# Optimization of coupled driving-and-charging strategies for EV in urban environment

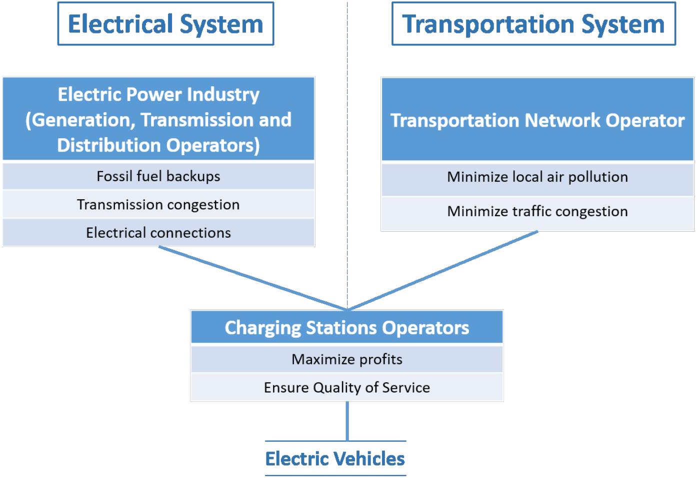
**Benoit Sohet**[1,2], Yezekael Hayel[2]
Olivier Beaude[1], Alban Jeandin[3], Jean-Baptiste Breal[1]

[1] EDF R&D, MIRE & OSIRIS Dept., EDF Lab Paris-Saclay
[2] LIA/CERI, University of Avignon
[3] Izivia, EDF Group

*benoit.sohet@edf.fr*

Electric mobility and territories
April 8

# Context: Coupled electrical and transportation systems



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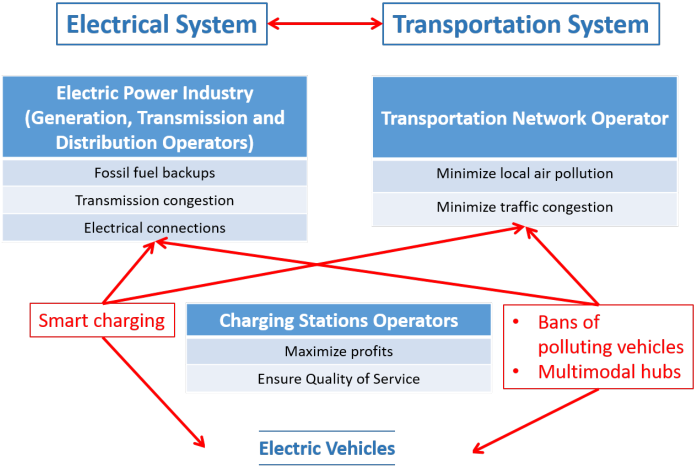
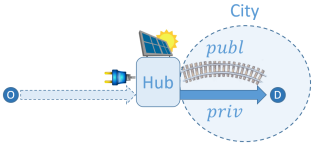


# Use case: e-Park & Ride hub

A group of **E**lectric and **G**asoline **V**ehicles (EV and GV) arrives at an e-Park & Ride hub. They can either:

1. Park and charge at the hub with its **P**hoto**V**oltaic (PV) solar panels, and take **P**ublic **T**ransport (PT);
2. Drive all the way to the city center.



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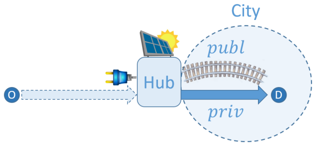
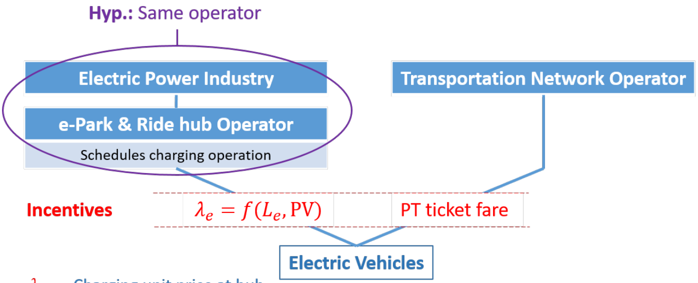


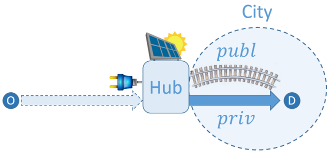




$\lambda_e$ = Charging unit price at hub
$L_e$ = Total charging need at hub

# EV model: Game theory

*publl* Pay for energy consumed to get to the hub and take Public Transport

*priv* Drive into congested city center and pay for total energy consumed



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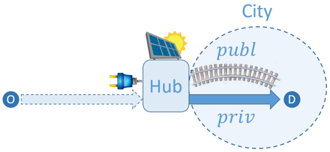


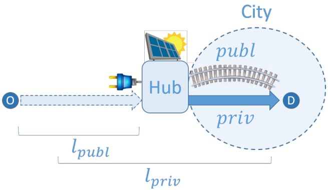

| Transport mode | Travel duration | Consumption cost |
|---|---|---|
| Public | • Constant | • Charging price depends on EV nb<br>+ Constant PT fare |
| Private | • Depends on vehicles nb (congestion)<br>→ BPR function | • Constant (distance-dependent) |

