An Efficient Robust Approach to the Day-ahead Operation of an Aggregator of Electric Vehicles

Álvaro Porras Cabrera

Joint work with:

- Ricardo Fernández-Blanco Carramolino
- Juan Miguel Morales González
- Salvador Pineda Morente

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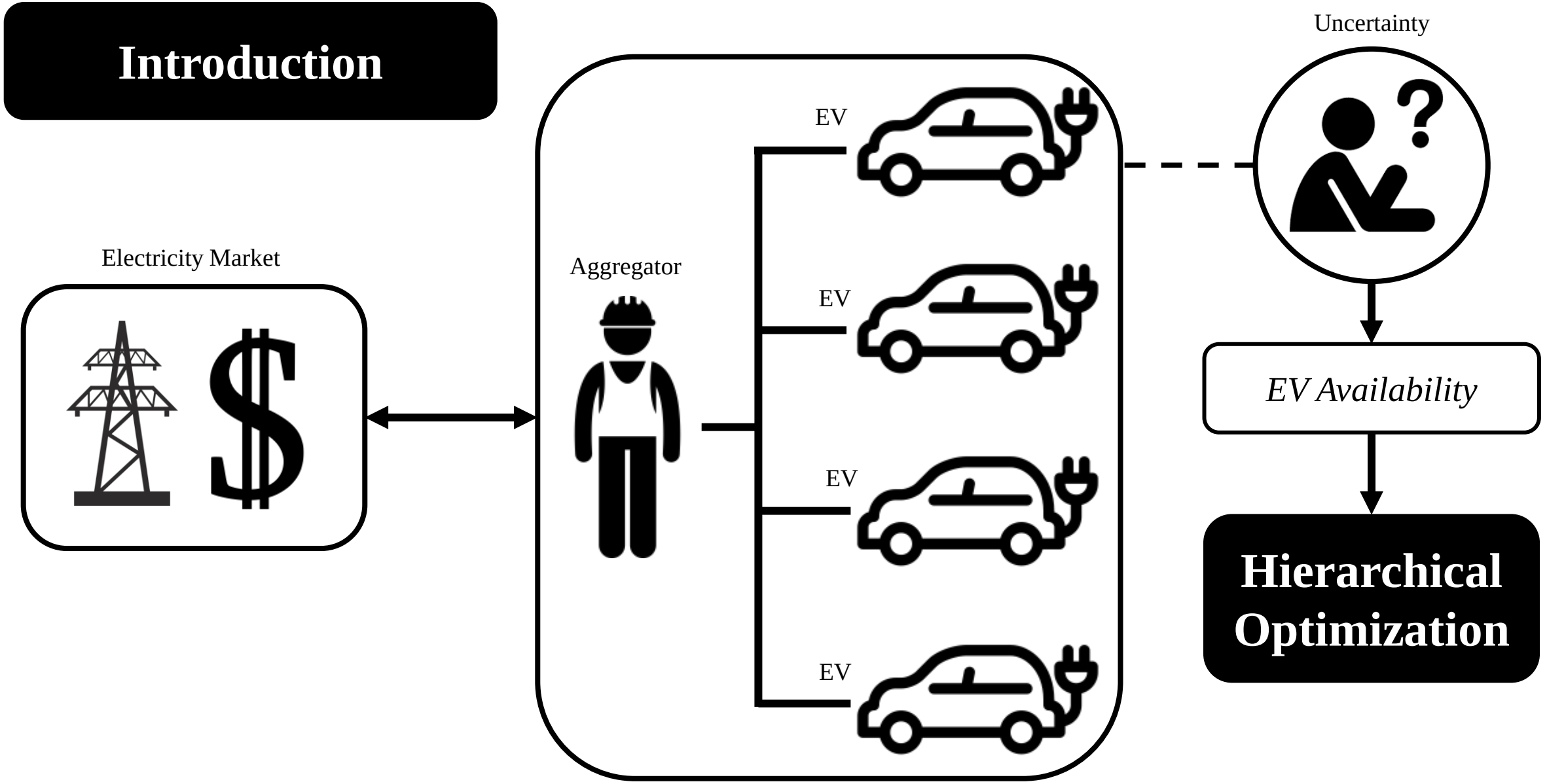
Introduction



Problem Formulation

Deterministic Formulation

- Uncertainty is disregarded.
- Optimal for expected values.
- Computationally tractable.

Stochastic Formulation

- Uncertainty using scenarios.
- Optimal on average.
- Number of scenarios.

