Quantifying the Benefits of Extending Electric Vehicle Charging Deadlines with Solar Generation

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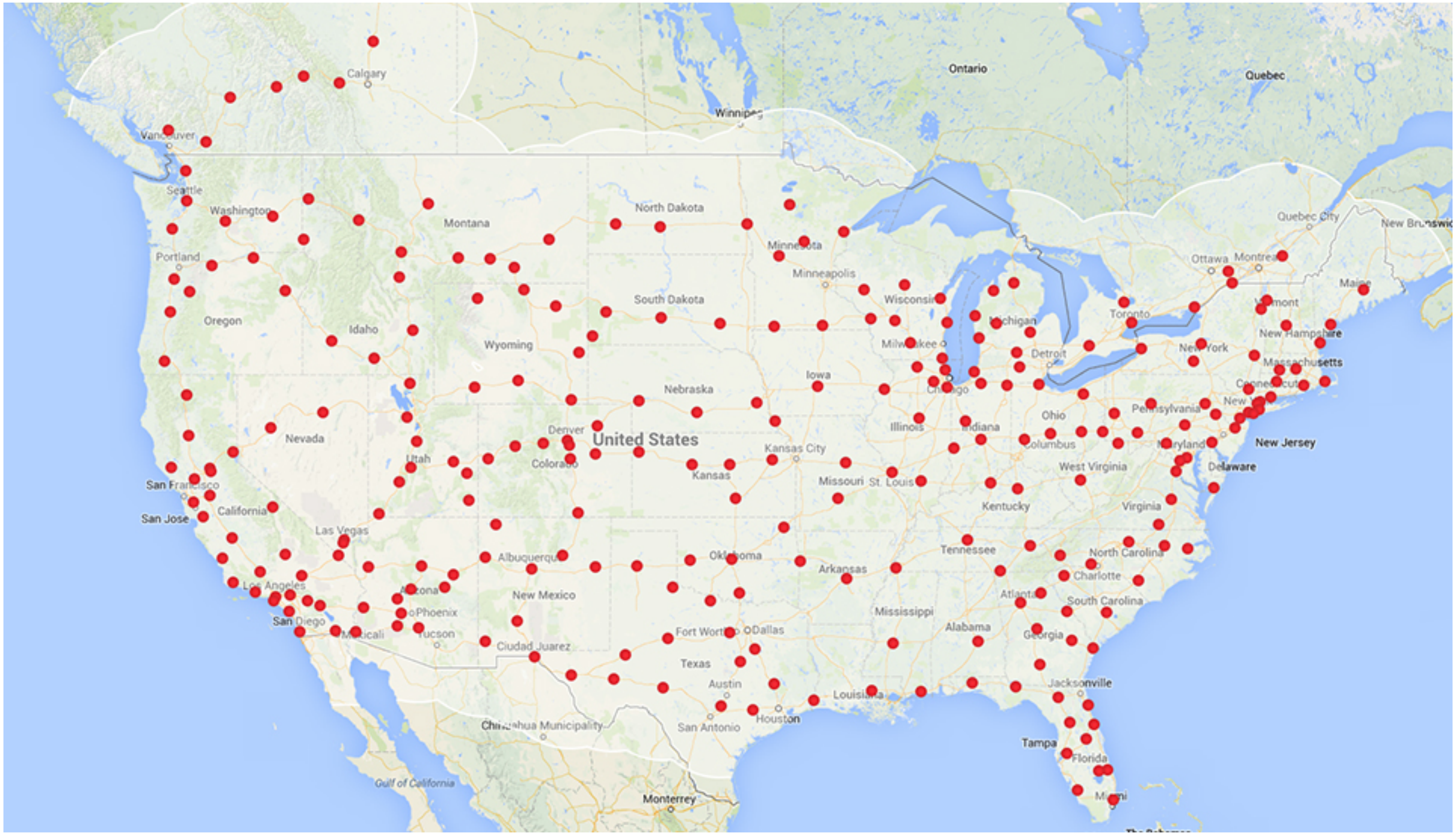
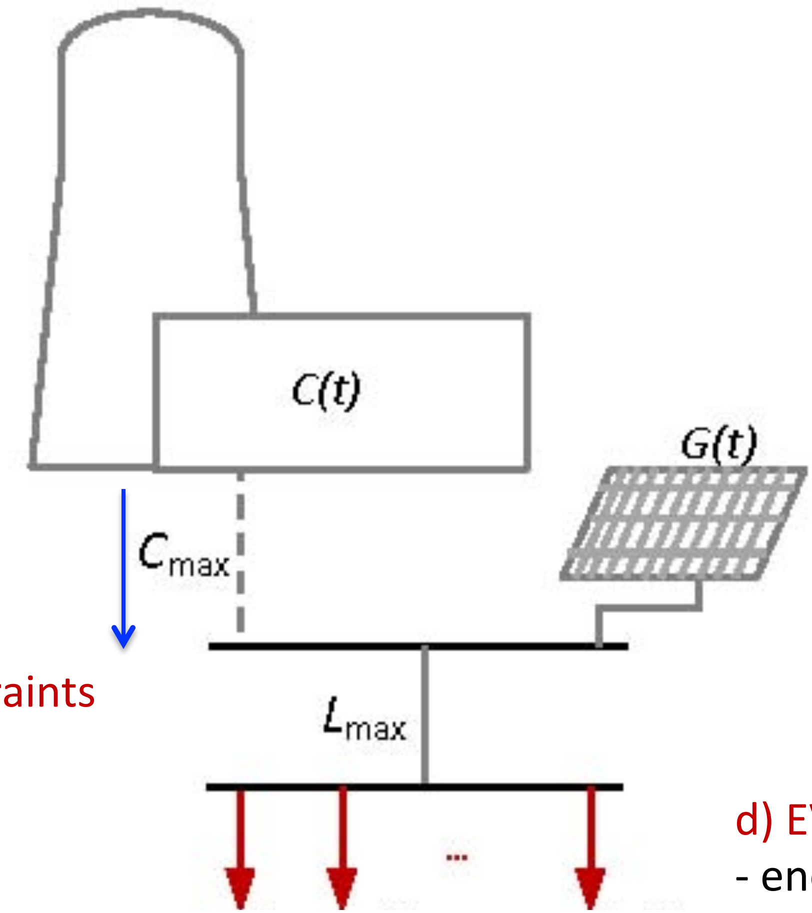


