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Modeling Plug-in Electric Vehicle-Grid Integration: Case Study of Sacramento Region

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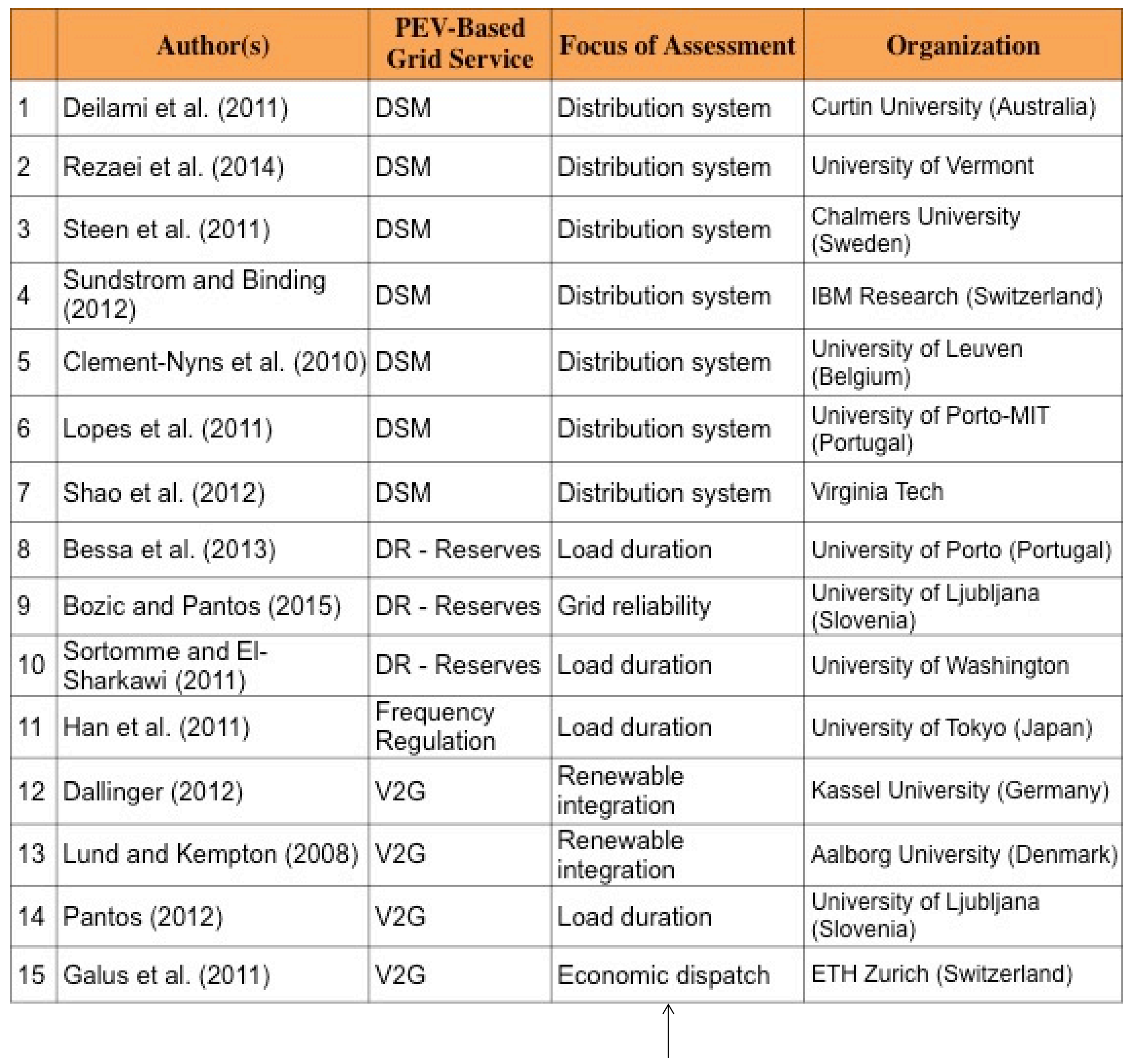
Abstract