Hierarchical Formulation

- Uncertainty using a few intuitive parameters.
- Robust against adverse situations.
- Scalability.

Problem Formulation

Deterministic Formulation

- λ_t are expected values → $\hat{\lambda}_t$
- $\alpha_{v,t}$ are expected values → $\hat{\alpha}_{v,t}$

$$\min_{\Xi^D} \sum_{t\in\mathcal{T}} \hat{\lambda}_t p_t + \sum_{t\in\mathcal{T}}\sum_{v\in\mathcal{V}} \left(c^D_{v,t} + C^p_1 s_{v,t}\right)$$

subject to:

$$p_t = \sum_{v\in\mathcal{V}} \left(c_{v,t} - d_{v,t}\right), \quad \forall t \in \mathcal{T}$$

$$-P^G \le p_t \le P^G, \quad \forall t \in \mathcal{T}$$

$$e_{v,t} = e_{v,t-1} + \eta_v c_{v,t}\,\hat{\alpha}_{v,t} - \frac{d_{v,t}}{\eta_v} - \hat{\tau}_{v,t} + s_{v,t}, \quad \forall v \in \mathcal{V}, t \in \mathcal{T}$$

$$c_{v,t} \le \overline{C}_v, \quad \forall v \in \mathcal{V}, t \in \mathcal{T}$$

$$d_{v,t} \le \overline{D}_v\,\hat{\alpha}_{v,t}, \quad \forall v \in \mathcal{V}, t \in \mathcal{T}$$

$$\underline{E}_v \le e_{v,t} \le \overline{E}_v, \quad \forall v \in \mathcal{V}, t \in \mathcal{T}$$

$$e_{v,N_T} = e_{v,0}, \quad \forall v \in \mathcal{V}$$

$$c^D_{v,t} = \left|\frac{S}{100}\right| C^E_v \left(\frac{1}{\eta_v} d_{v,t} + \hat{\tau}_{v,t}\right), \quad \forall v \in \mathcal{V}, t \in \mathcal{T}$$

$$c_{v,t}, d_{v,t}, e_{v,t}, c^D_{v,t}, s_{v,t} \ge 0, \quad \forall v \in \mathcal{V}, t \in \mathcal{T}$$

$$(c_{v,t}, d_{v,t}, s_{v,t}, c^D_{v,t}) \in \Phi(\hat{\alpha}_{v,t}, \hat{\tau}_{v,t})$$

Problem Formulation

Proposed Approach

- Characterization of the uncertainty in EV availability using a parameter set:

$$\Theta_v = \left\{K_v, \underline{\alpha}_{v,t}, \overline{\alpha}_{v,t}\right\}$$

- Now, $\alpha_{v,t}$ are variables that depend on an uncertainty set:

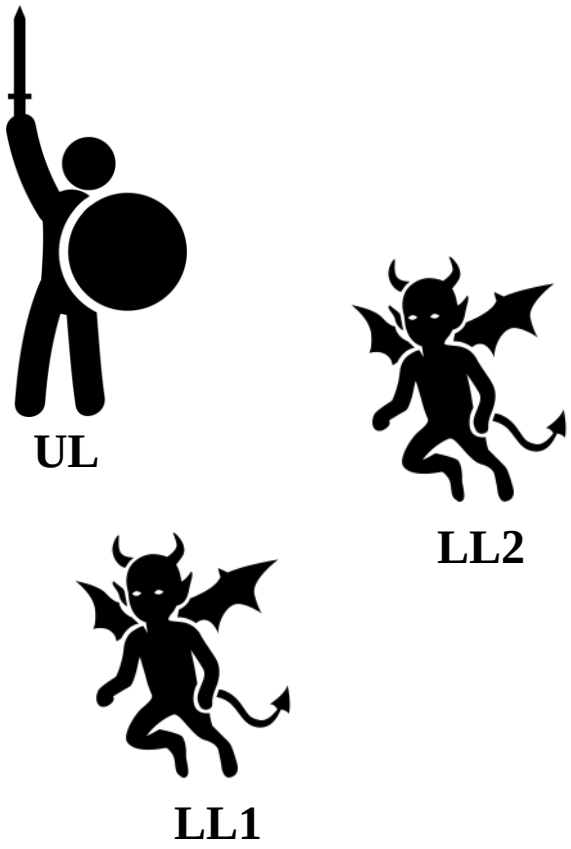
$$\sum_{t \in \mathrm{T}} \alpha_{v,t} \geq K_v, \forall t \in \mathcal{T}, v \in \mathcal{V}$$