EV charging infrastructure is expanding rapidly

image source: Tesla Supercharger Stations in North America

System Model

a) conventional power
the carbon footprint of conventional power is assumed to be a convex function of C(t)

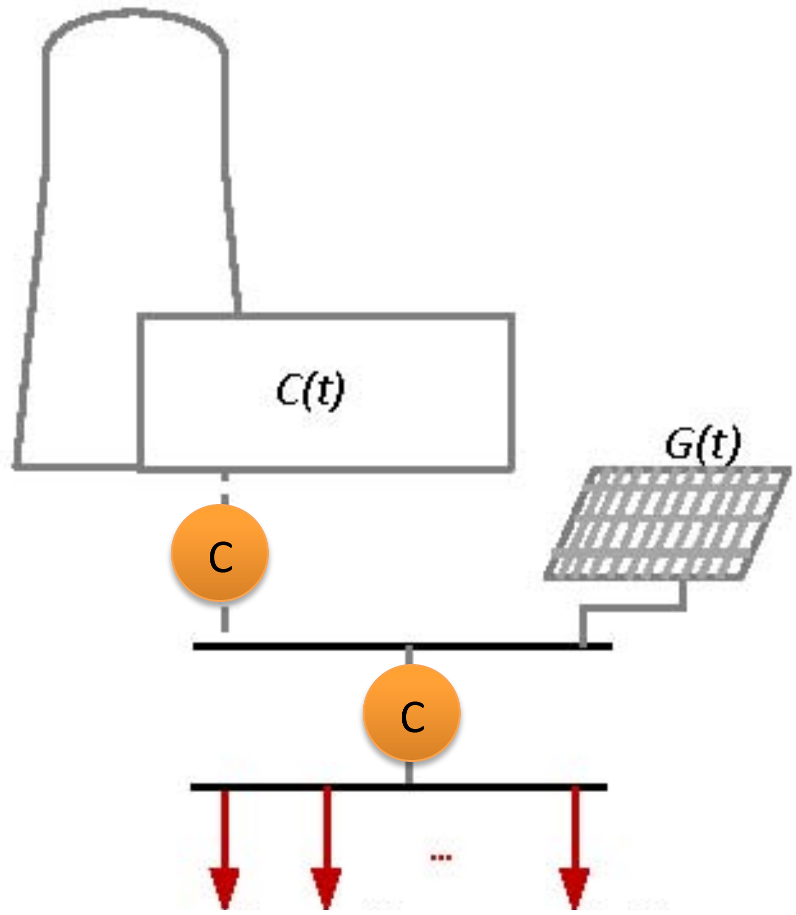


b) on-site solar generation but no storage

c) feeder constraints

d) EVs
- energy demand
- initial state of charge
- deadline (set by owners)

Our Goal



Takeaways

- A performance-guaranteed carbon-minimizing charging scheme is required and can be designed
- There is a three-way tradeoff between the charging deadlines, the average utility of EV owners, and the carbon footprint
- Extending charging deadlines might increase the utility of EV owners, reduce the carbon emissions, or have no impact