**Equilibrium**

Stable situation between strategic decision-makers

# EV model: Game theory

| | |
|---|---|
| $\lambda_e$ | Charging unit price |
| $L_e$ | Total charging need at hub |
| $m_e$ | Energy consumption per distance unit |
| $x_{e,m}$ | Number of EVs in mode $m$ |




### Charging impacts driving

At hub, charging unit price $\lambda_e$ depends on total charging need $L_e$

$$\lambda_e(L_e)$$

### Driving impacts charging

Total charging need at hub $L_e$ depends on total driving distance

$$L_e = m_e \times l_{publ} \times x_{e,publ}$$

### Equilibrium

Stable situation between strategic decision-makers

# Hub charging service

At the hub, the operator schedules the charging operation to minimize the costs $G$ related to peak demand.

- **Constraint:** Total charging need $L_e$ ($\propto$ EV nb at hub)
- **Control:** Aggregated charging profile $(\ell_{e,t})_t$ s.t. $\sum_{t=1}^{T} \ell_{e,t} = L_e$

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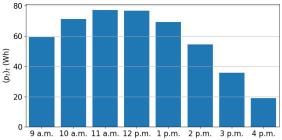

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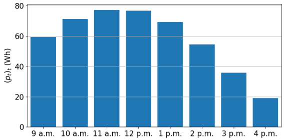
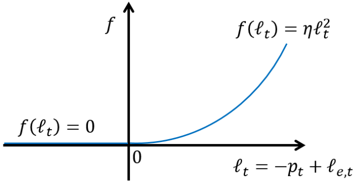



- **Objective:** Minimize hourly electricity distribution costs $f$

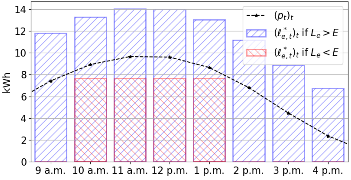


# Charging unit price

- Minimal distribution costs:

$$G^*(L_e) = \begin{cases} 0\,, & \text{if } L_e \leq E \\ \frac{\eta}{8}(-E + L_e)^2\,, & \text{if } L_e > E \end{cases}$$

- EV pay equally for the grid costs:
$\lambda_e(L_e) = \lambda_{\text{cst}} + \frac{G^*(L_e)}{L_e}$



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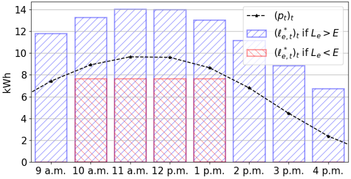
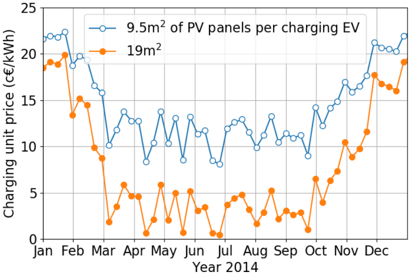



- PV panels located in Paris[a]
- Hub charging service cheaper from March to October
- Depending on EV proportion at hub, charging may be free or not (see end of June)

[a] https://www.renewables.ninja/

# Sensitivity analysis: Public Transport fare

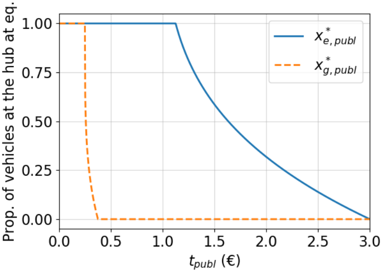



Figure: Equilibrium computed for any PT fare

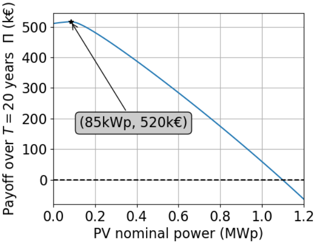
- More EV than GV at hub thanks to charging incentives (PV production cheaper than electricity from the grid)
- $\searrow$ 0.50€ in PT fare $\longrightarrow$ +25% of EV at the hub

# Incentive design: PhotoVoltaic surface

## Hub operator payoff (with 500 EV)

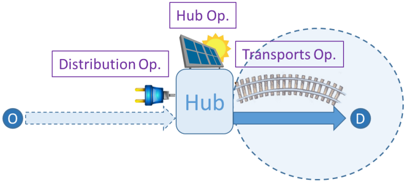
$$\Pi = -I + T \times (R - G)\,,$$

- $I$ = Initial Investment in PV = 750€/kWp
- $T$ = Period of time considered
- $R$ = Revenues from EV charging = $L_e \lambda_e$
- $G$ = Grid costs




- The first solar panels are profitable because the grid costs avoided compensate for the investments
- Optimal nominal power equivalent to a PV surface of 39 parking spots

# Conclusion




## Summary

- **Model:** EV **coupled** behavior while driving and charging
- **Scenario:** Multimodal hub with PhotoVoltaic production
- **Use:** Design of Public Transport fare and PV surface