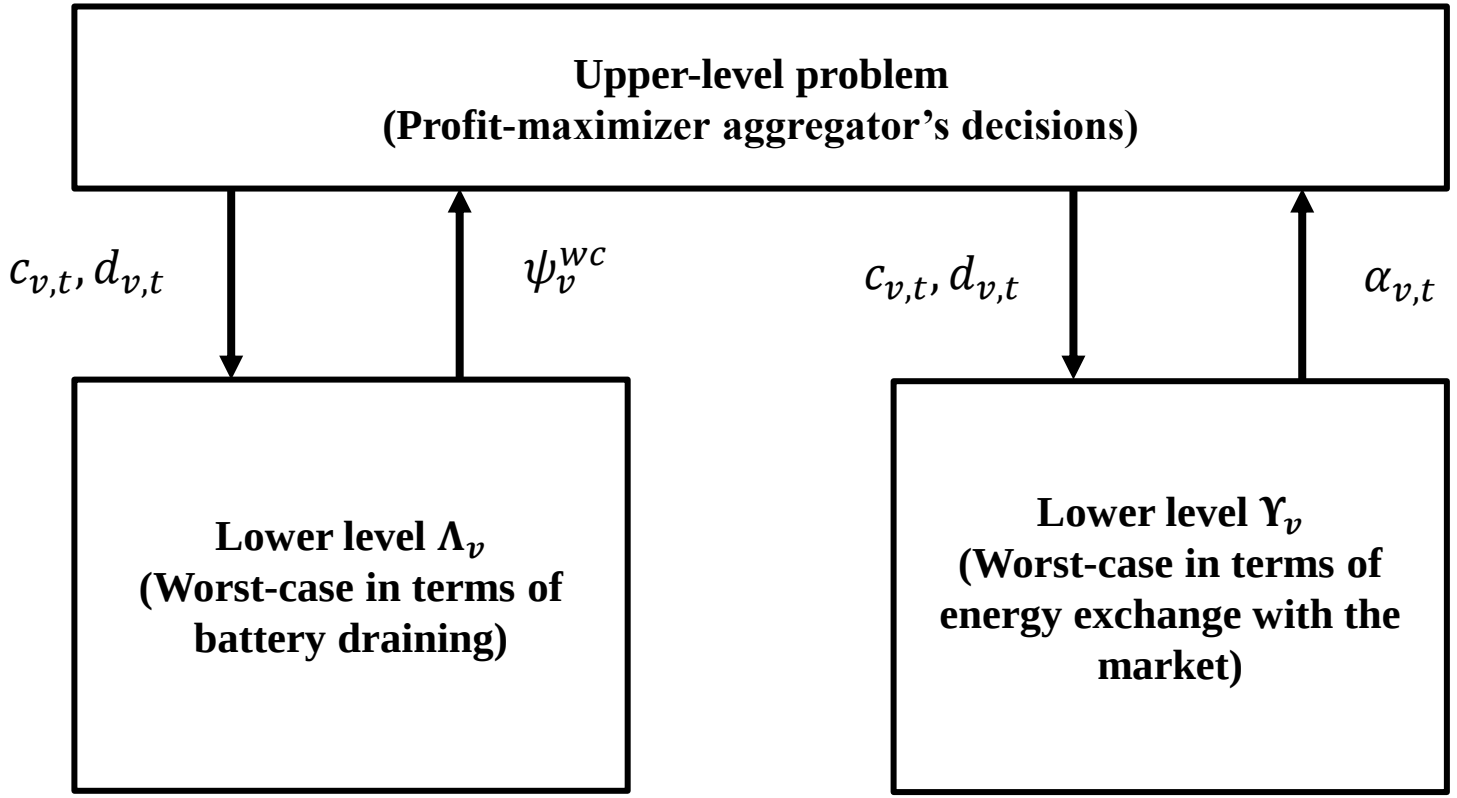
$$\underline{\alpha_{v,t}} \leq \alpha_{v,t} \leq \overline{\alpha_{v,t}}, \forall t \in \mathcal{T}, v \in \mathcal{V}$$