Utility of EV Owners

- The utility of an EV owner is the ratio of the energy supplied before the deadline to the initial energy demand

- For example: an EV with a 24kWh battery
  - energy demand: 50% of the battery size
  - energy supplied before the deadline: 8kWh
  - utility: 8kWh/12kWh=0.67

Effects of charging deadlines

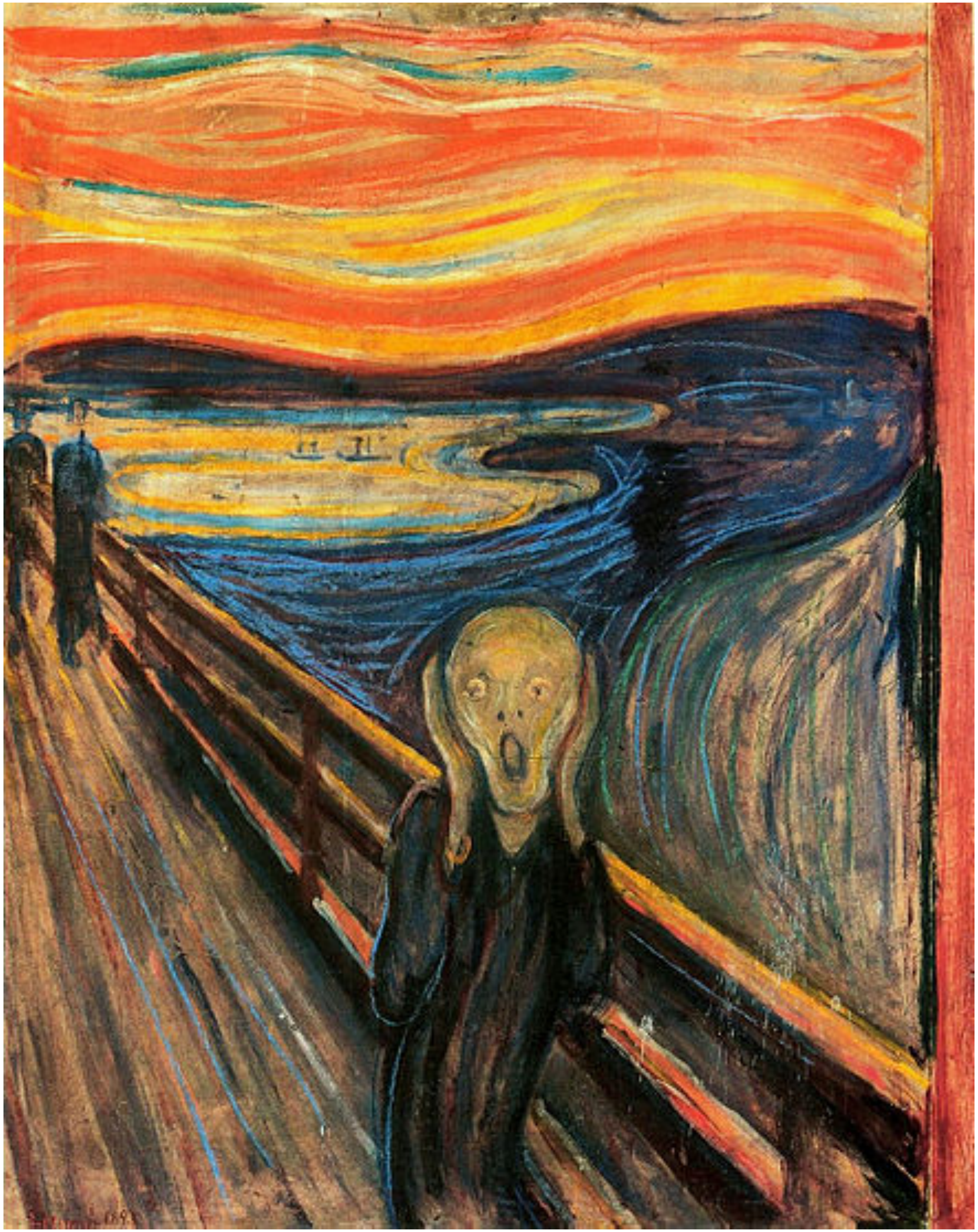
- Extending the charging deadlines might
  - increase the utility of EV owners
  - reduce the use of conventional power and carbon emissions

Objectives

Simultaneously satisfy the following requirements (in this order)

- PVs should not negatively affect the utility of users
- carbon emissions must be minimized
- power allocation must be fair to users

This is a multi-objective optimization problem!



