Modeling Demand Response of Charge Point Operators to Consider Flexibility in Grid Planning

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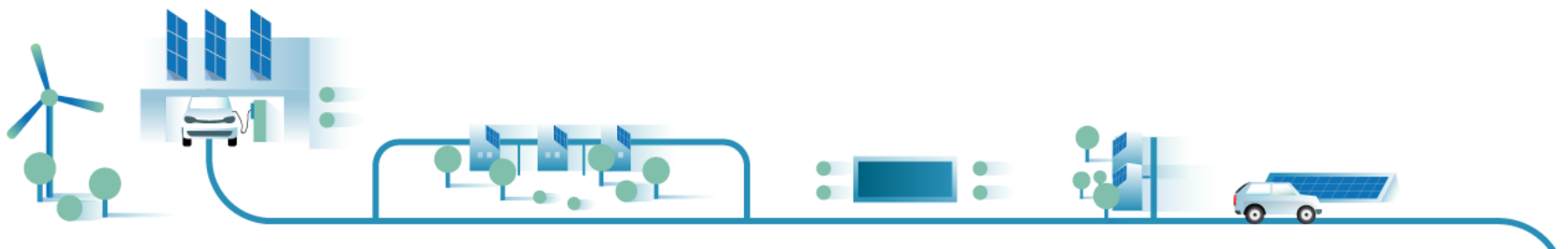


Research Gap and Proposal

EV Distribution Grid Services

- **Congestion Management**
- Loss Minimization
- **Load Shifting**
- **Peak Shaving and Valley Filling**
- Voltage Control

Identified Research Gaps

Many variables regarding EV user preferences (SoC)

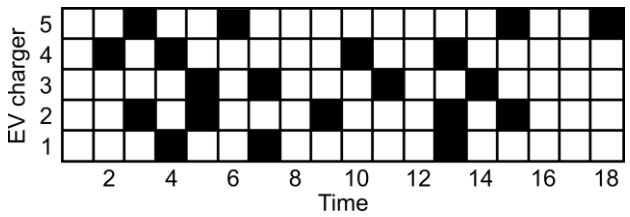
Disregard of shifting dynamics

Missing a simplified EV flexibility model to be used in planning tools

Proposal

Particle hopping model

(first presented in [1])

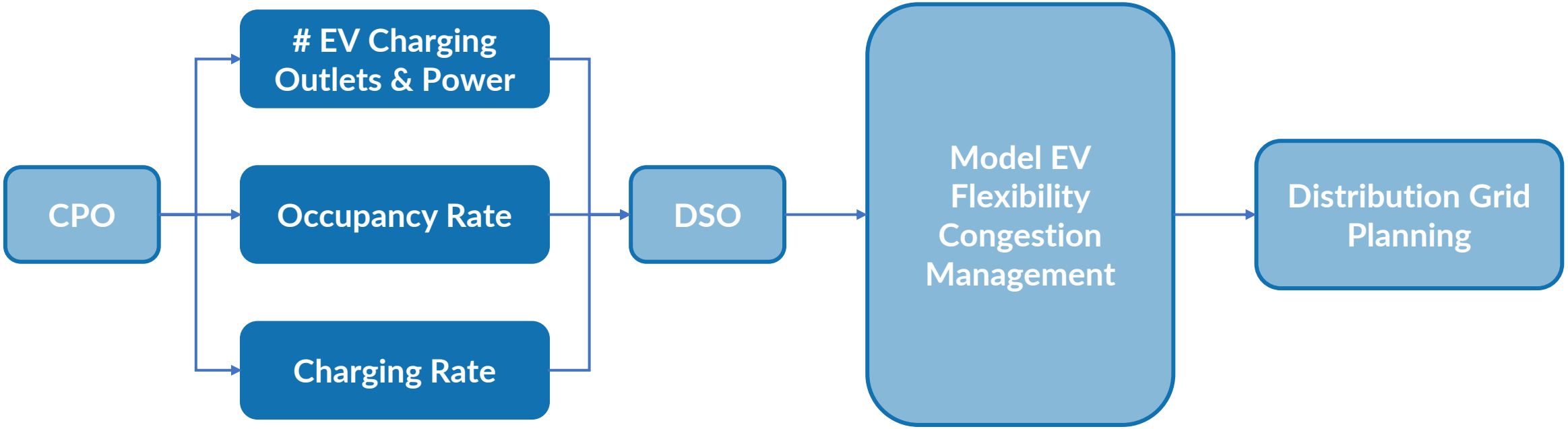


- ✓ Simple and easy to characterize flexibility using few parameters
- ✓ Dynamics of load flexibility
- ✓ Limitations of load flexibility

[1] Carvalho, P.M.S. and Ferreira, L.A.F.M. (2019), Intrinsic limitations of load-shifting response dynamics: preliminary results from particle hopping models of homogeneous density incompressible loads. IET Renewable Power Generation, 13: 1190-1196. https://doi.org/10.1049/iet-rpg.2018.5838