Energy-planning agencies in California consider plug-in electric vehicle (PEV)-based grid services as a potential way to integrate renewables into the grid and to increase economic value in the electrification of transportation. This study demonstrates a stochastic method for impact assessment of widespread PEV deployment on the grid, and PEV-based grid services such as demand-side management (DSM), frequency regulation, and energy storage. The Sacramento Municipal Utility District (SMUD), a mid-size utility company, is chosen as a case study as it currently provides DSM programs for the PEV consumers. The reference scenario includes 60,000 PEVs in SMUD territory, where vehicles are being used for commute purposes only. Stochastic parameters such as PEV owners' daily energy needs, home arrival/departure hours, vehicle charging levels, and PEV locations are considered in a series of Monte-Carlo simulations. The preliminary results show that the deployment of 60,000 PEVs in the Sacramento Region would have a significant impact on the peak demand, and may overload 16% of the distribution (neighborhood) transformers. Providing dynamic-pricing signals to the PEV drivers, however, can greatly decrease these negative impacts depending on the varying-electricity prices.

Research Question: How can PEV-grid stakeholders quantify technical and economic impacts of large PEV load on the grid and evaluate PEV-based grid services?

Literature Review

The following table is a list of recent studies focused on the assessment of PEV-based grid services with respect to different aspects of grid operations. (Acronyms: DSM: demand-side management; DR: demand response; V2G: vehicle-to-grid).