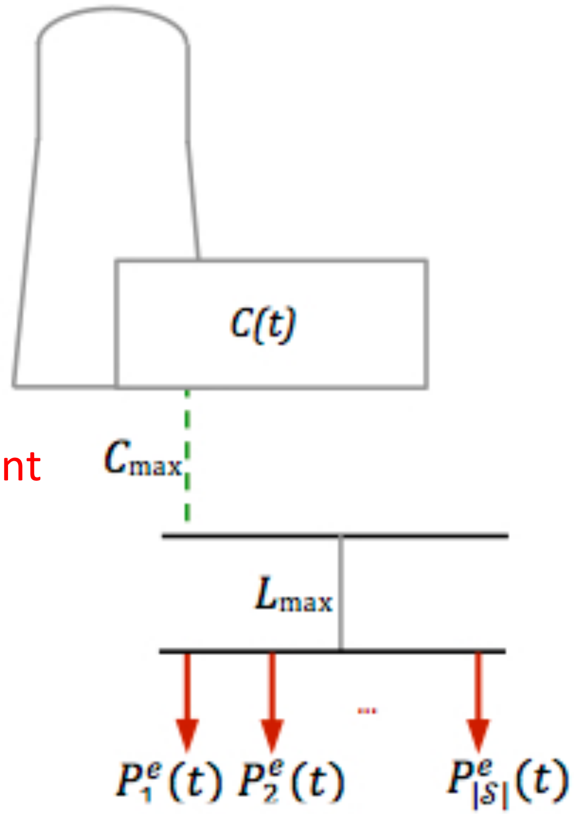
Offline Scheduling Algorithm

- Has three steps:
  - Compute the worst-case utility, assuming no solar (satisfying the first requirement)
  - Compute the carbon-minimizing power allocation to meet the worst-case utility, given the amount of solar power available (satisfying the second requirement)
  - Allocate the available power fairly among the users (satisfying the third requirement)

Step 1: Compute the Worst-Case Utility

Convex optimization

binding constraint

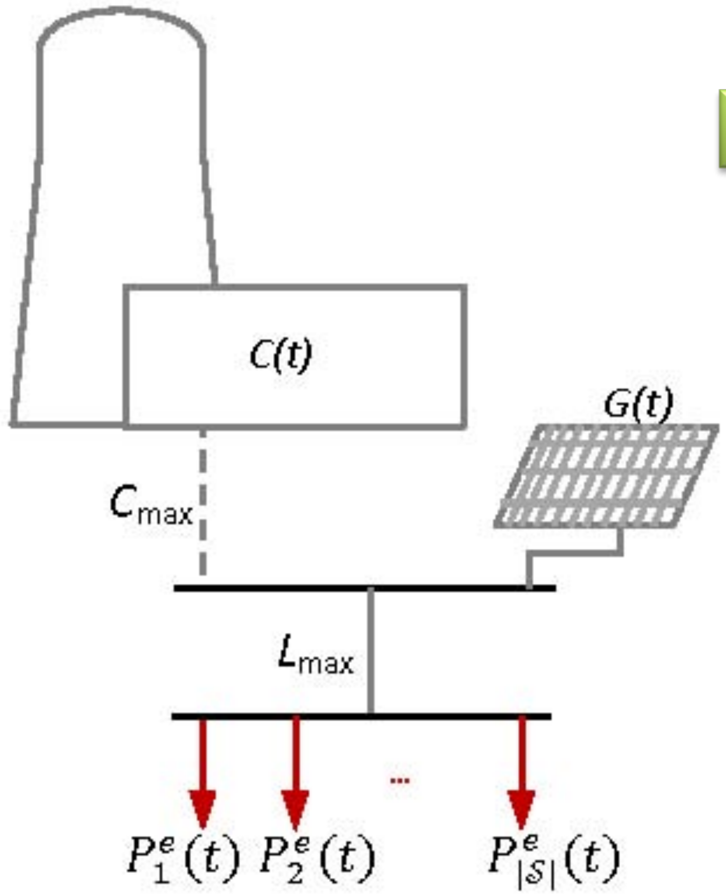


Input: EV arrival times, initial demands, and deadlines

Output: energy supplied to every EV, i.e., the worst-case utility of every EV

Step 2: Find the Carbon-Minimizing Dispatch

Linear programming



Input: worst-case utilities, incoming solar radiation

Output: optimal use of grid power - C*(t)