Modeling CPO Flexibility for Congestion Management

Characterization of CPOs



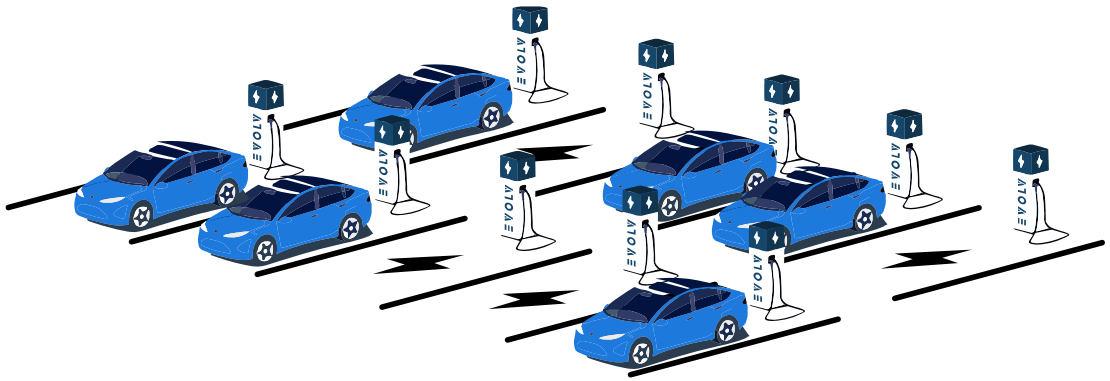
Modeling CPO Flexibility for Congestion Management

Characterization of CPOs

 # EV Charging Outlets & Power

Occupancy Rate

Charging Rate



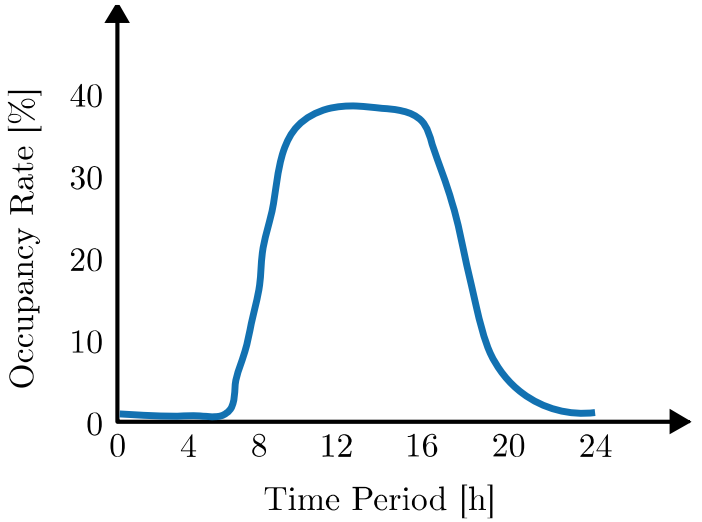
- Number of EV charging outlets, N
- Each EV charging outlet charges 1 EV at a time
- EV charging outlet power, P

Modeling CPO Flexibility for Congestion Management

Characterization of CPOs

 # EV Charging Outlets & Power | **Occupancy Rate** | **Charging Rate**

- Obtained through the expected occupancy profile of the EV charging station
- Percentage of EV charger outlets that are occupied (either charging or not)



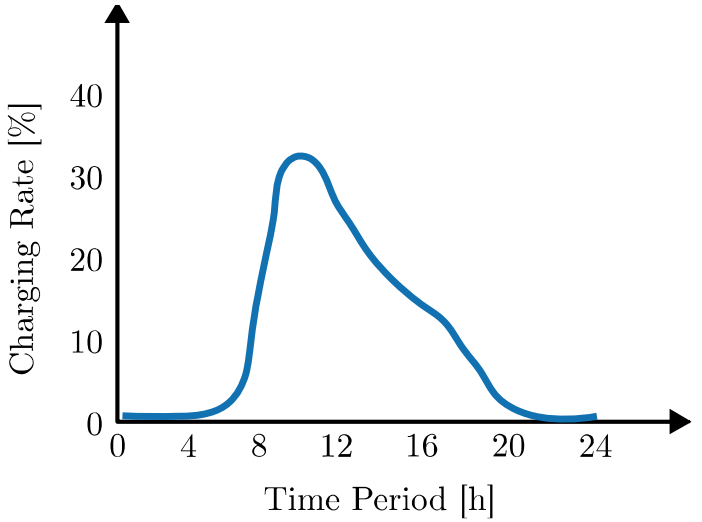
Analysis of a 52 EV parking lot located in the NASA *Jet Propulsion Laboratory* using the ACN Dataset

Modeling CPO Flexibility for Congestion Management

Characterization of CPOs

 # EV Charging Outlets & Power | **Occupancy Rate** | **Charging Rate**

- Obtained through the expected load profile of the EV charging station
- Percentage of EV charger outlets that are actively charging an EV



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Modeling CPO Flexibility for Congestion Management