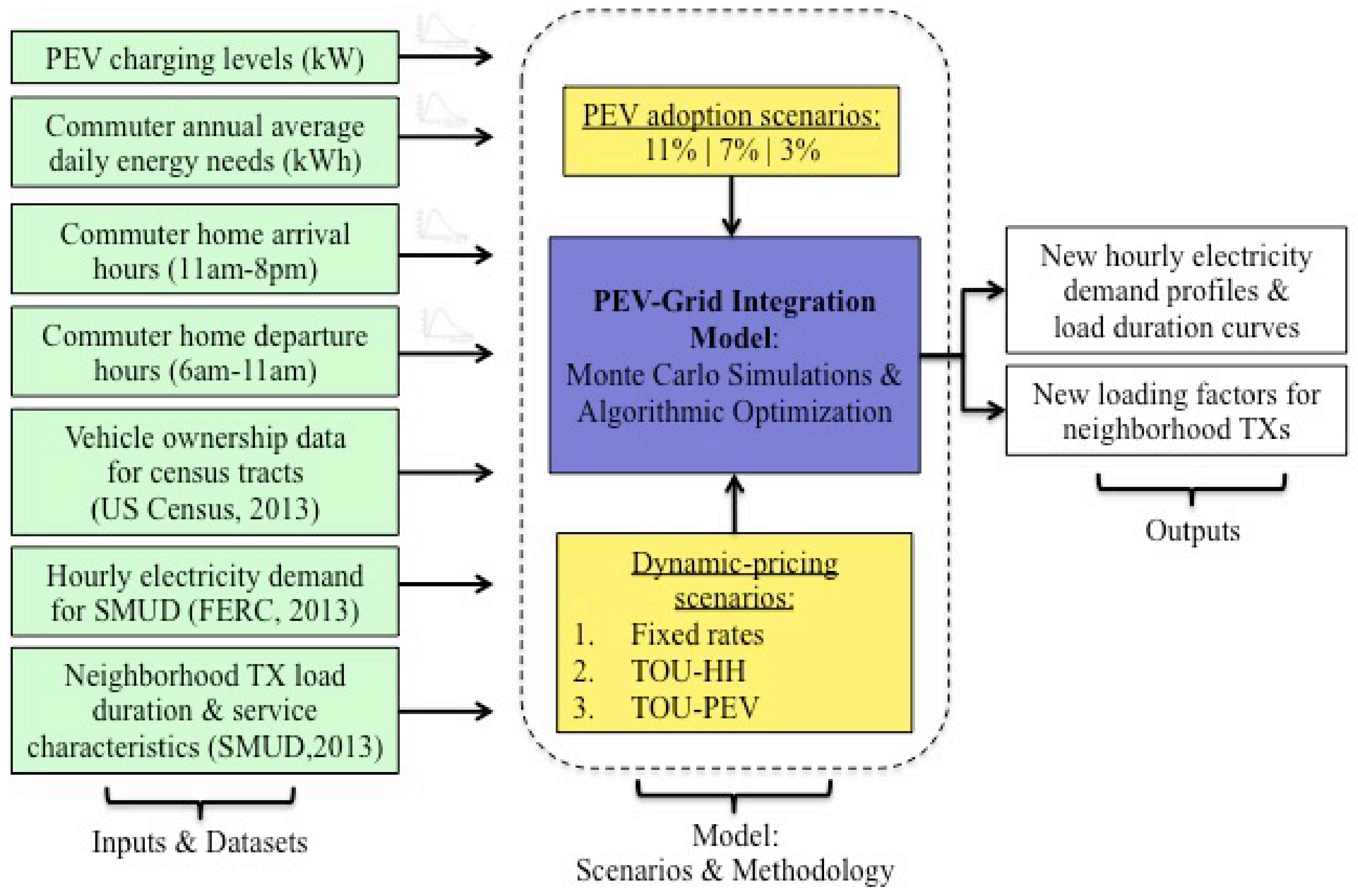
	Author(s)	PEV-Based Grid Service	Focus of Assessment	Organization
1	Deilami et al. (2011)	DSM	Distribution system	Curtin University (Australia)
2	Rezaei et al. (2014)	DSM	Distribution system	University of Vermont
3	Steen et al. (2011)	DSM	Distribution system	Chalmers University (Sweden)
4	Sundstrom and Binding (2012)	DSM	Distribution system	IBM Research (Switzerland)
5	Clement-Nyns et al. (2010)	DSM	Distribution system	University of Leuven (Belgium)
6	Lopes et al. (2011)	DSM	Distribution system	University of Porto-MIT (Portugal)
7	Shao et al. (2012)	DSM	Distribution system	Virginia Tech
8	Bessa et al. (2013)	DR - Reserves	Load duration	University of Porto (Portugal)
9	Bozic and Pantos (2015)	DR - Reserves	Grid reliability	University of Ljubljana (Slovenia)
10	Sortomme and El-Sharkawi (2011)	DR - Reserves	Load duration	University of Washington
11	Han et al. (2011)	Frequency Regulation	Load duration	University of Tokyo (Japan)
12	Dallinger (2012)	V2G	Renewable integration	Kassel University (Germany)
13	Lund and Kempton (2008)	V2G	Renewable integration	Aalborg University (Denmark)
14	Pantos (2012)	V2G	Load duration	University of Ljubljana (Slovenia)
15	Galus et al. (2011)	V2G	Economic dispatch	ETH Zurich (Switzerland)

What is New?

"Our study provides an assessment on both, load duration & distribution system impacts of PEVs on a 'utility-scale' grid system."