Proportional Fairness

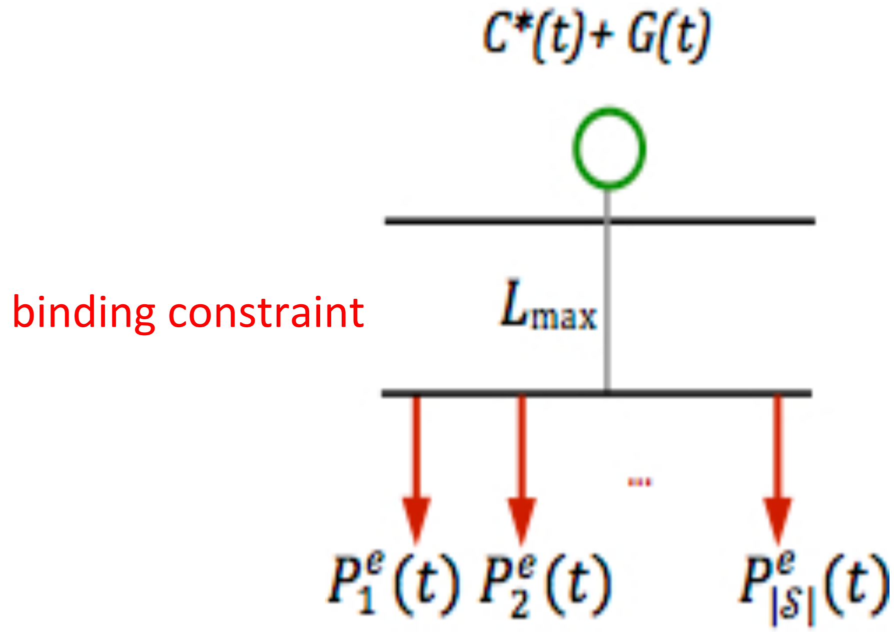
A proportionally fair allocation is the one that maximizes the sum of the log utility function of EV owners:

$$\sum_{i:EVs} \log \frac{energy\_provided_i}{energy\_demand_i}$$

Intuition: the charging time must be inversely proportional to the normalize energy demand

Step 3: Compute the Fair Allocation of Available Power

Convex optimization



Input: worst-case utilities, total available power

Output: fair energy allocation to EVs, never less than before

Results – A Homogeneous Population of EVs

- Optimization problems are solved using *Minos*

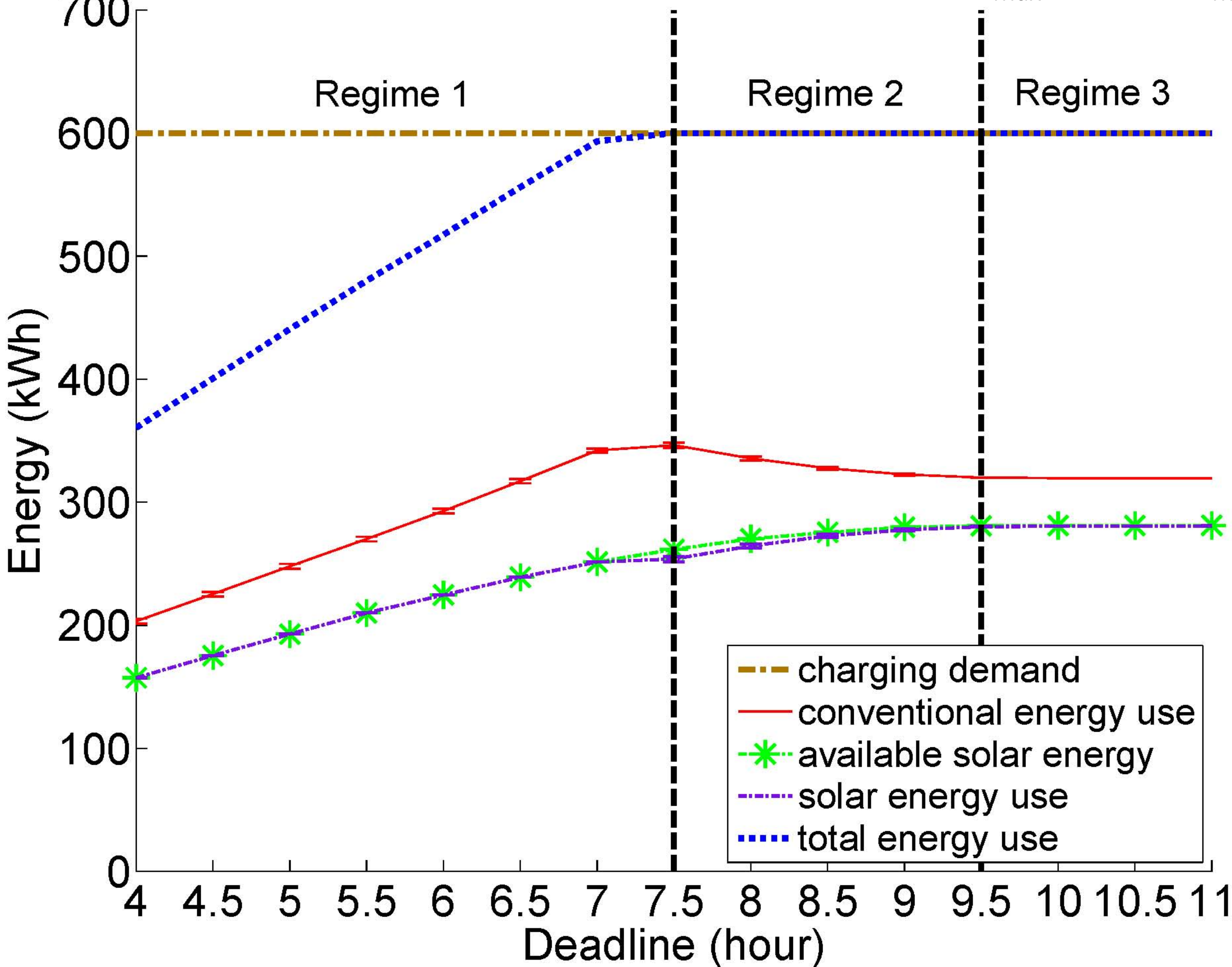
- Parameters:
  - Arrivals: Poisson (25 arrivals in an hour) after 7am
  - Chargers: Level 1 (a maximum load of 1.8kW)
  - Energy demand of every EV upon connection: 12kWh
  - Rated capacity of the main feeder (L_{max}): 90kW
  - Charging deadline: 4 to 11 hours after arrival
  - Solar irradiation data from US Virgin Islands measurement station