Characterization of CPOs

 # EV Charging Outlets & Power

Occupancy Rate

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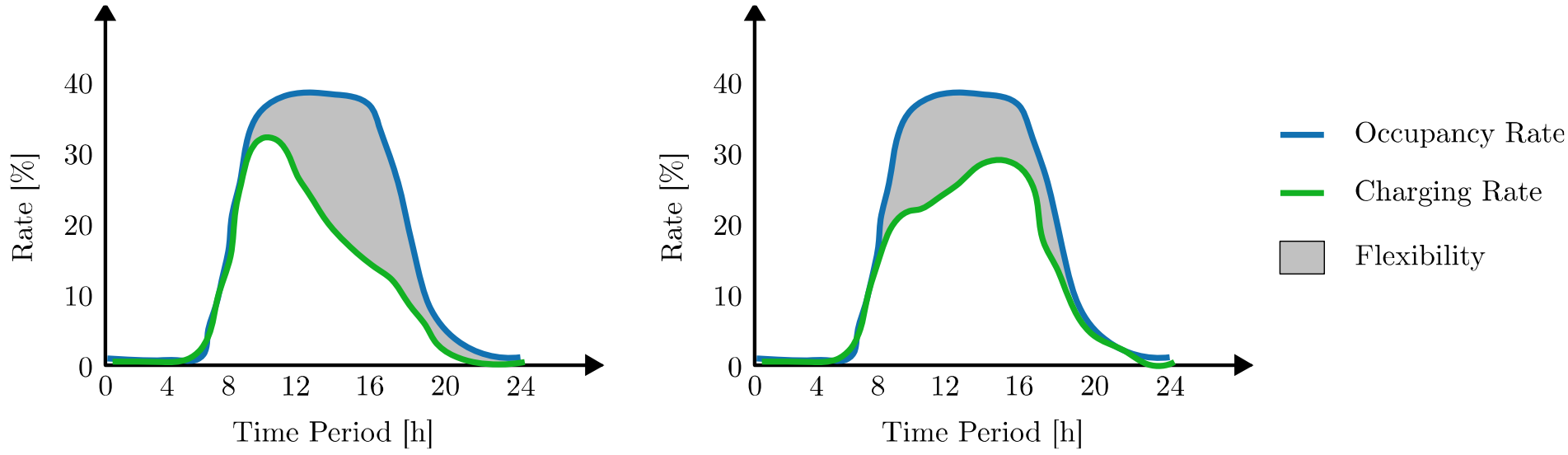
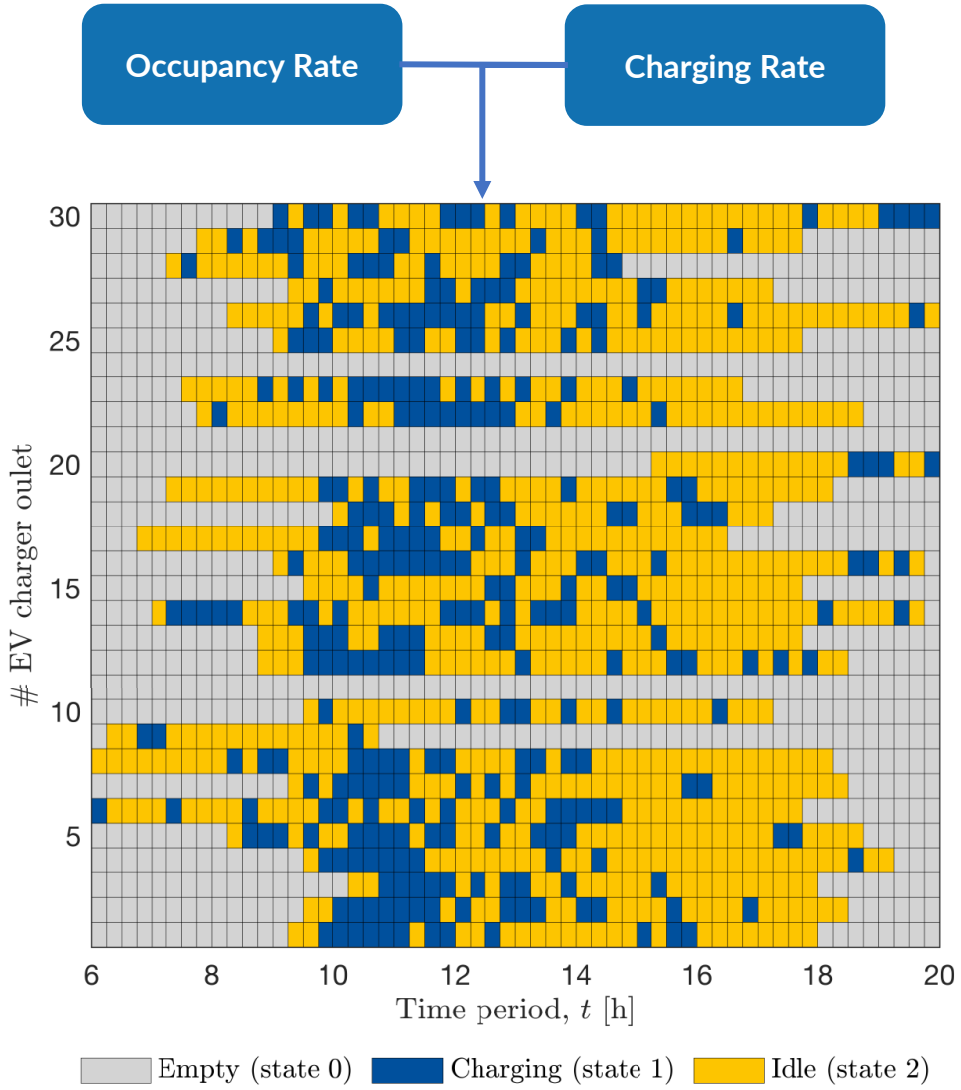