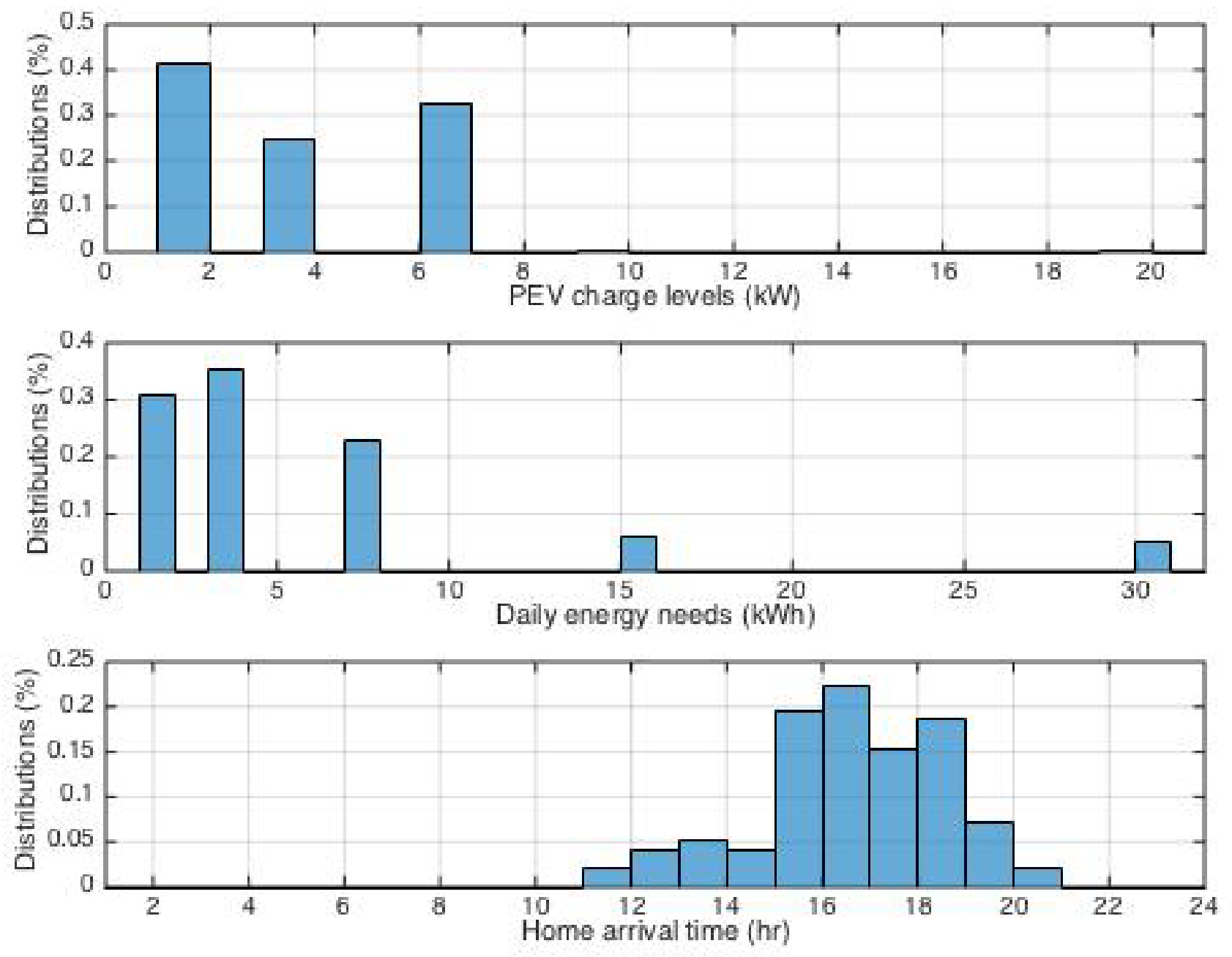
Modeling, Methodology and Data

The following chart demonstrates a conceptual design of the proposed systems model:



