AN OPTIMIZATION MODEL
FOR LOCATING ELECTRIC VEHICLE CHARGING STATIONS
IN CENTRAL URBAN AREAS

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Structure

1. Background
2. Objective
3. Optimal Stations Location Model
4. Lisbon Case Study
5. Conclusions

Adaptado de: (Reis, 2010)
1. Background – Electric Vehicles

- More efficient in energy consumption
- More environmentally friendly
- Cheaper in terms of fuel consumption

- Main disadvantages:
  - Charging
  - Battery autonomy (160 - 60 Km)
1. Background – Electric Vehicles

• Battery charging depends on:
  ▪ Vehicle characteristics
  ▪ Charging system type

• 3 different charging systems
  ▪ battery replacement
  ▪ fast charge (20 to 30 minutes)
  ▪ normal (or slow) charge (6 to 8 hours).
1. Background - Portugal

- Electric Mobility Program

  - 3 Phases:
    - Pilot Phase (end of 2011)
    - Growing Phase (beginning of 2012)
    - Consolidation Phase (with a sustainable number of EV’s)

  - Several incentives to electric mobility
1. Background - Portugal

Incentives to electric mobility (Decree-Law No. 39/2010):

- Installing charging points networks
- A 5000€ budget for the first 5000 EV until the end of 2012
- Benefits Tax - exemption from vehicle taxes
- Priority conditions for EV in congested traffic situations
- Construction / Reconstruction of charging stations
2. Objective

• To help in the definition of a planning strategy for the electric mobility infrastructures, using a model for the optimal location of EV charging stations

— Using Lisbon as a Case Study
3. Model

- Maximal covering model, the objective being to maximize the demand covered within a given distance (service level) with a fixed number of charging stations.

After the charging posts location, determination of the number of charging points in each post (varying between 2 and 10).
3. Model

- Daily demand – EV’s that need to charge during the day (24 hours).

- Slow charging: 6 to 8 hours

  - Residential areas
    Night charging
    (from 7 p.m. To 7 a.m.)

  - Employment Areas
    Day charging
    (from 7 a.m. To 7 p.m.)
3. Model

Input variables

- Demand network;
- Supply network;
- Distance between demand \((j)\) and supply \((k)\) – \(d_{j,k}\);
- Number of possible charging operations (day - \(N_d\), night - \(N_n\));
- Number of charging posts to locate – \(P\);
- Optimal walking distance – \(d_{opt}\), and maximal walking distance - \(d_{max}\).
3. Model

\[
\text{Max } \sum_{j=1}^{J} \sum_{k=1}^{K} N_n \cdot R_{jk} \cdot u_{nj} \cdot X_{jk} + \sum_{j=1}^{J} \sum_{k=1}^{K} N_d \cdot R_{jk} \cdot u_{dj} \cdot X_{jk} - 0.01 \cdot Q_k
\]

subject to:

1. \( \sum_{k=1}^{K} X_{jk} \leq 1 \quad \forall j = 1 \ldots J \)

2. \( X_{jk} \leq R_{jk} \cdot Y_k \quad \forall j = 1 \ldots J, k = 1 \ldots K \)

3. \( \sum_{k=1}^{K} Y_k = P \)

4. \( Z_k = \sum_{j=1}^{J} [(u_{nj} + u_{dj}) \times X_{jk}] \quad \forall k = 1 \ldots K \)

5. \( Q_k \geq \frac{Z_k}{N_n + N_d} \quad \forall k = 1 \ldots K \)

6. \( 2Y_k \leq Q_k \leq 10Y_k \quad \forall k = 1 \ldots K \)

7. \( X_{jk}, Z_{jk} \geq 0 \quad \forall j = 1 \ldots J, k = 1 \ldots K \)

8. \( Y_k \in \{0,1\} \quad \forall k = 1 \ldots K \)

9. \( Q_k \) is integer \( \forall k = 1 \ldots K \)
3. Model

Output variables

- Posts location;
- Coverage level for each zone;

\[ R_{j,k} = \begin{cases} 
1 & \text{if } d(j,k) < d_{opt} \\
 f(j,k) & \text{if } d_{opt} \leq d(j,k) \leq d_{max} \\
0 & \text{if } d(j,k) > d_{max} 
\end{cases} \]

\[ f_{j,k} = \frac{d_{max} - d_{j,k}}{d_{max} - d_{opt}} \]

- Number of charging points per post.
4. Lisbon case study

Study area
4. Lisbon case study

Demand

• Daily chargings for each vehicle:
  ▪ Average daily distance in Lisbon Metropolitan Area: 20 Km;
  ▪ Vehicle autonomy: 60 Km;

Each vehicle needs, in average, one charging in each 3 days period (0.33 chargings/day).
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Demand

• Nighttime demand, $u_n(j)$

$$un_j = 0.33 \times V_{he}$$

• Daytime demand, $u_d(j)$

$$ud_j = 0.33 \times V_{Ee}$$
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Demand – Night shipment

\[ Vh_e = \begin{cases} 
3\% \times Vh & \text{if } Vh \geq 2 \\
2\% \times Vh & \text{if } Vh < 2 
\end{cases} \]

\[ VE_e = 2\% \times VE \]

\( Vh_e \) – number of electric cars per family;
\( Vh \) – number of cars per family;
\( VE_e \) – number of electric cars related to work;
\( VE \) – number of cars related to work.
4. Lisbon case study
Demand — Night shipment