Modeling CPO Flexibility for Congestion Management

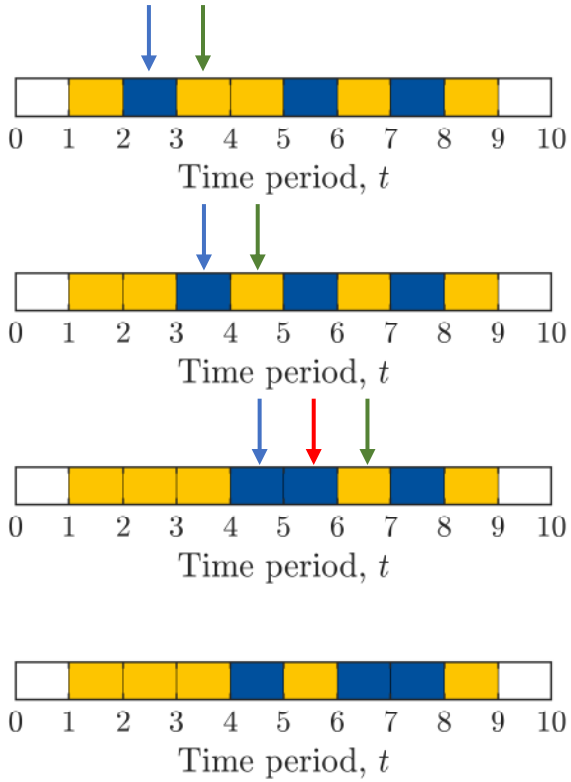
Modelling CPO Shifting Flexibility

- Particle Hopping Models
- Lattice representing the generated EV outlet charging scheduled
- Stochastic charging schedules generated using a Markov Chain
- Three states: Empty, Idle, and Charging



Modeling CPO Flexibility for Congestion Management

Modelling CPO Shifting Flexibility



- Shifting flexibility represented in the lattice by the idle position ahead of each charging particle
- Allows regulating the EV charging station power output
- Dynamic process

Modeling CPO Flexibility for Congestion Management

Flexibility Evaluation of CPOs

- $L(t)$ - Aggregate (normalized) demand of EVCS at time t

$$L(t) = \sum_{n=1}^{N} x_n(t), \qquad t = 1, \dots, T$$

$x_n(t)$: Load demand of the n^{th} EV outlet at time t

$$x_n(t) \in \{0,1\}, n = 1, \dots, N, t = 1, \dots, T$$

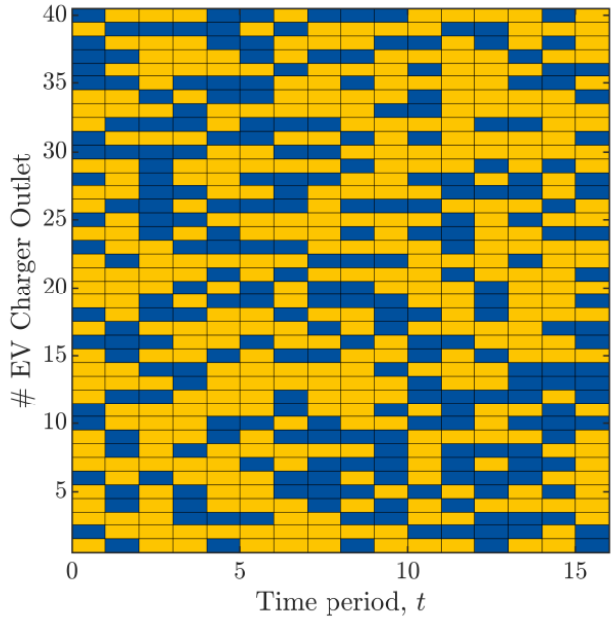
- $L^*(t)$ - Target set for the aggregate demand of the EVCS at time t
- $\Delta L(t)$ - Changes in aggregate demand of EVCS at time t