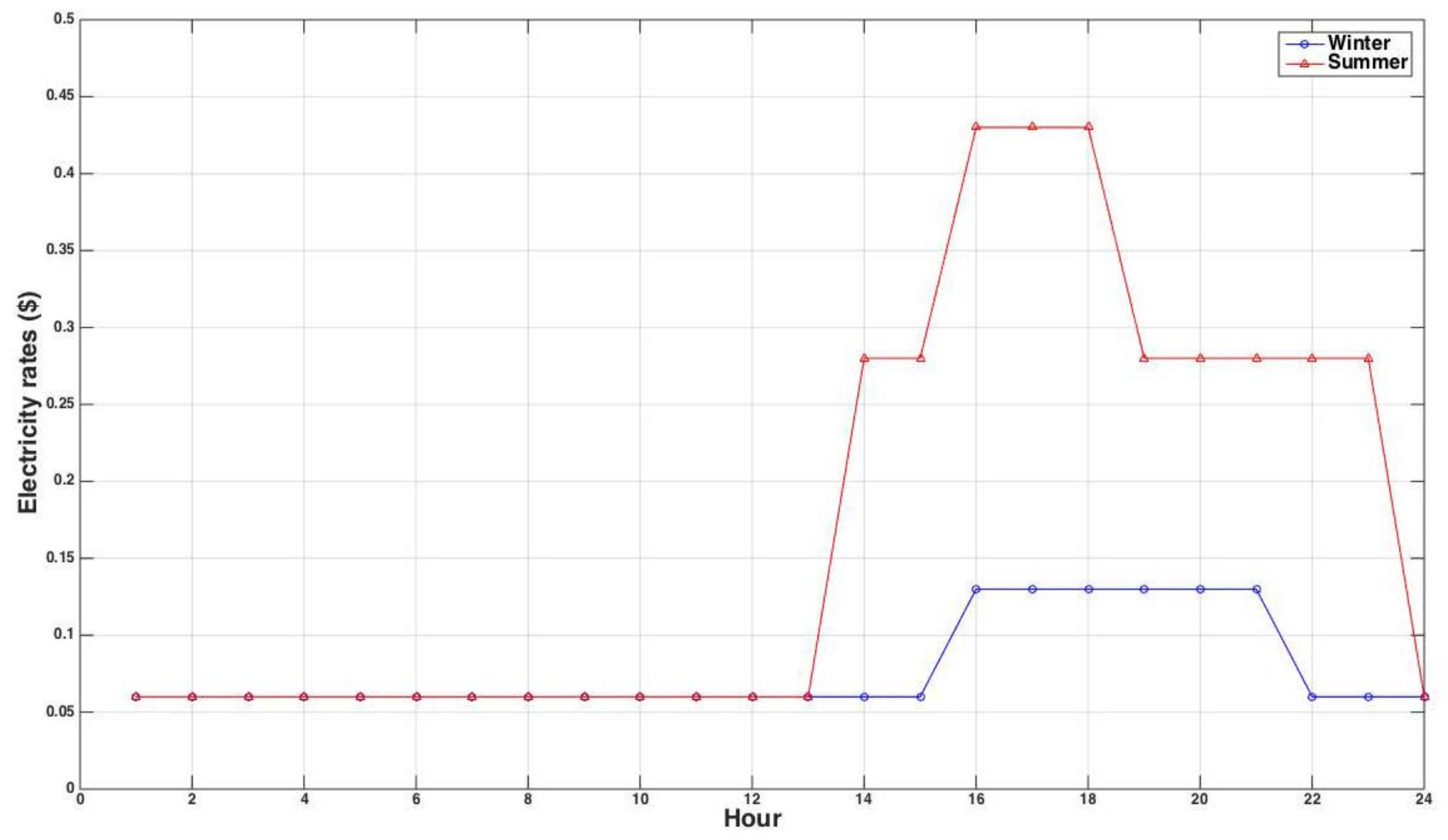
- TX is the neighborhood transformer which typically provides power to a total of 10 households in a single-unit residential neighborhood in the SMUD territory.
- SMUD is a mid-size utility region, which includes 317 census tracts and 512,496 households (US Census, 2013).
- California's goal of 1.5 million zero-emission vehicles (ZEV) corresponds to about 60,000 PEVs or 11% adoption rate for the Sacramento region.

Model Inputs: The following distributions considered in this study are the projected PEV charging levels (SMUD, 2013), daily energy needs (UCD PEV Market Tool, 2015), and home arrival hours (SACOG, 2012).



Scenario Formulation:

The PEV-grid analysis has been performed for three major scenarios: (1) business-as-usual (BAU), where fixed prices were considered (9.98 cents/kW in winter and10.76 cents/kW in summer); (2) household time-of-use (TOU-HH), where time-varying rates are provided for the households with a PEV. (2) PEV time-of-use (TOU-PEV), where the PEV charging load is billed separately through an additional utility meter or submeter.



