytical method to estimate energy consumption
4. Simulation method to estimate power consumption

Why do we study the travel pattern?

GM-Volt: 8 kWh usable energy in the battery
40 miles all-electric range

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  - If all vehicles travel 20 miles: 4 kWh
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- What's the electric power consumption from the grid?

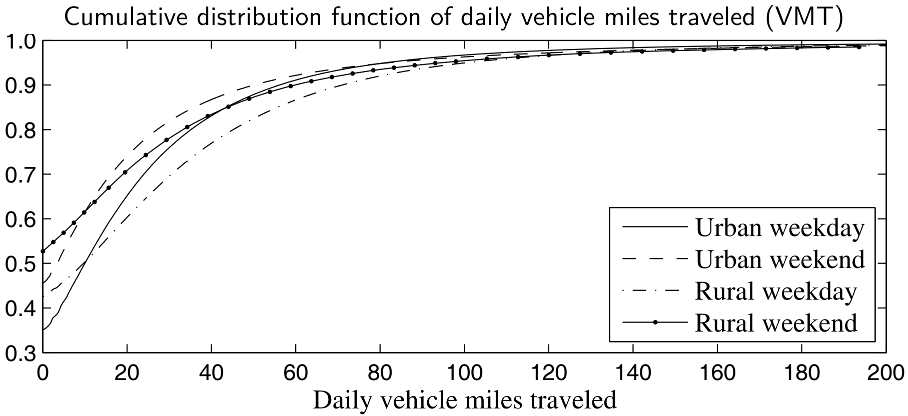
National Household Travel Survey (NHTS)

The 2009 NHTS collects information on the travel behavior of a national representative sample of U.S. households, such as mode of transportation, trip origin and purpose, and trip distance. The survey consists of 150,147 households and 294,408 Light-Duty Vehicles (LDVs).

Data Example from the 2009 NHTS

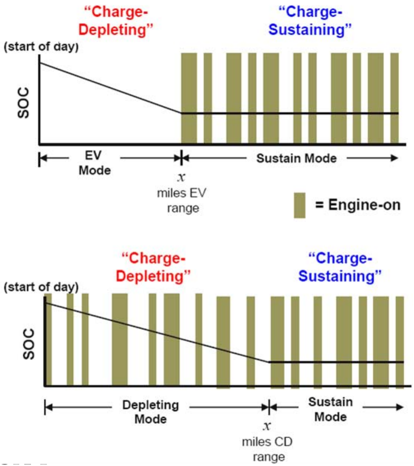
Vehicle	Type	Origin/purpose	Start time	Destination/purpose	End time	Trip miles
Veh1	Car	Home	07:30	Work	07:40	2
		Work	16:30	Home	16:40	2
Veh2	SUV	Home	07:30	Work	07:45	3
		Work	17:30	Home	17:45	3
		Home	19:20	Shopping	19:35	4
		Shopping	21:10	Home	21:25	4

Daily vehicle miles traveled (VMT)



PEV operation

The tractive energy per mile that is provided by the battery in charge-depleting mode (h_e) is a fraction (ξ) of total tractive energy per mile (h_{tr}): $h_e = \xi h_{tr}$.



Source: M. Duoba, 2005
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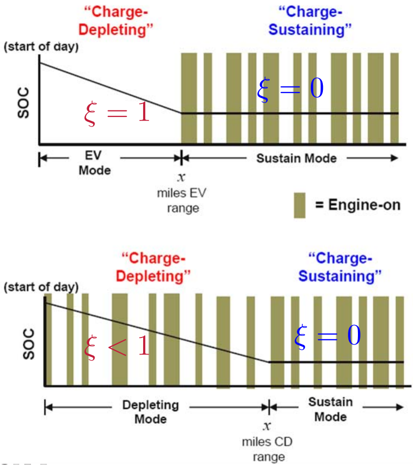

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Vehicle Class	Specific Energy Requirements [kWh/mile]	Size of Battery for PHEV33 [kWh]
Compact sedan	0.26	8.6
Mid-size sedan	0.30	9.9
Mid-size SUV	0.38	12.5
Full-size SUV	0.46	15.2

Source: M. Kintner-Meyer, K. Schneider, and R. Pratt, "Impacts assessment of plug-in hybrid vehicles on electric utilities and regional U.S. power grids. Part 1: Technical analysis,"J. EUEC, vol. 1, no. 4, 2007.