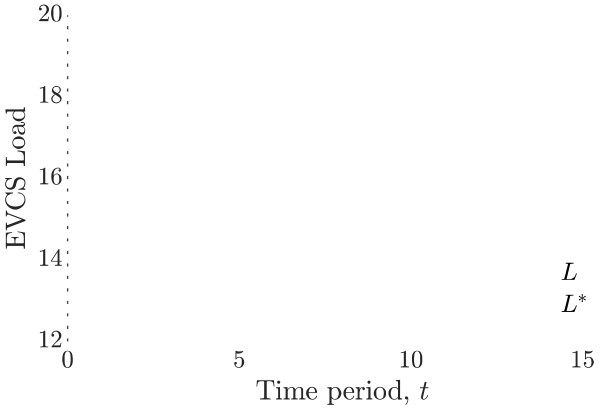
$$\Delta L(t) = L^*(t) - L(t)$$

Control aggregate demand? → Shifting charging particles

- $v(t)$ - Load particle shifting velocity (number of shift per time period) at time t

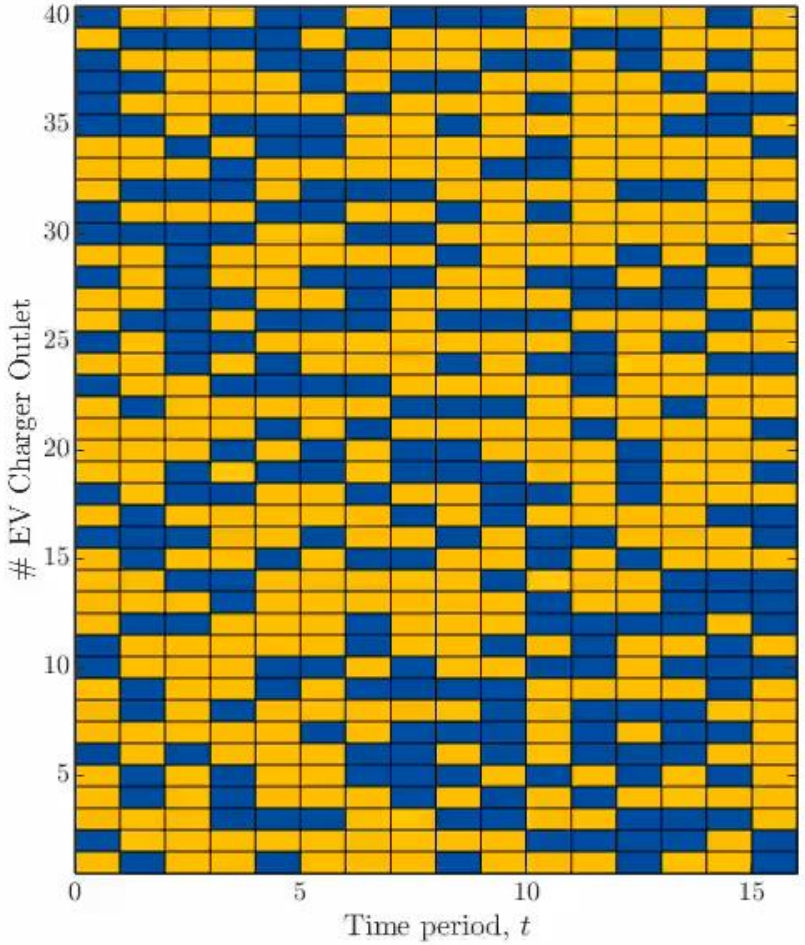
$$v(t) = \sum_{n=1}^{N} v_n(t), \qquad v_n \in \{0,1\}, n = 1, \dots, N$$