Case Studies

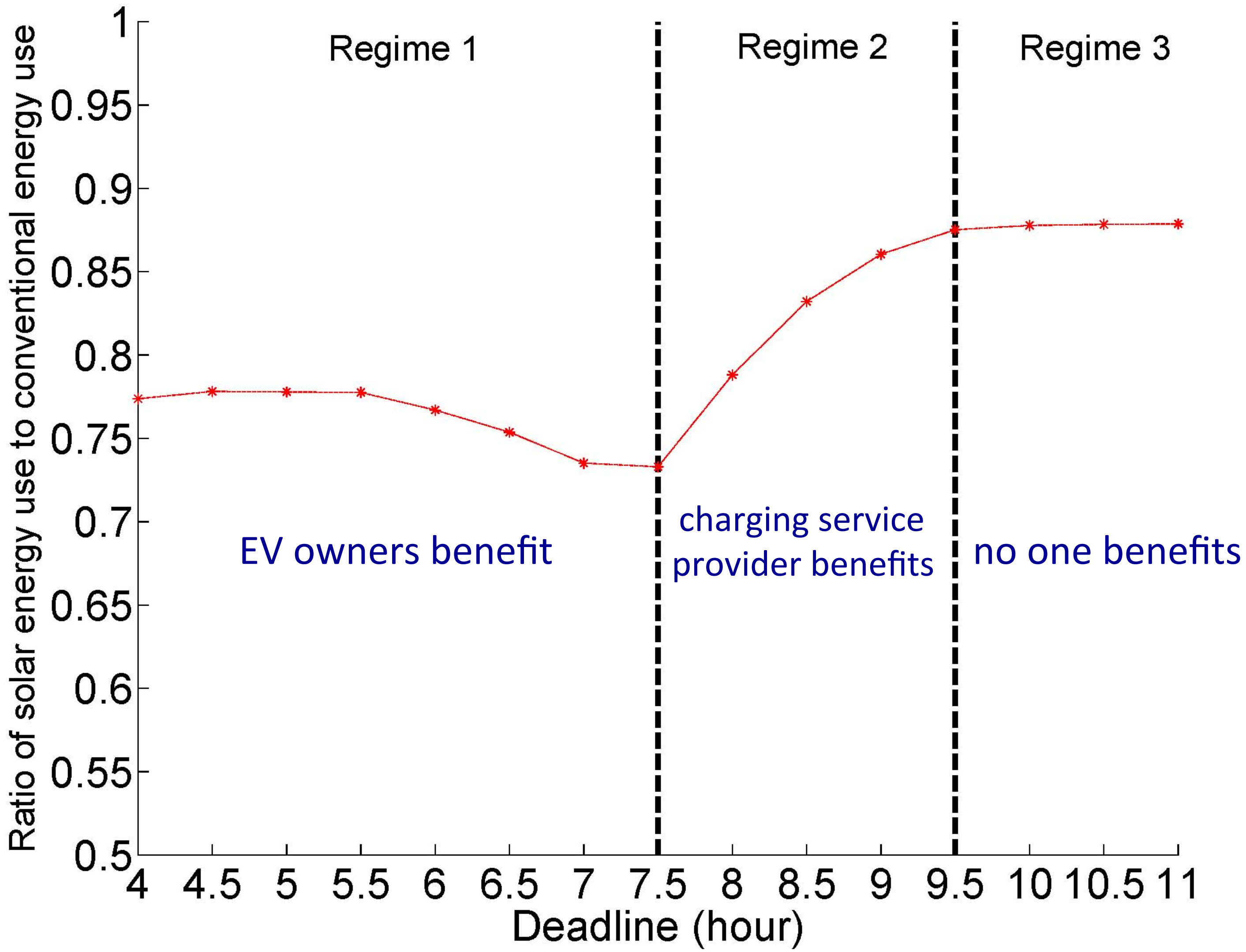
- Plenty of Solar Power
- Limited Solar Power
- Plenty of Conventional Power