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Type of PHEV20	Pack size (kWh)
Compact sedan	5.1
Mid-size sedan	5.9
Mid-size SUV	7.7
Full-size SUV	9.3

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- simplified travel pattern
- entire h_{tr} from battery
- unique CDR

Proposed methodology

For a random PEV in an urban (or rural) area, on a random weekday (or weekend), the daily electric energy consumption from the outlet:

$$\begin{aligned}\boldsymbol{\epsilon} &= \frac{1}{\eta}\mathbf{h}_{\mathsf{e}}\mathbf{m}_{\mathsf{cd}} \\ &= \frac{1}{\eta}\boldsymbol{\xi}\mathbf{h}_{\mathsf{tr}}\mathbf{m}_{\mathsf{cd}}\end{aligned}$$

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Assuming that the all the random variables are independent to each other, the expected value:

$$\begin{aligned}E(\boldsymbol{\epsilon}) &= \frac{1}{\eta}E(\boldsymbol{\xi})E(\mathbf{h}_{\mathsf{tr}})E(\mathbf{m}_{\mathsf{cd}}) \\ \sigma(\boldsymbol{\epsilon}) &= \sqrt{E(\boldsymbol{\epsilon}^2) - E^2(\boldsymbol{\epsilon})} \\ &= \sqrt{E(\boldsymbol{\xi}^2)E(\mathbf{h}_{\mathsf{tr}}^2)E(\mathbf{m}_{\mathsf{cd}}^2)/\eta^2 - E^2(\boldsymbol{\epsilon})}\end{aligned}$$

Assumptions

1. Tractive energy per mile at the wheel ($\mathbf{h}_{\text{tr}}$) is a normal distribution and standard deviation equal to 10% of its mean.

Vehicle Class	Car	Van	SUV	Pickup truck
$E(\mathbf{h}_{\text{tr}})$ (kWh/mile)	0.21	0.33	0.37	0.40

2. The outlet-to-wheel efficiency (η) is assumed to be constant and equal to 67%.
3. Fraction of tractive energy derived from electricity (ξ) in CD mode:

$$f_{\xi}(x) = \begin{cases} 1 & \text{for } 0.2 \leq x < 1\,, \\ 0.2\delta(x-1) & \text{for } x = 1\,. \end{cases}$$

4. Charge-depleting range or CDR ($\mathbf{d}$): log-normal distribution function with expected value and standard deviation equal to $(40{,}10)$.
5. Probability density function of daily VMT ($\mathbf{m}$) is extracted from 2009 NHTS.

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Miles in CD mode

Assuming that PEVs start the daily trips with fully charged battery and can be only charged after finishing all the trips, daily miles in charge-depleting (CD) mode:

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After derivation,

$$f_{m_{\text{cd}}}(x) = f_m(x) \int_x^{\infty} f_d(v)\, dv + f_d(x) \int_x^{\infty} f_m(u)\, du\,.$$

Results

- Individual PEV:

kWh	$E(\epsilon)$	$\sigma(\epsilon)$
Urban weekday	4.16	5.36
Urban weekend	3.23	4.98
Rural weekday	4.88	6.43
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- PEV fleet:
  $\mathbf{W}_n = \sum_{i=1}^{n} \epsilon_i \Rightarrow E(\mathbf{W}_n) = nE(\epsilon)$
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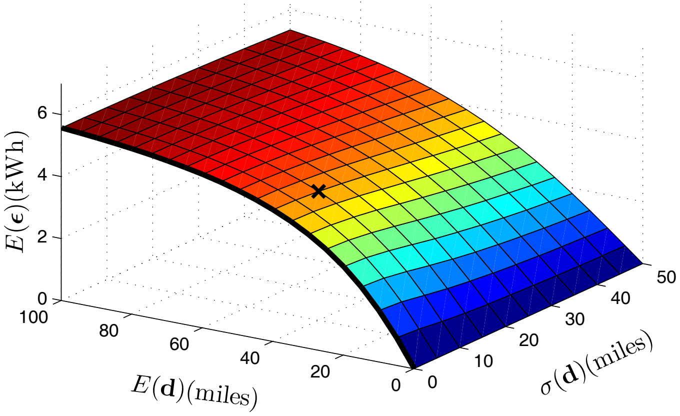
Therefore, $\sigma(\mathbf{W}_n)/E(\mathbf{W}_n) =$ is proportional to $1/\sqrt{n}$.
For a fleet size of one million "urban-weekday" PEVs, the standard deviation over expected value is equal to 0.13%.