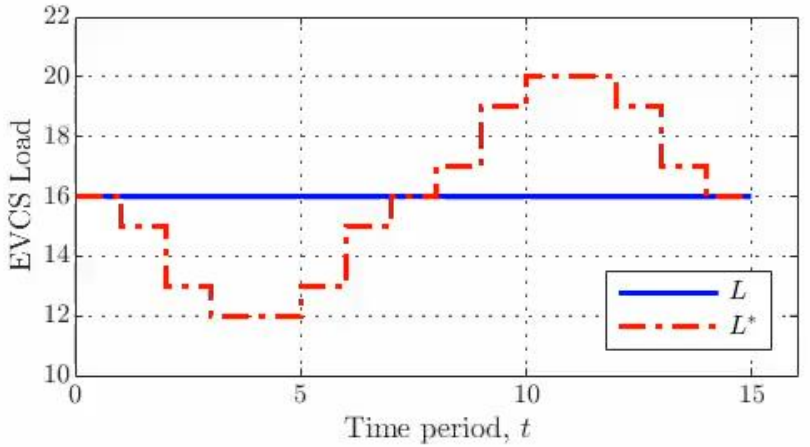


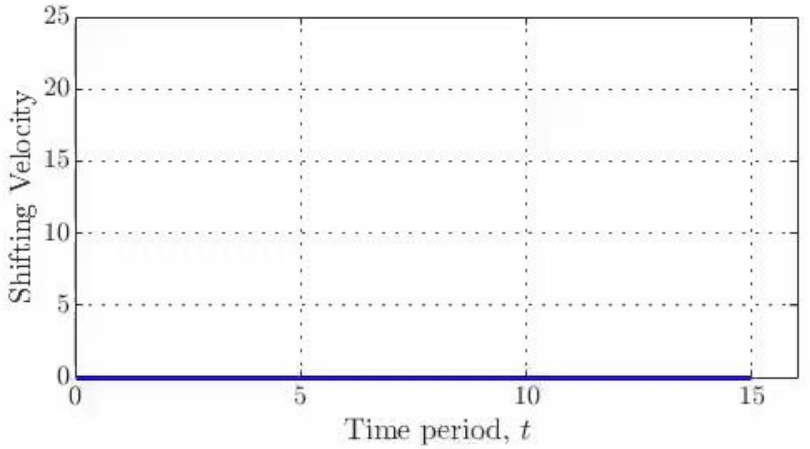


Modeling CPO Flexibility for Congestion Management

Flexibility Evaluation of CPOs

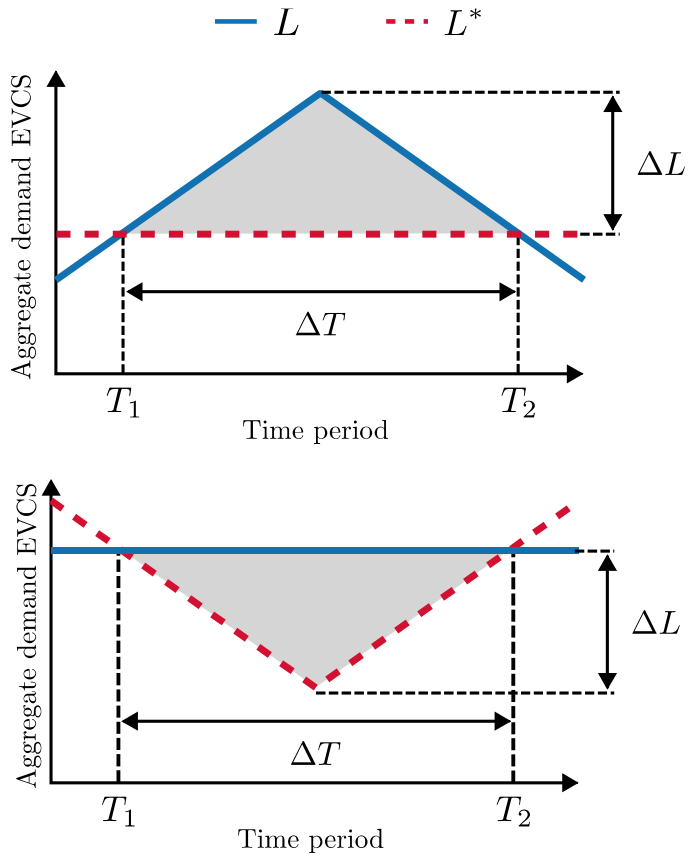






Modeling CPO Flexibility for Congestion Management

Flexibility Evaluation of CPOs



Load particle shifting acceleration

$$\Delta L(t) \approx -v(t+1) + v(t)$$

- v^* - Maximum Shifting Velocity

$$v^* = \frac{\Delta L \Delta T}{2}$$

Is there a limit for the maximum shifting velocity?

- Proportional to the probability of having an idle particle ahead of a charging particle