$$\alpha_{v,t} \in \{0,1\}, \forall t \in \mathcal{T}, v \in \mathcal{V}$$

Problem Formulation

Hierarchical Formulation





Problem Formulation

Hierarchical Formulation

Energy required for transportation

Total net energy injections into the EV-battery

Availability profiles

$$\min_{\Xi^R} \sum_{t\in\mathcal{T}} \widehat{\lambda}_t p_t + \sum_{t\in\mathcal{T}}\sum_{v\in\mathcal{V}} \left(c^D_{v,t} + C^p_1 s_{v,t}\right)$$

subject to:

$$p_t = \sum_{v\in\mathcal{V}} \left(c_{v,t} - d_{v,t}\right), \quad \forall t \in \mathcal{T}$$

$$-P^G \leq p_t \leq P^G, \quad \forall t \in \mathcal{T}$$

$$(c_{v,t}, d_{v,t}, s_{v,t}, c^D_{v,t}) \in \Phi(\alpha_{v,t}, \tau_{v,t}), \quad \forall v \in \mathcal{V}, t \in \mathcal{T}$$

$$\sum_{t\in\mathcal{T}} \tau_{v,t} = \widehat{\xi}_v, \quad \forall v \in \mathcal{V}$$

$$\tau_{v,t} \leq \left(\overline{E}_v - \underline{E}_v\right)\left(1 - \alpha_{v,t}\right), \quad \forall v \in \mathcal{V}, t \in \mathcal{T}$$

$$\tau_{v,t} \geq 0, \quad \forall v \in \mathcal{V}, t \in \mathcal{T}$$

$$\psi^{wc}_v \geq \widehat{\xi}_v, \quad \forall v \in \mathcal{V}$$

$$\psi^{wc}_v \in \Lambda_v(c_{v,t}, d_{v,t}), \quad \forall v \in \mathcal{V}$$

$$\alpha_{v,t} \in \Upsilon_v(c_{v,t}, d_{v,t}), \quad \forall v \in \mathcal{V}$$

Problem Formulation

Lower level Problems Determining the Sets Λ_v

$$\psi_v^{wc} = \min_{\alpha'_{v,t}} \sum_{t\in\mathcal{T}} \alpha'_{v,t}\left(\eta_v c_{v,t} - \frac{1}{\eta_v} d_{v,t}\right)$$

subject to:

$$\sum_{t\in\mathcal{T}} \alpha'_{v,t} \geq K_v : (\zeta'_v)$$

$$\underline{\alpha}_{v,t} \leq \alpha'_{v,t} \leq \overline{\alpha}_{v,t} : (\underline{\beta}'_{v,t}, \overline{\beta}'_{v,t}), \quad \forall t \in \mathcal{T}$$

$$\alpha'_{v,t} \in \{0,1\}, \quad \forall t \in \mathcal{T}$$

Lower level Problems Determining the Sets Υ_v

$$\min_{\alpha_{v,t}} \sum_{t\in\mathcal{T}} \alpha_{v,t}\left(\eta_v c_{v,t} + \frac{1}{\eta_v} d_{v,t}\right)$$

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Methodology

- *Non-convex.*
- *KKT conditions not applicable.*

$$\psi_v^{wc} = \min_{\alpha'_{v,t}} \sum_{t \in \mathcal{T}} \alpha'_{v,t} \left(\eta_v c_{v,t} - \frac{1}{\eta_v} d_{v,t} \right)$$

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$$\min_{\alpha_{v,t}} \sum_{t \in \mathcal{T}} \alpha_{v,t} \left(\eta_v c_{v,t} + \frac{1}{\eta_v} d_{v,t} \right)$$

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$$\alpha_{v,t} \in \{0, 1\}, \quad \forall t \in \mathcal{T}$$

- *Convex.*
- *KKT conditions applicable.*

$$\psi_v^{wc} = \min_{\alpha'_{v,t}} \sum_{t \in \mathcal{T}} \alpha'_{v,t} \left(\eta_v c_{v,t} - \frac{1}{\eta_v} d_{v,t} \right)$$

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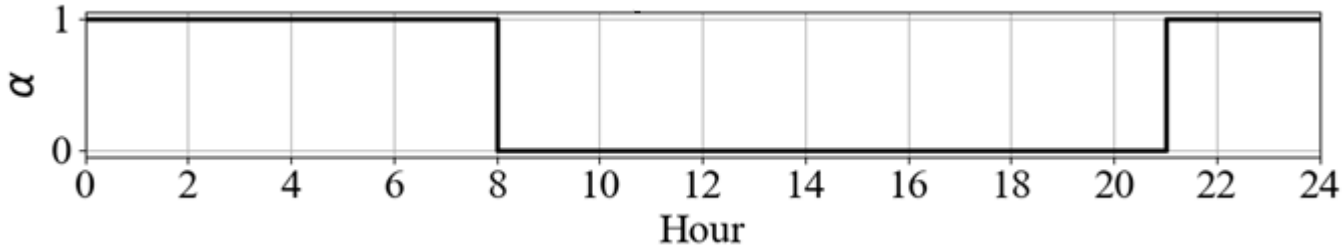
Methodology