Sensitivity analysis



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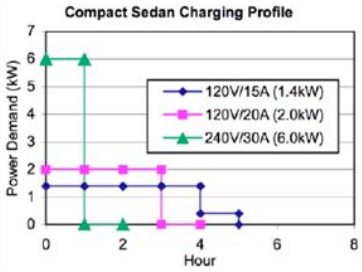

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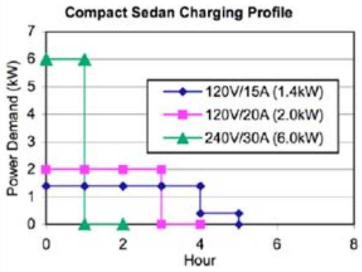

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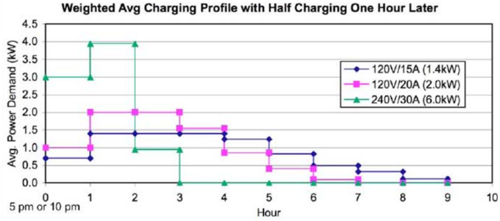

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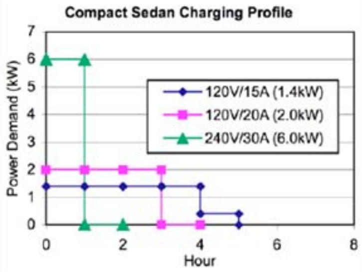

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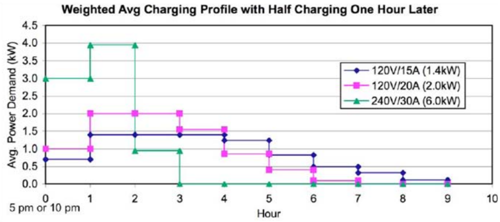

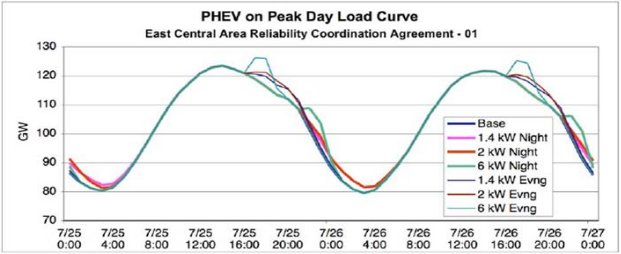

Figure 8. Added demand from PHEV charging scenarios on the peak day in ECAR for 2020.

Source: S. W. Hadley and A. Tsvetkova, "Potential impacts of plug-in hybrid electric vehicles on regional power generation," Oak Ridge National Laboratory, Oak Ridge, TN, Tech. Rep. ORNL/TM-2007/150, Jan. 2008.

Factors that affect the power consumption

- Configuration and operation of PEVs
  vehicles' tractive energy, battery size, how the electric energy in the battery is consumed as vehicle is driving.
- Charging scenarios
  where the PEVs can be charged—only at home or anywhere, the charger size.
- Travel pattern
  the time and distance of each trip for all the PEVs, etc.

Charging scenarios

Two uncontrolled charging scenarios are simulated:

(A) charging any time the vehicle is parked at home

(B) "opportunistic" charging at any location (home, shopping mall, work, etc.)

Typical Charging Circuits

Charging circuit	Charger size (kW)	Ratio
120 V, 15 A (Level 1)	1.4	1/3
120 V, 20 A (Level 1)	2	1/3
240 V, 30 A (Level 2)	6	1/3

In the mixed-charger case, home chargers are evenly distributed among three charger types. For scenario (B), it is assumed that the public charging infrastructure involves only 6-kW chargers (i.e., the most expensive option).