Occupancy density

$$\mathcal{V}^*_{\text{lim}} \approx (d_o - d_c)N$$

Limit for maximum shifting velocity

Charging density

Modeling CPO Flexibility for Congestion Management

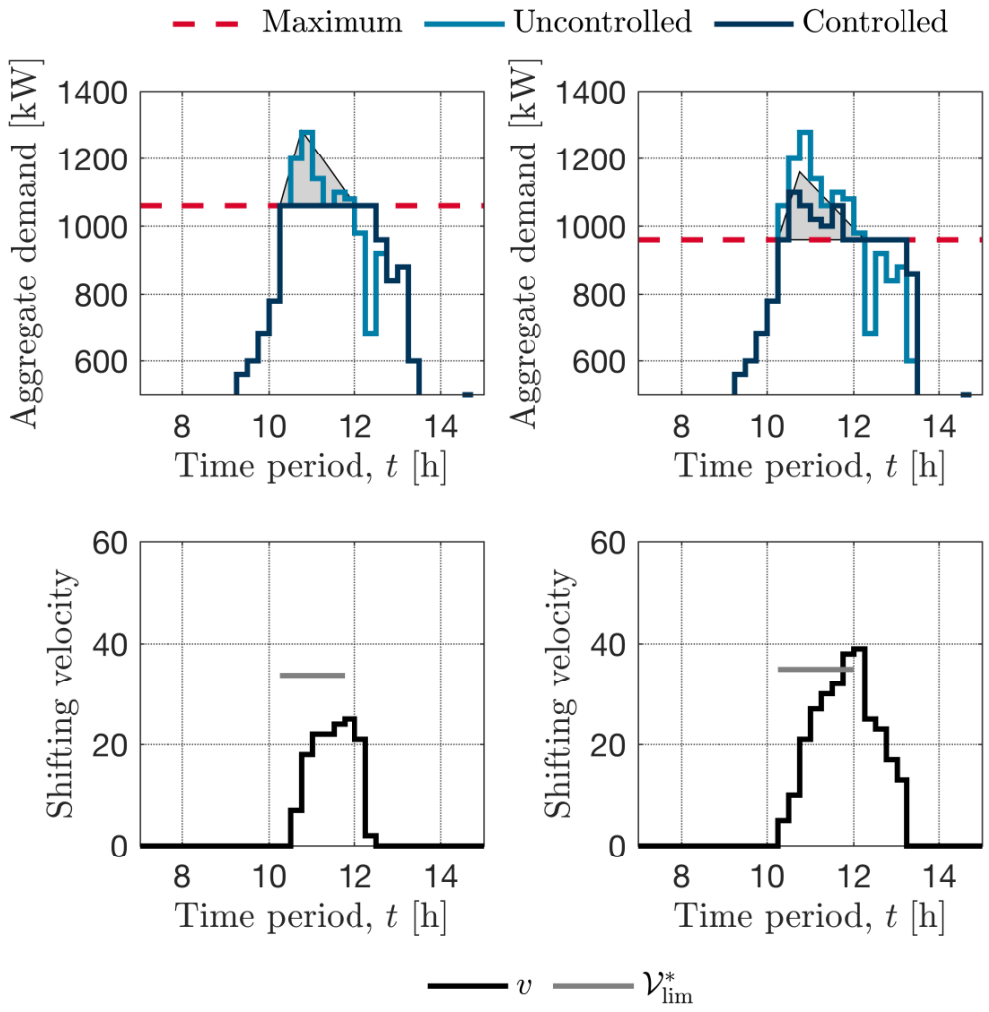
Flexibility Evaluation of CPOs

- Condition to be flexibility enough to follow the target

$$v^* \leq \mathcal{V}^*_{\text{lim}}$$

$$\Delta L \leq 2\frac{d_o - d_c}{\Delta T}N$$

Magnitude of the target function is set by the charging and occupancy densities as well as the congestion time



Grid Planning with Flexibility

Traditional Grid Planning

$$\min \quad R \quad + \quad S \quad + \quad I$$

Grid Planning with Flexibility

$$\min \quad R' \quad + \quad S \quad + \quad I \quad + \quad F$$

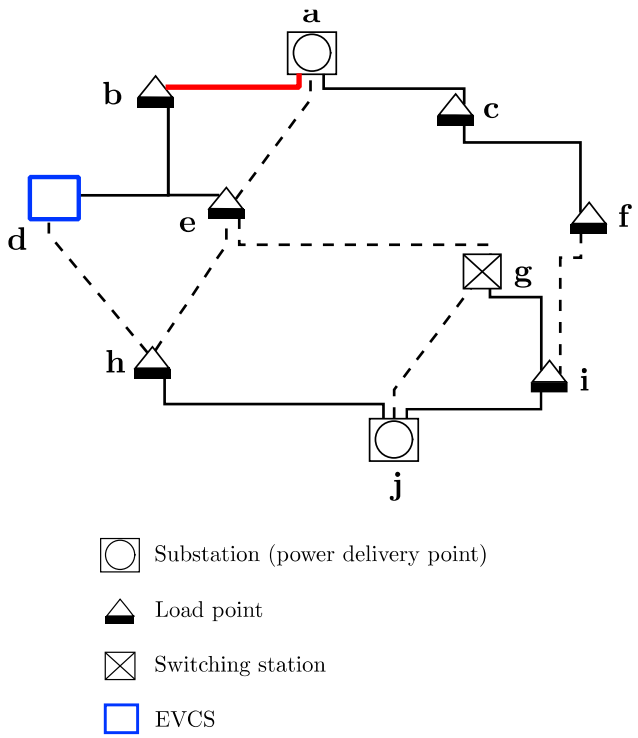
Modified Reliability Cost Function

New Flexibility Cost Function

- Congestions are translated into Energy-Not-Supplied (ENS)
- Economical value for ENS is set by regulators
- Cost functions evaluated for a given planning horizon
- Minimization of corresponding costs

Grid Planning with Flexibility

Flexibility Cost function



Defining:

s	Congested asset
ΔL_s	Load shed downstream congested asset
D_s	Maximum Load Reduction downstream congested asset
N_s	Set of flexibility resources downstream congested asset
ΔT_s	Congestion duration

Then:

$$D_g = 2\frac{d_o - d_c}{\Delta T_s} N$$

$$D_s = \min \left\{ \sum_{\substack{g \in N_s \\ \pi_g < \gamma}} D_g, \quad \Delta L_s \right\}$$