Simulation Results
Case 3: Plenty of Conventional Power

50 chargers, C_{max}=80kW, G_{max}=40kW



Three Regimes



Conclusions

- There is a three-way tradeoff between the charging deadlines, the average utility, and the carbon footprint
- EV owners should be careful when setting strict deadlines
- Charging service providers may design mechanisms to encourage EV owners to extend their deadlines to benefit from the second regime

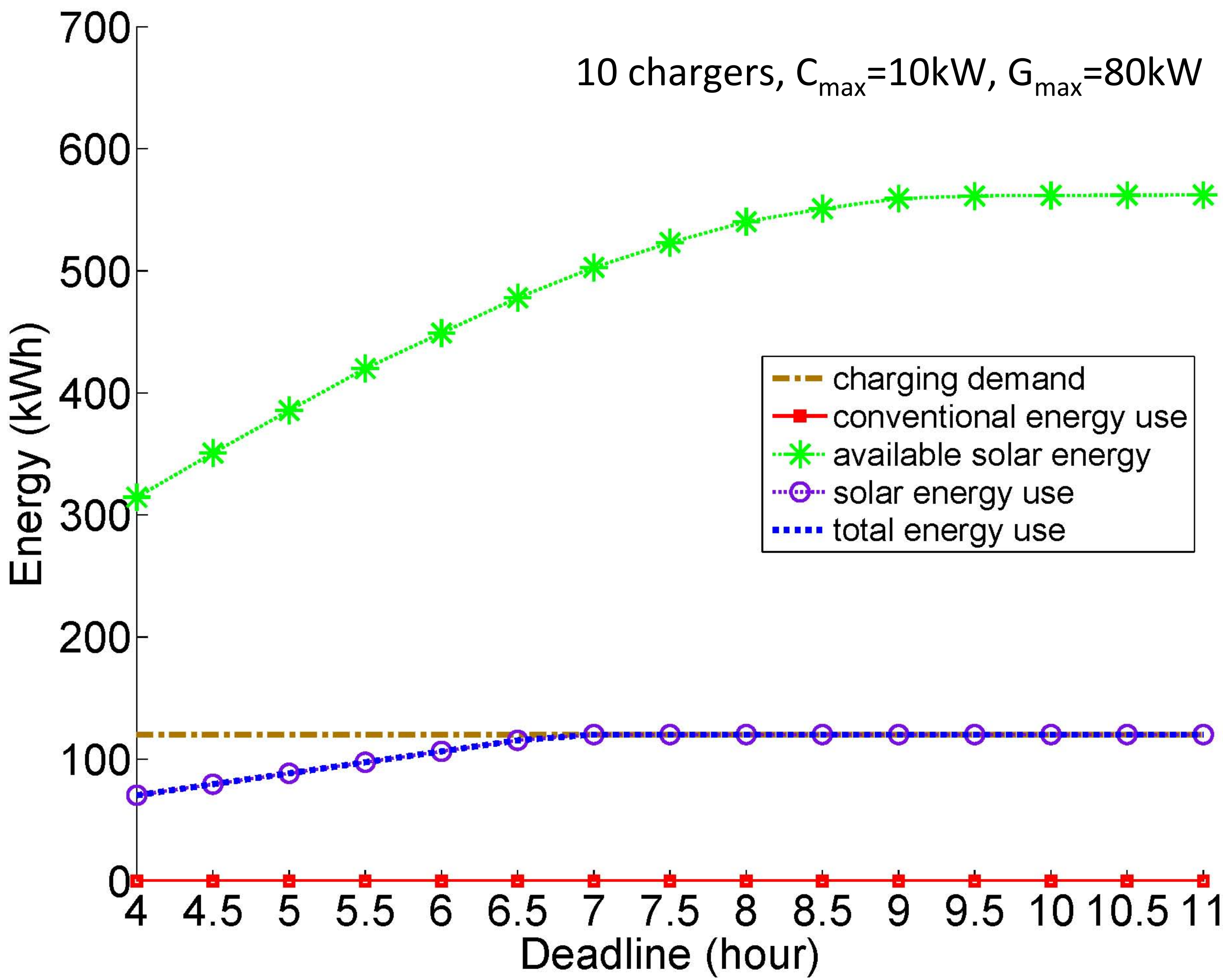