TOU-PEV pricing schedule for summer (red) and winter (blue) (source: smud.org, 2015)

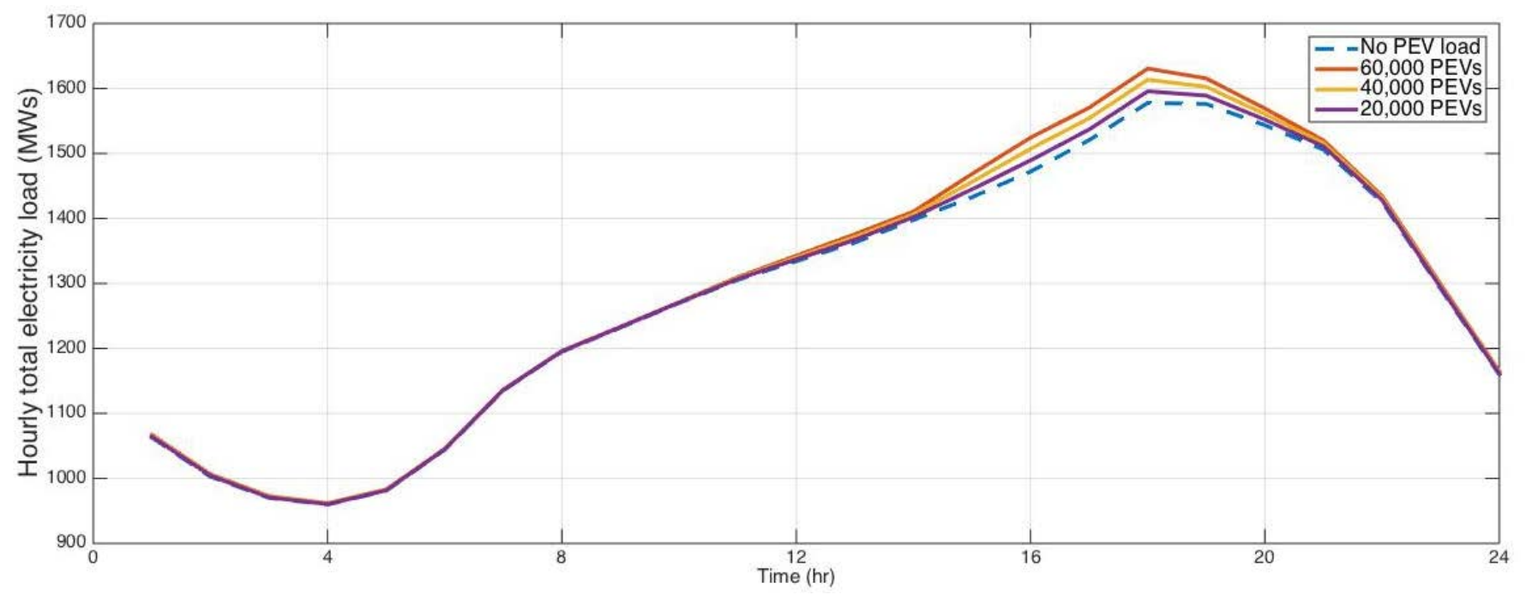
Algorithmic Optimization: PEV consumers are assumed to first determine lowest-cost charging schedules, then to choose the earliest charge start time from the available options. This algorithm is enabled for the dynamic-pricing scenarios.

➢The consumers' choice on charging schedule for the lowest-cost options are constrained based on their home arrival, home departure, charging level, and daily energy needs.