Less than marginal cost of ENS

Grid Planning with Flexibility

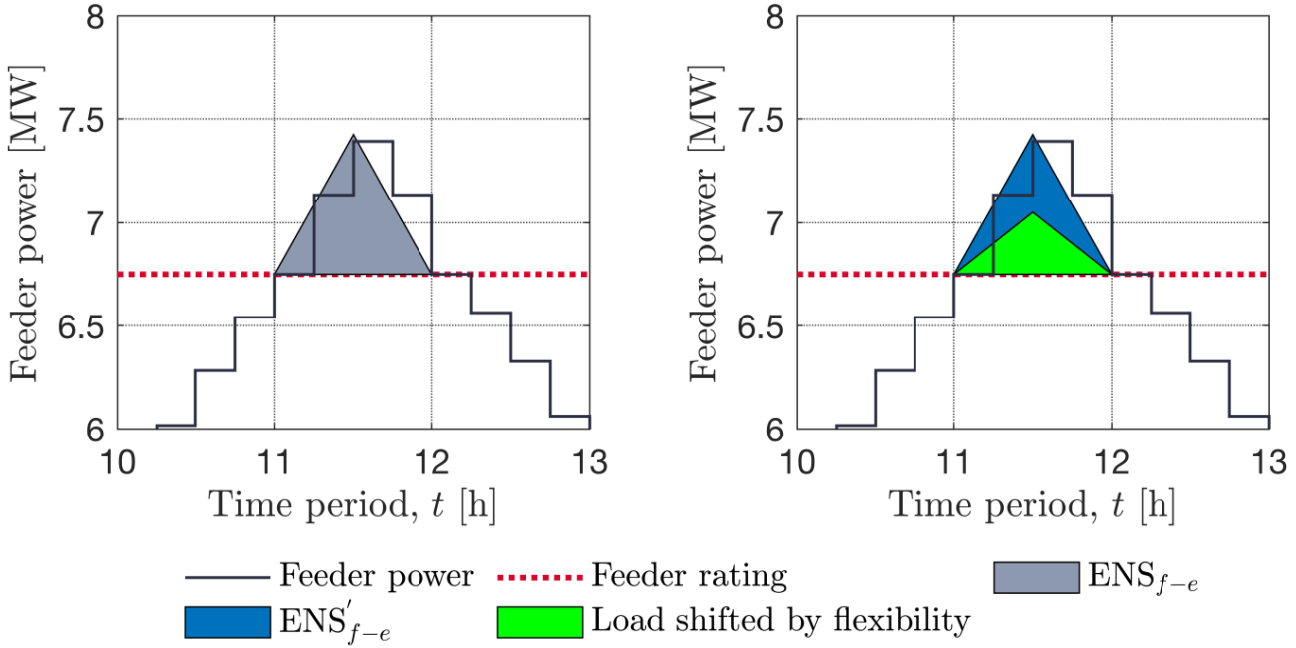
Flexibility Cost function

$$F = \frac{1}{2}\sum_{s} \lambda_s \pi_s^* D_s \Delta T_s$$

Clearing price for the purchased flexibility D_s

Dependent on the auction mechanism

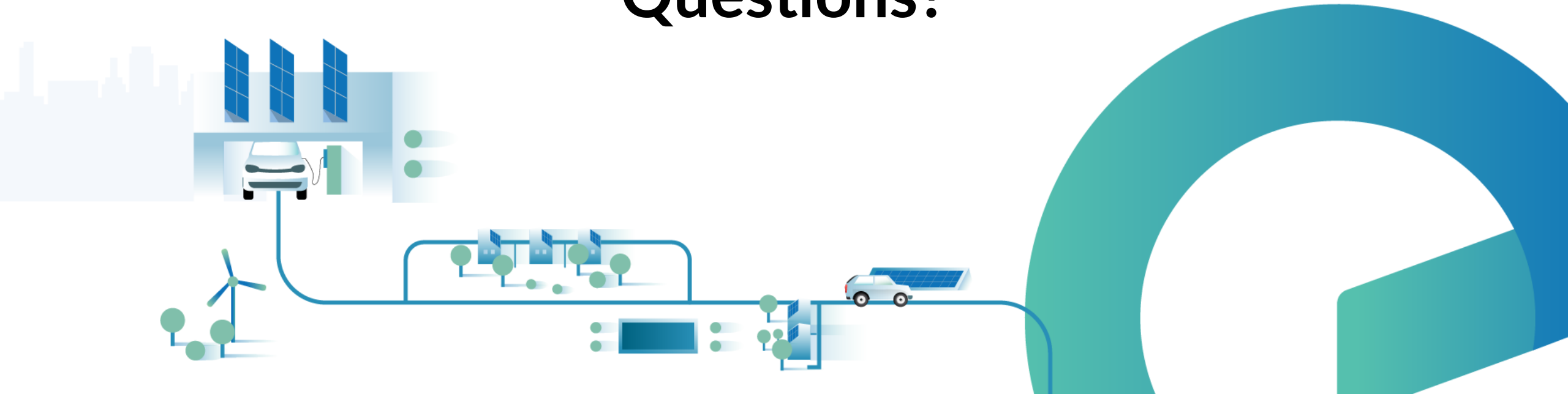
- Pay-as-bid
- Pay-as-clear
- Other



Conclusions

- ✓ Developed an EV Charging Flexibility model that considers dynamics and limitations of load shifting
- ✓ CPOs characterized by their charging and occupancy rates
- ✓ Definition of a new flexibility cost function to be traded off again reliability, energy-losses and investment costs
- ✓ This methodology allows finding hybrid solutions where both flexibility and reinforcement strategies are employed

Thank you!
Questions?



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