Future Work

- Design an online-algorithm for grid-tied solar EV charging stations

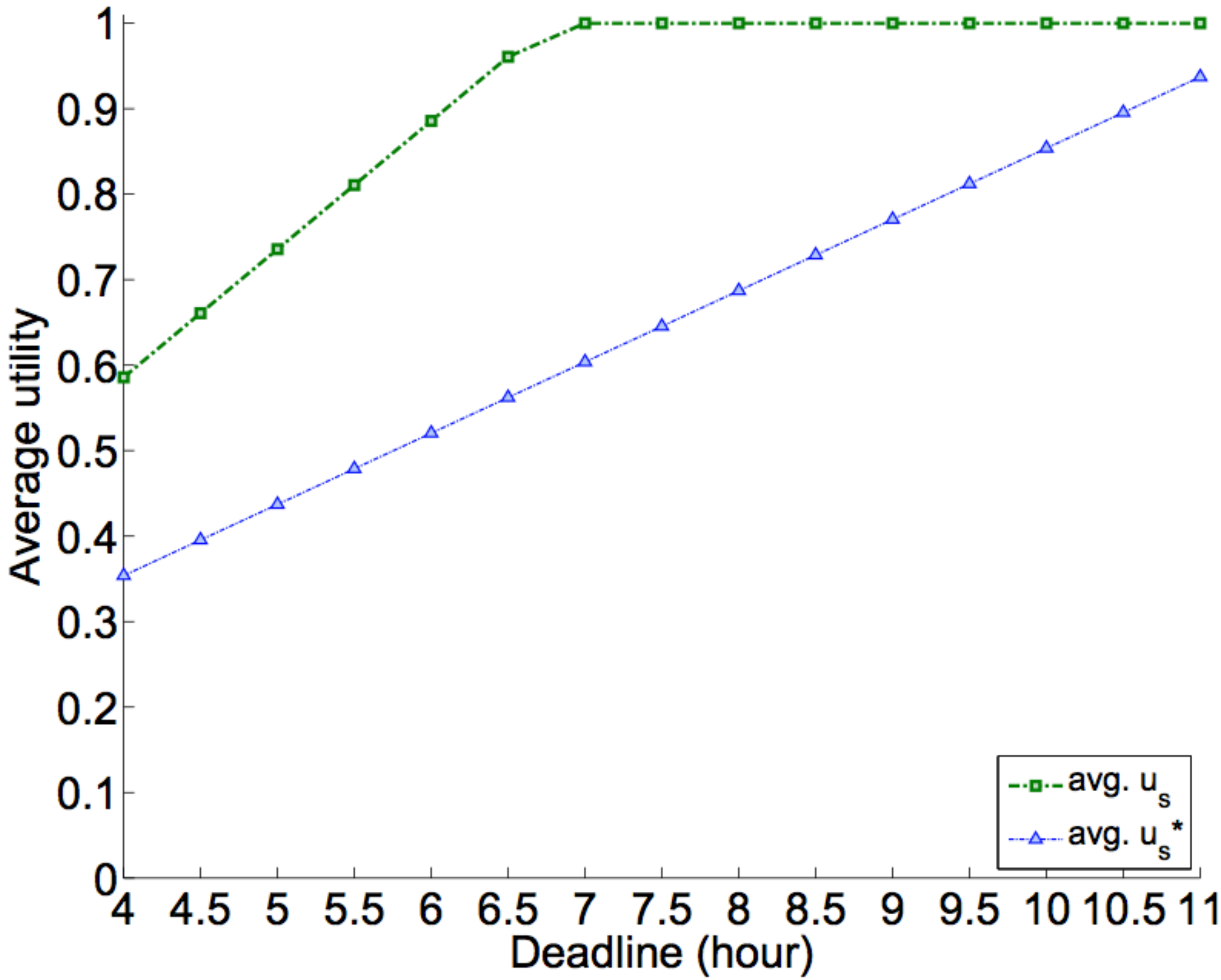
- Introduce flexibility into the algorithm
  - users might be willing to trade off a slight reduction in their average utility for the reduction in carbon emissions

Backup Slides

Simulation Results
Case 1: Plenty of Solar Power



Simulation Results
Case 1: Plenty of Solar Power (cont'd)



Simulation Results
Case 2: Limited Solar Power