Matrix Totally Unimodular

Integer

$$\psi_v^{wc} = \min_{\alpha'_{v,t}} \sum_{t\in\mathcal{T}} \alpha'_{v,t}\left(\eta_v c_{v,t} - \frac{1}{\eta_v} d_{v,t}\right)$$

subject to:

$$\sum_{t\in\mathcal{T}} \alpha'_{v,t} \geq K_v \quad (\zeta'_v)$$

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$$0 \leq \alpha_{v,t} \leq 1, \quad \forall t \in \mathcal{T}$$

Optimal solution takes integer values

Case Study

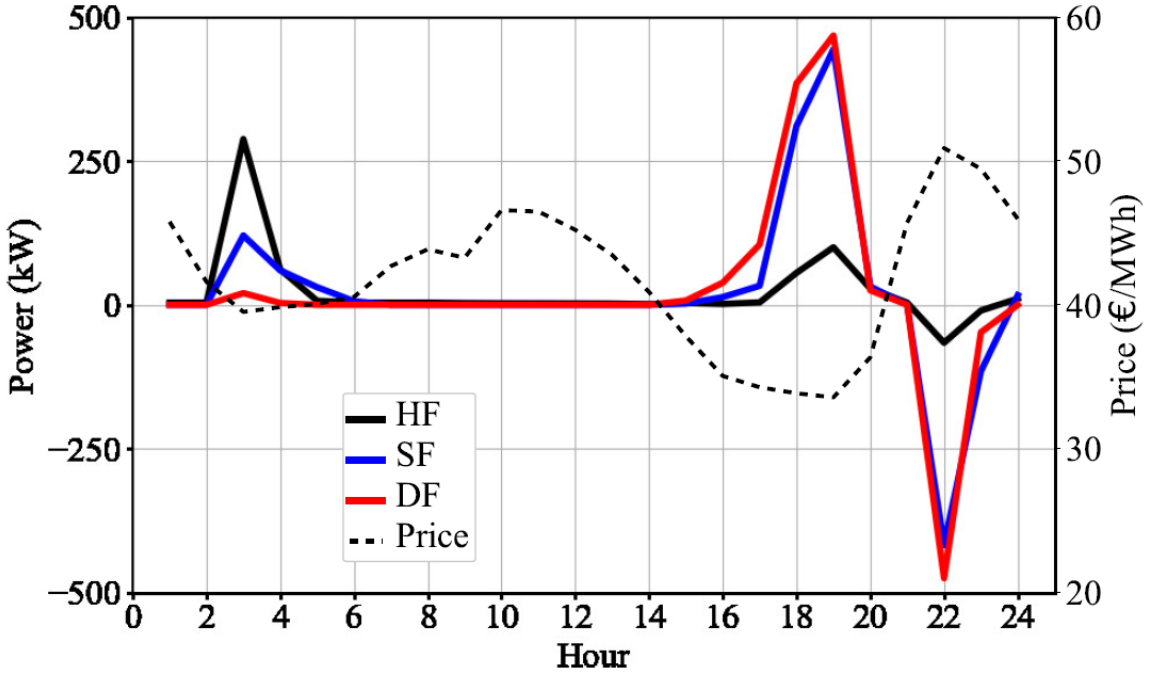
Base Case

- 120 days of simulation.
- 100 EVs.

Metric	DF	SF	HF
Total Cost (€)	2.282,4	2.708,4	2.888,4
Total energy bought (MW)	162.2	155.1	114.2
Total energy sold (MW)	96.5	83.1	47.7
Deviations from energy balance of EV's battery (MW)	10,3	4,7	4,0
Deviations from the minimum value of energy sold (MW)	13,4	1,2	0,4

DF and SF compared with HF:

- Total cost decreases by 21.0% and 6.2%.
- Energy deviations from EV-batteries increase by 157.5% and 17.5%.
- Deviations from the minimum value of the energy sold increase up to 13.4 and 1.2 MWh.