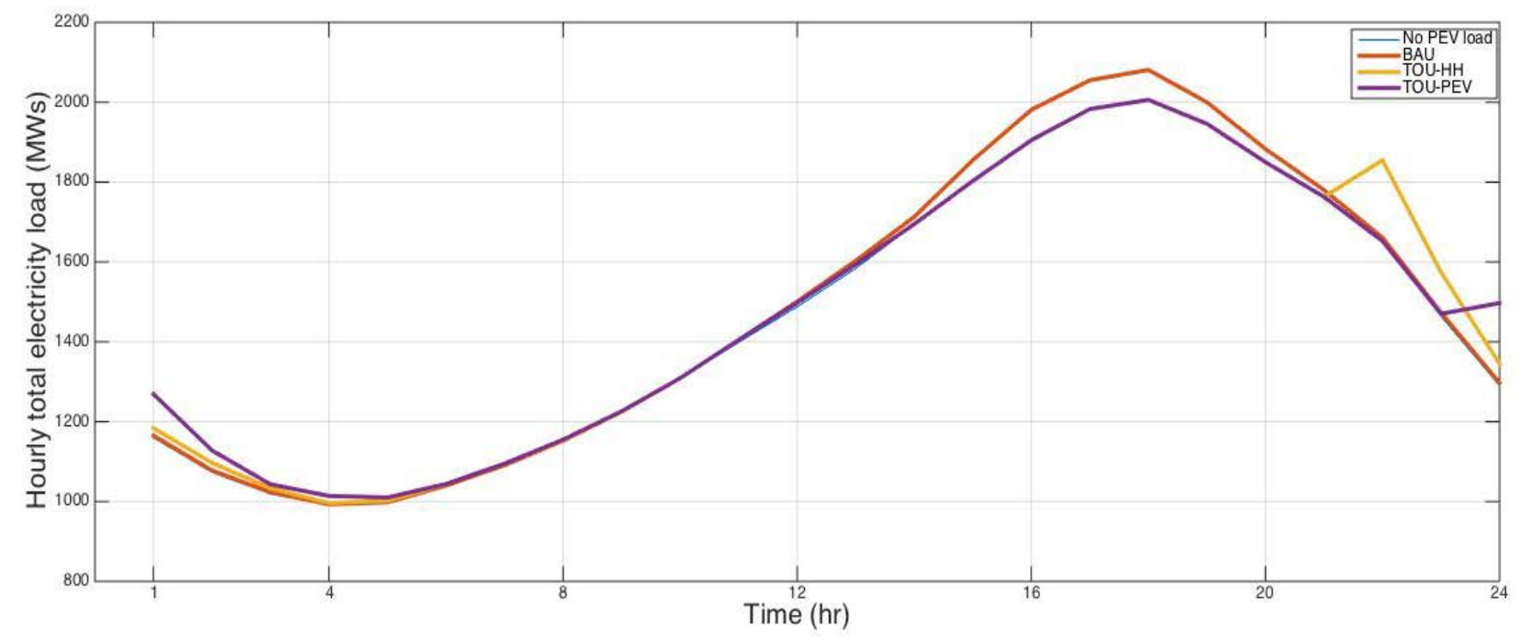
Results

➢Monte-Carlo based analysis is repeated 1000 times where the average coefficient of variation for 24 hour data approaches 0.02. Charging levels, daily energy needs, and home arrival/departure hours are randomly assigned to the PEV households based on the given distributions, and inverse transform sampling in Matlab.