Proposed methodology

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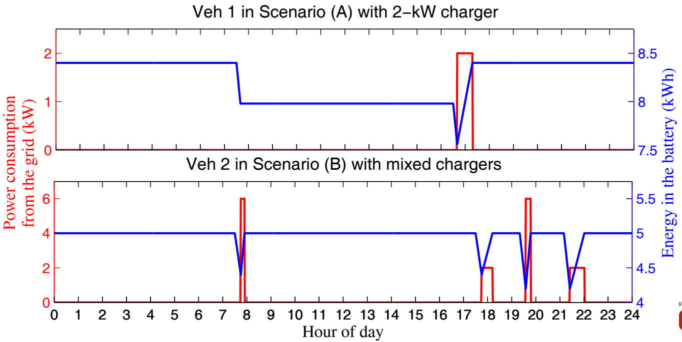
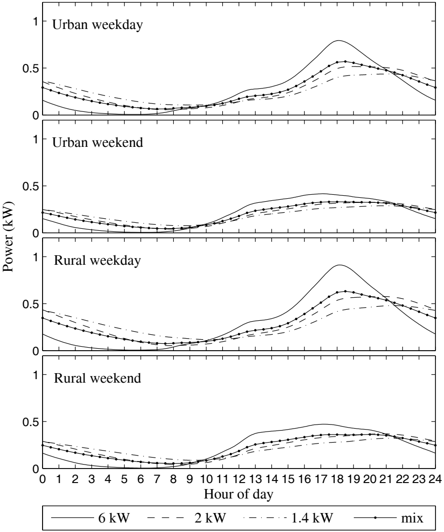


Power consumption vs. AER in Scenario (A)

AER = 40



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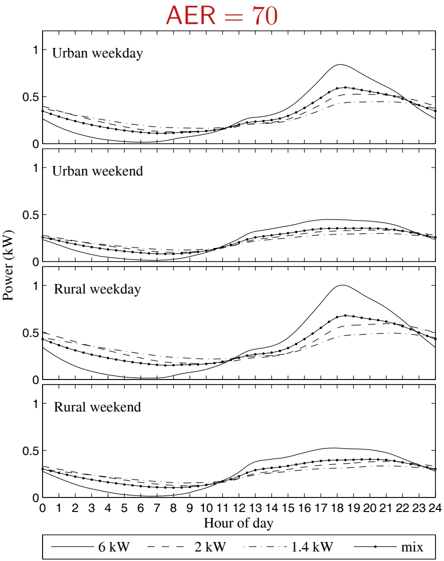

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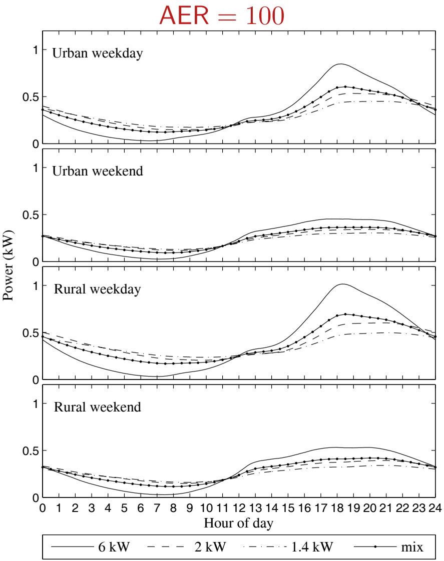

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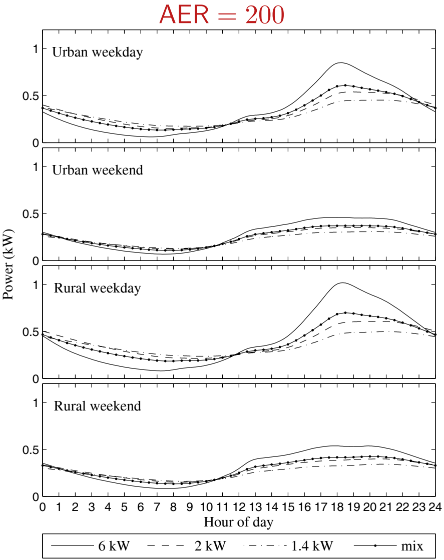

