



Renewable Energy Supply for Electric Vehicle Operations in California

Anthony Papavasiliou, PhD student, IEOR, UC Berkeley
Shmuel S. Oren, Professor, IEOR, UC Berkeley
Ikhlaq Sidhu, Adjunct Professor, IEOR, UC Berkeley
Phil Kaminsky, Professor, IEOR, UC Berkeley

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Outline

- Introduction
- EV service provider optimization problem
- Solution Methodology
- Assumptions and data
- Results
- Conclusions and future work

Context

- Unpredictable, variable supply of renewable energy results in costly requirements for system reserves
- California hosts large amounts of wind power
 - 2493 MW, 2nd greatest installed wind power capacity in the US
 - 11% of state energy supply (2006)
- California policy facilitates renewable energy
 - Renewable Portfolio Standard: 20% by 2010
 - Assembly Bill 32: goal for capping California emissions to 1990 levels by 2020
 - Remote Resource Interconnection Program
- California market regulations facilitate renewable energy
 - Market Redesign and Technology Upgrade, 2007
 - Participating Intermittent Resources Program, 2002
- Better Place launches operations in California in December 2008

Renewable “coverage” of EV demand (%)

Solar (MW)	0	30	60	90	120	150	180
Wind (MW)							
0	0.0	12.5	25.0	35.8	43.7	47.4	50.0
30	17.4	29.9	42.2	51.2	56.4	59.9	62.0
60	34.6	46.9	57.6	64.5	68.4	71.0	72.7
90	48.9	59.8	68.4	73.6	76.8	78.8	80.2
120	59.0	68.2	75.1	79.3	81.8	83.5	84.7
150	65.9	73.7	79.6	83.2	85.3	86.7	87.7
180	70.9	77.7	82.8	86.0	87.7	89.0	89.8

Demand Coverage Vs Wind Utilization

	Demand coverage (%)	Wind power utilization (%)
Wind (MW)		
30	17.4	100.0
60	34.6	99.8
90	48.9	96.6
120	59.0	89.8
150	65.9	81.6
180	70.9	74.0

EV Service Provider Optimization Problem

$$\min_{q_{ff}, q_w, q_s} P^\pi(q_{ff}, q_w, q_s) + \lambda_{ff} q_{ff} + \lambda_w q_w + \lambda_s q_s$$

$$P(q_w, q_s, q_{ff}):$$

$$\min_{\pi} E \left\{ \sum_{t=1}^{8760} \lambda_t \left(\sum_{i \in I} c_{t,i} - w_t - s_t - f_t \right)^+ + \lambda_{rec} e_{rec} \right\}$$

s.t

$$0 \leq c_{t,i} \leq C$$

$$\sum_{t=T_i^a}^{T_i^d} c_{t,i} = r_i$$

$$c_{t,i} = 0, t \leq T_i^a$$

$$\sum_{t=1}^{8760} (w_t + s_t) + e_{rec} = \sum_{i \in I} r_i$$

Stage 1: minimize total energy procurement costs

Stage 2: minimize average expenditures in spot market and REC market

Subject to

- Vehicle capacity constraint
- Energy delivery constraint
- Arrival time constraint
- Carbon neutrality constraint

Solution Methodology

Stage 2 problem: suboptimal policy

- If all standby vehicles can be charged at current time period by fossil fuel/wind/solar power contracts
 - Charge all vehicles
 - Discard excess supply

- Else if not all vehicles can be charged and all vehicle charges can be postponed without deadline violations
 - Charge as many vehicles as possible (EDF priority)
 - Postpone lower priority vehicles

- Else (vehicles which cannot wait require more energy than what is available)
 - Purchase energy deficit from hour ahead market
 - Charge all vehicles whose charging cannot be delayed

Stage 1 problem: exhaustive search

Baseline Assumptions and Data

Vehicles

- 100,000 vehicles
- Battery energy capacity: 20 kWh
- Battery power capacity: 3 kW
- 25 mile/day commute
- Mileage: 0.25 kWh/mile
- Deterministic driving patterns
- Full battery charge by 6 am, 4 pm

Renewable power supply

- Wind power: 2004 annual NREL datasets for 6 locations in California
- Solar power: 2005 annual dataset of National Solar Database