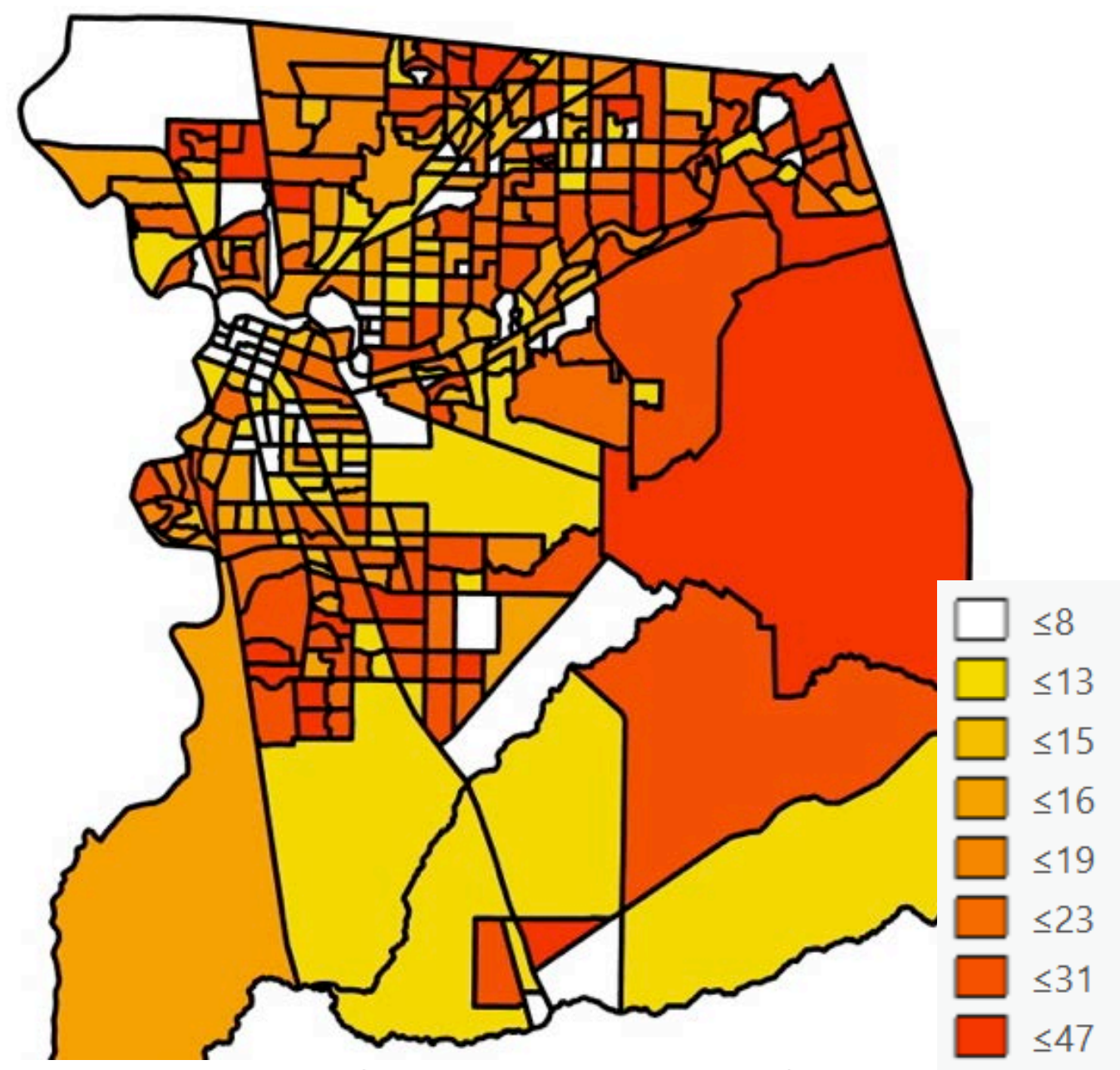
"Additional electricity load from PEV charging increases annual peak electricity demand for 74 MWs, 50 MWs, and 25 MWs in 60K, 40K, and 20K scenarios respectively."



"In high PEV adoption (60K) case, most of the additional electricity demand during the peak hour is shifted to 10pm or 12am based on the time-varying price signals."



"In high PEV adoption (60K) case, the additional PEV load causes transformer overloading for about 16% of the neighborhood transformers – mostly at the single-residential suburban areas."



Sacramento County -- The density map for overloaded transformers caused by the unmanaged PEV load in high PEV adoption (60K) scenario.

Key Takeaways:

1.Widespread PEV adoption, especially at the adoption rate of 7% or higher, may have a significant impact on the "utility-level" grid operations such as increasing peak demand and overloading distribution infrastructure.

1.Demand-side management programs, notably time-of-use rates, have enough potential for mitigating adverse grid impacts of the PEV load on both peak demand and distribution infrastructure.

2.The proposed method of PEV-grid assessment can be applied to other utility regions in the State, and can be improved by adapting grid infrastructure data with higher levels of detail.

Future Work: (1) The economic implications of the PEV load impacts will be analyzed; (2) Consumer adoption of demand-side management will be extended to real-time pricing, demand response, and PEV integration with residential solar panels.

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