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

Benoit Sohet\textsuperscript{1,2}, Yezekael Hayel\textsuperscript{2}
Olivier Beaude\textsuperscript{1}, Alban Jeandin\textsuperscript{3}, Jean-Baptiste Breal\textsuperscript{1}

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

benoit.sohet@edf.fr

Electric mobility and territories
April 8
Context: Coupled electrical and transportation systems

**Electrical System**

**Electric Power Industry (Generation, Transmission and Distribution Operators)**
- Fossil fuel backups
- Transmission congestion
- Electrical connections

**Transportation System**

**Transportation Network Operator**
- Minimize local air pollution
- Minimize traffic congestion

**Charging Stations Operators**
- Maximize profits
- Ensure Quality of Service

**Electric Vehicles**

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Evaluation of Coupled Driving & Charging Incentives for EV
Context: Coupled electrical and transportation systems

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  - Transmission congestion
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**Electric Vehicles**
- Smart charging

**Additional Points**
- Bans of polluting vehicles
- Multimodal hubs
A group of Electric and Gasoline Vehicles (EV and GV) arrives at an e-Park & Ride hub. They can either:

1. Park and charge at the hub with its PhotoVoltaic (PV) solar panels, and take Public Transport (PT);
2. Drive all the way to the city center.
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**Hyp.: Same operator**

**Electric Power Industry**

**e-Park & Ride hub Operator**

Schedules charging operation

**Incentives**

\[ \lambda_e = f(L_e, PV) \]

\( \lambda_e \) = Charging unit price at hub

\( L_e \) = Total charging need at hub

**Transportation Network Operator**

PT ticket fare

**Electric Vehicles**
**publ** 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
**publ** 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

<table>
<thead>
<tr>
<th>Transport mode</th>
<th>Travel duration</th>
<th>Consumption cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Public</td>
<td>• Constant</td>
<td>• Charging price depends on EV nb + Constant PT fare</td>
</tr>
<tr>
<td>Private</td>
<td>• Depends on vehicles nb (congestion) → BPR function</td>
<td>• Constant (distance-dependent)</td>
</tr>
</tbody>
</table>

**Equilibrium**

Stable situation between strategic decision-makers
**EV model: Game theory**

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
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<tbody>
<tr>
<td>$\lambda_e$</td>
<td>Charging unit price</td>
</tr>
<tr>
<td>$L_e$</td>
<td>Total charging need at hub</td>
</tr>
<tr>
<td>$m_e$</td>
<td>Energy consumption per distance unit</td>
</tr>
<tr>
<td>$x_{e,m}$</td>
<td>Number of EVs in mode $m$</td>
</tr>
</tbody>
</table>

**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
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 $(\ell_{e,t})_t$

\[ \sum_{t=1}^{T} \ell_{e,t} = L_e \]
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- **Input:** PhotoVoltaic production $p_t$ at time slot $t$ and total production $E = \sum_{t=1}^{T} p_t$
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  \]
- **Input:** PhotoVoltaic production $p_t$
  at time slot $t$ and total production
  
  \[
  E = \sum_{t=1}^{T} p_t
  \]
- **Objective:** Minimize hourly electricity distribution costs $f$

\[
 f(l_t) = \eta l_t^2
\]

\[
 f(l_t) = 0
\]

\[
 l_t = -p_t + l_{e,t}
\]
- Minimal distribution costs:
  \[ G^* (L_e) = \begin{cases} 
  0, & \text{if } L_e \leq E \\
  \frac{n}{8} (-E + L_e)^2, & \text{if } L_e > E 
 \end{cases} \]

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

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

- 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)
- $0.50\,\text{€}$ in PT fare $\rightarrow +25\%$ of EV at the hub
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