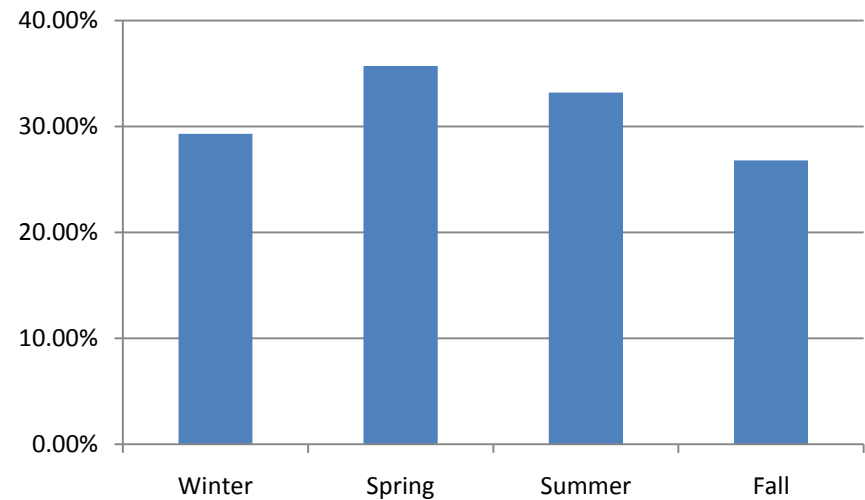
Market Prices

- 2006 annual CAISO ex post hourly energy price dataset
- Fossil fuel forward contracts: \$45/MWh
- Wind power forward contracts: \$60/MWh
- Solar power forward contracts: \$170/MWh
- REC prices: \$20/MWh

Baseline Results

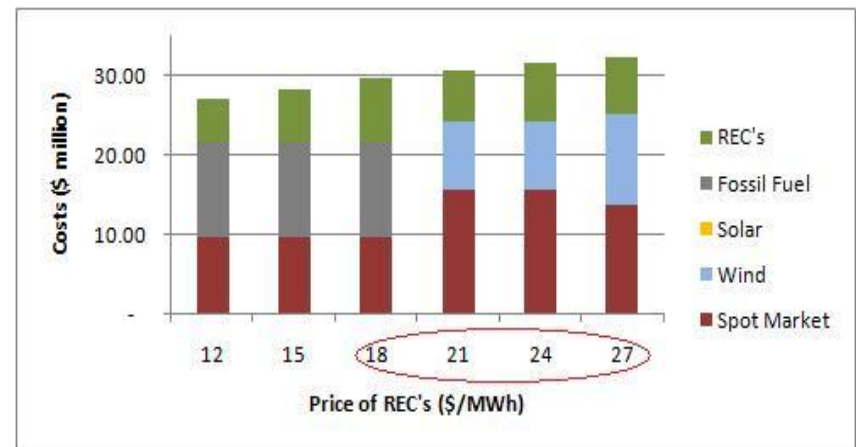
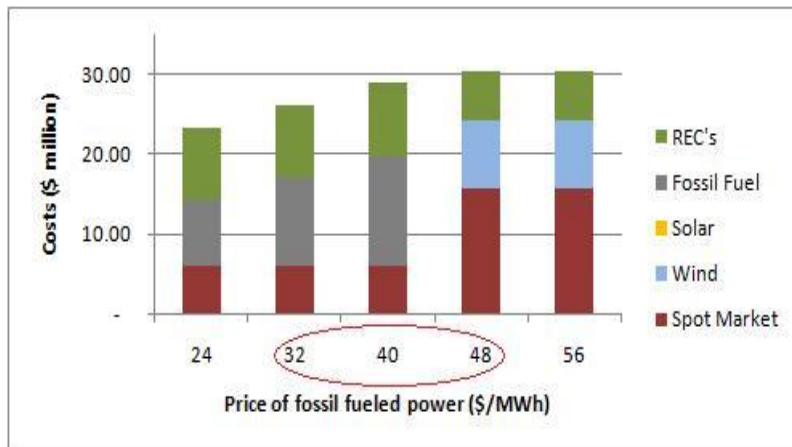
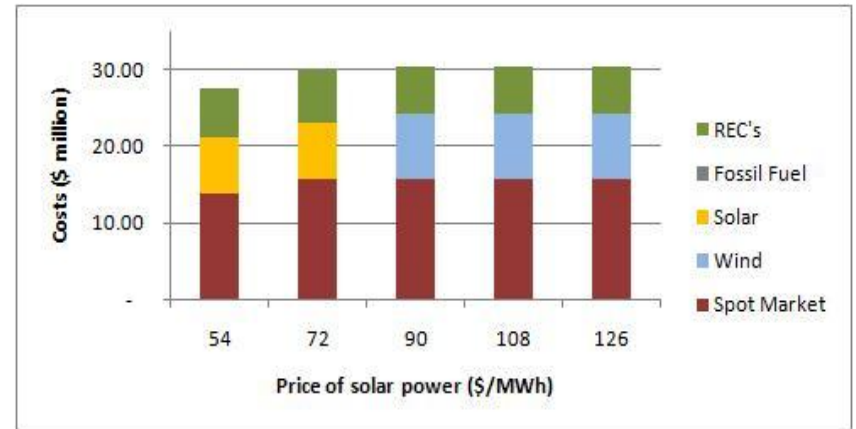
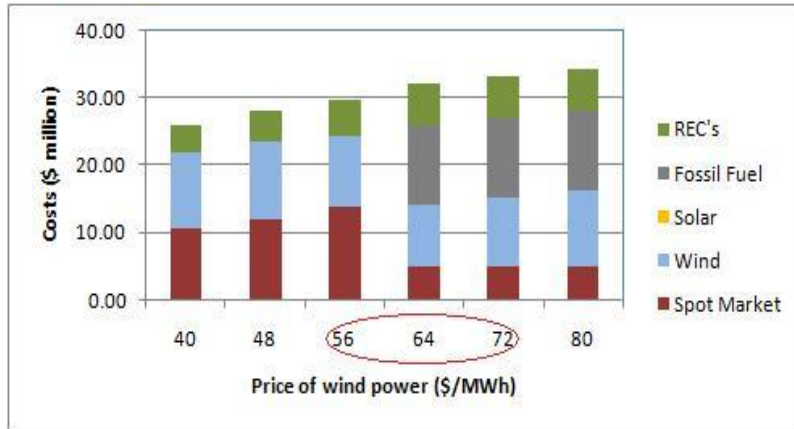
Baseline Results