Conclusion

- **Reduction** of deviations from the energy balance of EV batteries.
- Reductions come at the expense of increasing the total trading costs in the day-ahead market.
- The computational speed of the proposed model is up to 25% faster than its stochastic counterpart.

Á. Porras, R. Fernández-Blanco, J. M. Morales and S. Pineda, "An Efficient Robust Approach to the Day-Ahead Operation of an Aggregator of Electric Vehicles," in *IEEE Transactions on Smart Grid*, vol. 11, no. 6, pp. 4960-4970, Nov. 2020.

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Thank you for your attention

Any question?

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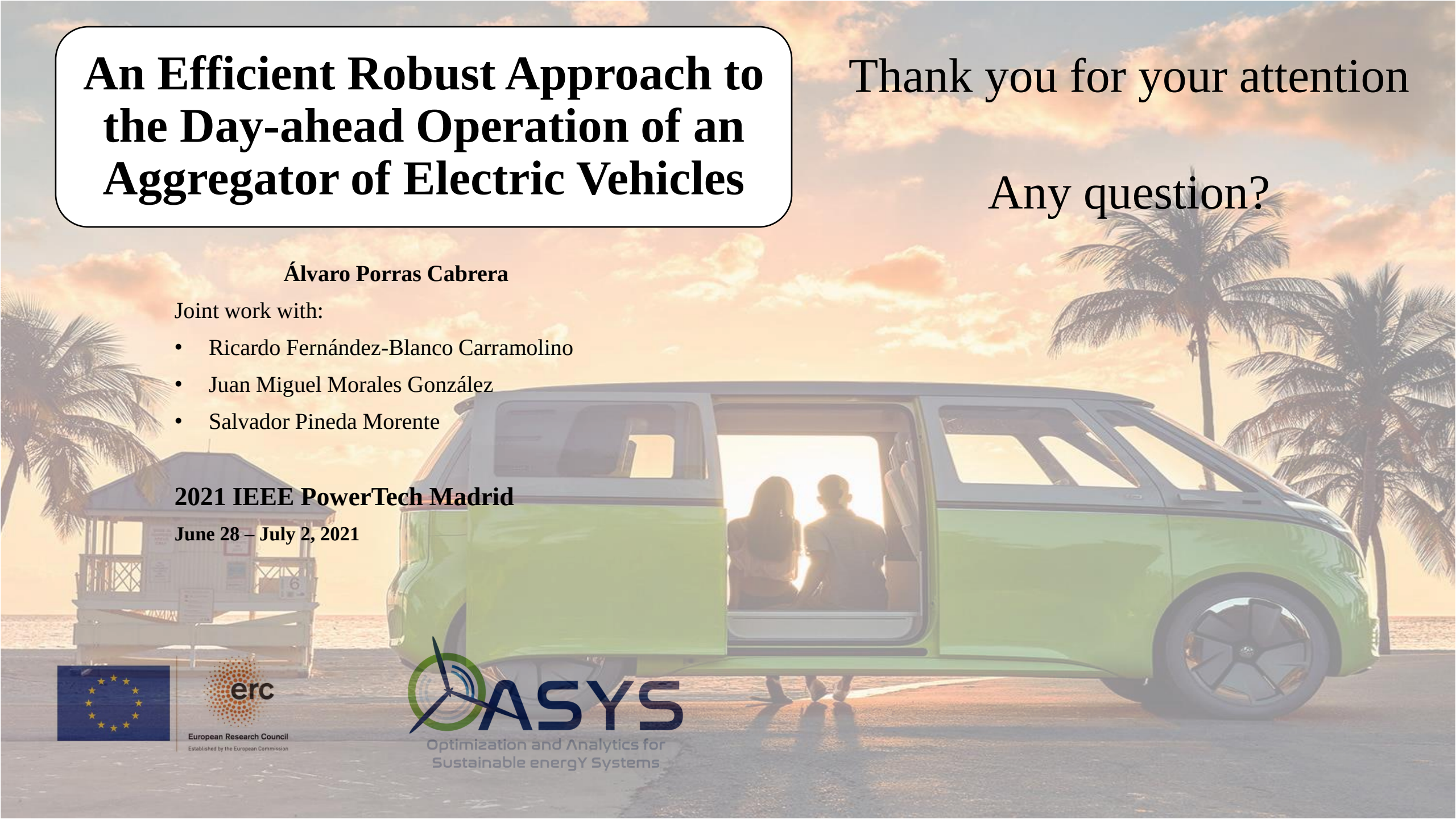

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