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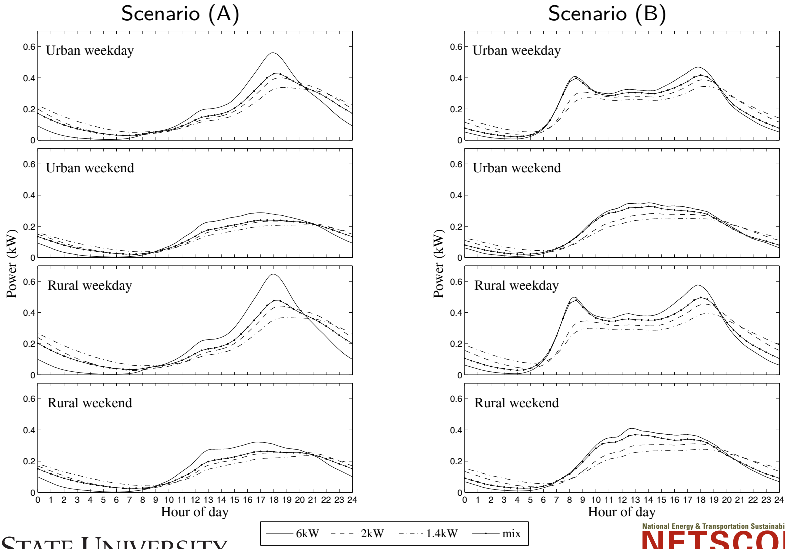
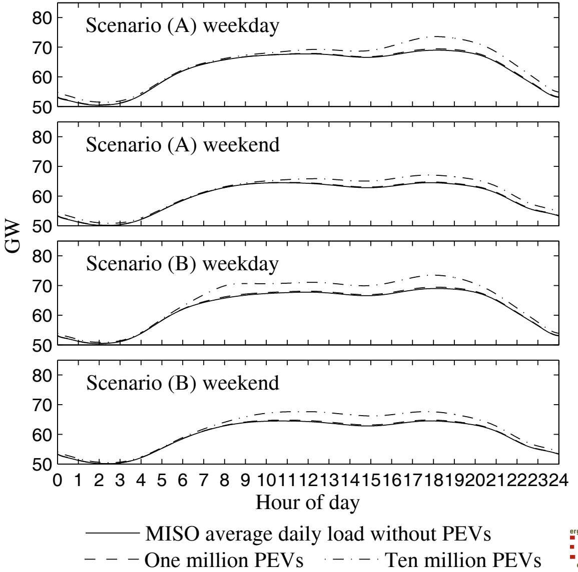
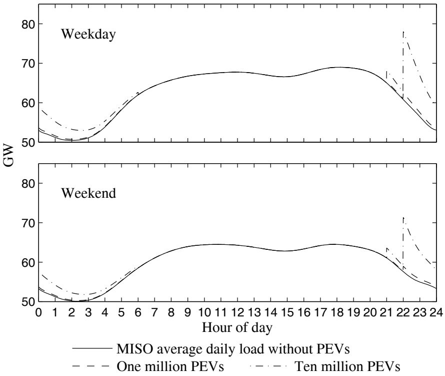
Expected power consumption per PEV



PEV load superimposed on Midwest ISO load curve



Simple-delayed charging



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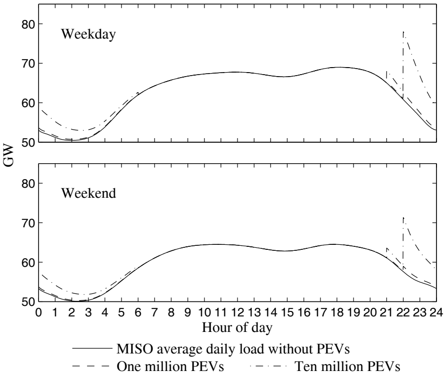

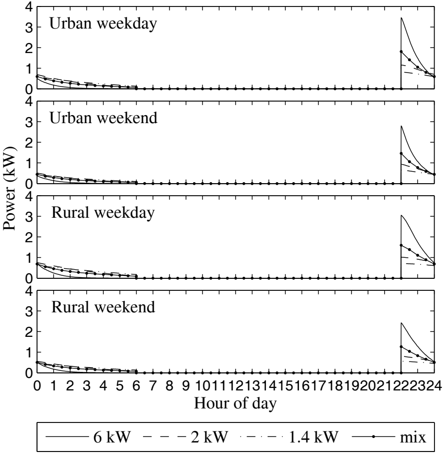

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THANK YOU!