- Optimal contract mix: 60 MW wind power
- Total costs: 0.4 cents per mile
- Cost breakdown:
 - 28.1% wind power contracts
 - 51% hour ahead market
 - 20.9% RECs
- EV demand coverage by wind: 32%
- Wind power utilization: 99.8%

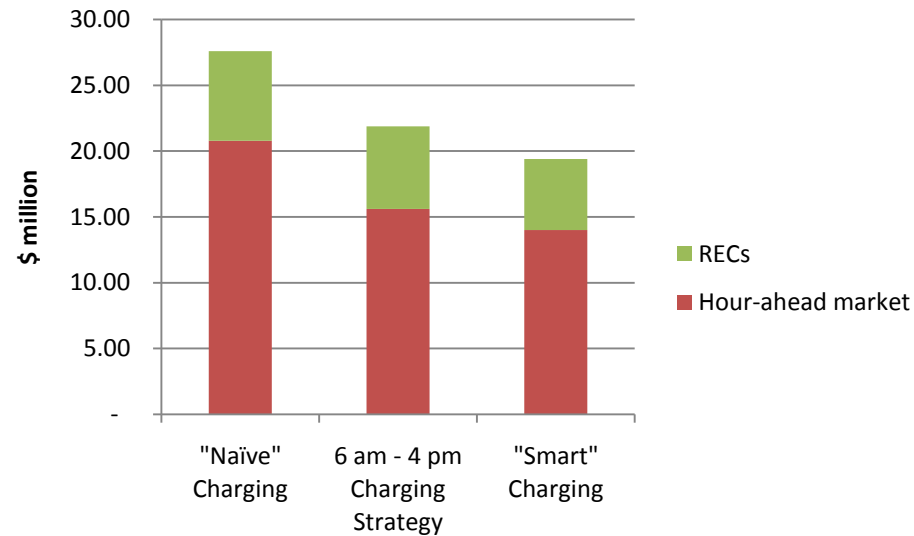


Demand coverage per season by wind power

Price Sensitivity of Optimal Mix



Smart charging



Conclusions and Future Work

Conclusions

- Wind power supply contracts are cost competitive with fossil fuel contracts
- Solar power generation does not seem cost competitive
- Cost of supplying electricity to EVs significantly lower than gasoline cost
- EV flexibility seems sufficient for integrating large amounts of wind power with minimal energy spillage
- Smart charging can have significant impact on EV service provider costs
- Renewable energy management and smart charging offer very interesting areas of application for stochastic optimization

Future work

- Smart charging algorithm improvement
- Development of unit commitment model of WECC 255 bus system
- Efficient compensation mechanisms for renewable energy suppliers and flexible loads