- Data: Region ‘Lisboa e \ do Tejo’ - 51 municipalities
4. Lisbon case study

Demand — Night shipment

\[ Vh = 3,90 \times P_H^{17} - 1,18 \times P_T + 3,41 \times P^{19} + 3,28 \times P^{65} \]

<table>
<thead>
<tr>
<th>Variables</th>
<th>Coefficients</th>
<th>Standard-error</th>
<th>Stat t</th>
<th>p-value</th>
</tr>
</thead>
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<td>( P_H^{17} )</td>
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<td>0,72</td>
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</tbody>
</table>
4. Lisbon case study

Demand – Night shipment

\[ Vh_e = \begin{cases} 
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\[ VE_e = 2\% \times VE \]

- \( Vh_e \) – number of electric cars per family;
- \( Vh \) – number of cars per family;
- \( VE_e \) – number of electric cars related to work;
- \( VE \) – number of cars related to work.
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Demand – Day shipment

• It was assumed that 20% of all home-to-work trips in the pilot area are done in individual car
(based on a Lisbon Mobility Survey)

\[ VE = 20\% \times E \]

*VE* – number of vehicles (individual cars) associated with jobs

*E* – number of jobs
4. Lisbon case study

Demand – Day shipment

• Data: Municipality - 39 units;

• The survey is done relating number of jobs (E) with number of buildings with different types of occupation

Fonte: Transporte, Inovação e Sistemas, SA, 2005
4. Lisbon case study

Demand – Day shipment

\[ E = 159.20 \times B_N + 14.89 \times B_{RN} - 1.42 \times B_R \]

<table>
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<td>42.76</td>
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</table>
4. Lisbon case study

Supply

- Parking lots and other public potential charging station points.

290 car parks
4. Lisbon case study

Results

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Year</th>
<th>No. of charges per day</th>
<th>No. of charges per night</th>
<th>Demand shares</th>
<th>No. of charging stations</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Cars per household</td>
<td>Cars per job</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>&lt;2</td>
<td>≥ 2</td>
</tr>
<tr>
<td>1</td>
<td>2011</td>
<td>2</td>
<td>1</td>
<td>2%</td>
<td>3%</td>
</tr>
<tr>
<td>2</td>
<td>2011</td>
<td>2</td>
<td>2</td>
<td>2%</td>
<td>3%</td>
</tr>
<tr>
<td>3</td>
<td>2012</td>
<td>2</td>
<td>2</td>
<td>4%</td>
<td>5%</td>
</tr>
<tr>
<td>4</td>
<td>2012</td>
<td>2</td>
<td>2</td>
<td>4%</td>
<td>5%</td>
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</tbody>
</table>

- 268 posts until the end of 2011
- 406 posts until the end of 2012
4. Lisbon case study

Results

<table>
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<tr>
<th>Scenario</th>
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<tbody>
<tr>
<td>Year</td>
<td>2011</td>
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<tr>
<td>No. of charges per day</td>
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<tr>
<td>No. of charges per night</td>
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</tr>
<tr>
<td>Demand shares</td>
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</tr>
<tr>
<td>Cars per household</td>
<td>&lt;2</td>
</tr>
<tr>
<td></td>
<td>≥ 2</td>
</tr>
<tr>
<td>Cars per job</td>
<td>2%</td>
</tr>
<tr>
<td>No. of charging stations</td>
<td>29</td>
</tr>
</tbody>
</table>

180 charging points
4. Lisbon case study

Results

| Scenario | 2 |
| Year     | 2011 |
| No. of charges per day | 2 |
| No. of charges per night | 2 |
| Demand shares |  |
| Cars per household | <2 | 2% |
|                      | ≥ 2 | 3% |
| Cars per job | 2% |
| No. of charging stations | 29 |

137 charging points  
- 43 points
4. Lisbon case study

Results

<table>
<thead>
<tr>
<th>Scenario</th>
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</thead>
<tbody>
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<td>Year</td>
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<tr>
<td>No. of charges per day</td>
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</tr>
<tr>
<td>No. of charges per night</td>
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</tr>
<tr>
<td>Demand shares</td>
<td>Cars per household</td>
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<td></td>
<td></td>
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<tr>
<td></td>
<td>Cars per job</td>
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<tr>
<td>No. of charging stations</td>
<td>43</td>
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</tbody>
</table>

324 charging points

Legend
- Stations
- Covered
- Partly Covered
- Not Covered
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Results

<table>
<thead>
<tr>
<th>Scenario</th>
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<tbody>
<tr>
<td>Year</td>
<td>2012</td>
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<tr>
<td>No. of charges per day</td>
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<td>Cars per job</td>
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<tr>
<td>No. of charging stations</td>
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</table>

236 charging points
- 88 points
5. Conclusions and Recommendations - Conclusions

- Acceptable demand estimation accordingly with the available data;
- Good coverage level;
- Significant reduction on the number of points with the increasing on the number of daily charges per point;
- The solution for 2011 is well integrated in the target year of 2012.
5. Conclusions and Recommendations - Recommendations

- Estimation on the demand in what concerns the relation vehicles/jobs;
- Surveys for the EV’s demand in Portugal;
- Definition of park capacities;
- Benefit - Cost Analysis;
- Battery evolution and EV’s future demand.
Thank You!