Analysis and assessment of the electrification of urban transport based on real-life mobility data

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European Commission DG Joint Research Centre
The Joint Research Centre is a Directorate General of the European Commission.

With its 7 institutes the JRC is the European Commission’s in-house science service.
Within the Sustainable Transport Unit of the IET we do:

- Pre-normative research on HEV/EVs.
- Experimental testing in the Vehicle Emissions Laboratories (VELA).
- Desktop research on mobility and transport analyses.
• Scope of the work
• Activity databases description
• E-mobility model features
• Results: Travel behavior
  EVs usability
  Impact on the electricity grid
  GIS-based spatial distributions
• Conclusions
Scope of the work

• Large-scale implementation of e-vehicles is a topic of interest to be addressed;

• Despite the progresses done in the last decades, there are still many open issues, e.g. limited range of BEV, life-cycle assessment of their parts and components, long-term sustainability of Li-ion batteries and their integration within urban environments and electricity grid.

• The DG JRC IET has initiated a new activity on electro-mobility, which includes supporting standardisation, addressing the interoperability between e-vehicles and smart grids, proving testing facilities for electric vehicles, smart grid, vehicles batteries and related equipments.

• Among all these activities a new study targeted to large scale activity databases analysis and EVs modelling has been initiated.
Activity databases description

- Vehicle ID number (anonymous, private/commercial conventional fuel vehicles)
- Calendar date and time [sec]
- Latitude and Longitude (GPS accuracy)
- Engine and travel data (e.g. engine status, distance driven, etc.)
- Acquisition frequency variable (≈ 0.01 Hz, but it always ensures the trips reconstruction).
Activity databases description

<table>
<thead>
<tr>
<th></th>
<th>Population (total)</th>
<th>Province Area</th>
<th>Population (density)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Province of Modena</td>
<td>706,509 (31/03/2012)</td>
<td>2,688.7 km²</td>
<td>262.77/km²</td>
</tr>
<tr>
<td>Province of Florence</td>
<td>1,002,831 (31/07/2011)</td>
<td>3,514.0 km²</td>
<td>285.38/km²</td>
</tr>
</tbody>
</table>

Population (total) | Province Area | Population (density)
--- | --- | ---
706,509 (31/03/2012) | 2,688.7 km² | 262.77/km²
1,002,831 (31/07/2011) | 3,514.0 km² | 285.38/km²

Registered Vehicles

<table>
<thead>
<tr>
<th>Surveyed Vehicles (% of the total)</th>
<th>Analysed Sample (% of the surveyed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>52,834 (12.0%)</td>
<td>16,263 (30.7%)</td>
</tr>
<tr>
<td>40,459 (5.9%)</td>
<td>12,478 (30.8%)</td>
</tr>
</tbody>
</table>

Modena Only

16223 EVs  $\Rightarrow$ 16·10⁶ Records  $\Rightarrow$ 14.9·10⁶ Kms  $\Rightarrow$ 2.6·10⁶ Trips
E-mobility model features

**INPUT**

- JRC Test-Labs
- Literature
- GIS Maps

**Database Importing Module**
1. Modena
2. Florence
3. [...]

**Cleaning & Consistency Module**

**Database Aggregation & Driving Patterns Reconstruction Module**

**STATISTICAL MOBILITY PROCESSING MODULE**

**EVs SIMULATION MODULE**
(Parameterized vehicle & behavioral recharging models)

**SPATIAL/TIME ANALYSIS MODULE**

**OUTPUT**

- Travel Behavior
- Usability Analysis
- Modal-shift analysis
- Spatial/Time Mapping of the Electricity Demand and Distributed SOC
- Interface with grid model

Organized by Hosted by In collaboration with Supported by
E-mobility model features

**EV Simulation Model**

- All the conventional fuel vehicles in the databases are replaced by EVs.
  - 6 EVs models are implemented, the results of 2 of them are presented:

  - Small size (4 seats) passenger car: 1080 kg - 47 kW Eng. - 16 kWh Batt. - 185 Wh/km;
  - Medium size (5 seats) passenger car: 1520 kg - 80 kW Eng. - 24 kWh Batt. - 210 Wh/km;

- Each trip is considered as a **discharge event** and each parking as a **recharge opportunity**;
  - 15 behavioral recharges models are implemented, the results of 3 of them are presented:

  - Long-Stop Random AC (2 kW): Stop > 120 minutes AND Random threshold > 0.6;
  - Short-Stop Random DC (40 kW): Stop > 20 minutes AND Random threshold > 0.6;
  - Smart AC (2 kW): Stop within 4 hrs (+/-2 hrs) from the minimum of electric demand peak load.
Results: Travel behavior

- 3 peaks from Monday to Friday
- 2 peaks on Saturday on Sunday
- private < 11.5%, commercial < 15.2%

Private vehicles (≈ 91%):
  - trip between 5 and 20 km
  - parking between 2 and 12 hrs

Commercial vehicles (≈ 9%):
  - trips between 5 and 60 km
  - parking between 2 and 16 hrs
Results: Travel behavior

Probability Distributions

- **Number of Trips per Day (a)**
  - Bin size = 2
- **Cumulative Trip Length per Day**
  - Bin size = 20 km
- **Cumulative Parking Duration per Day**
  - Bin size = 4%

- **Number of Trips per Week**
  - Bin size = 10
- **Cumulative Trip Length per Week**
  - Bin size = 100 km
- **Cumulative Parking Duration per Week**
  - Bin size = 4%

More than 50% of the sample does:
- < 6 trips/day AND < 20 km/day \(\rightarrow\) < 60 km/day (75%)
- < 20 trips/week AND < 200 km/week \(\rightarrow\) < 300 km/week (75%)

9% of the sample exceeds 100 km/day, reducing to 3% exceeding 150 km/day!

> 70% cars are parked for more than 90% of the time
Results: EVs usability

- > 80% of the trips can be driven by EVs
- between 10% and 25% of the vehicles can drive 100% of the trips with an EVs

50% EVs by shifting < 5 trips per month
Results: Impact on the electricity grid

**No. of recharges per day/month**

<table>
<thead>
<tr>
<th>Strategy</th>
<th>EV type</th>
<th>Averaged number of recharges</th>
<th>Str. 1 Long-Stop R-AC</th>
<th>Str. 2 Short-Stop R-DC</th>
<th>Str. 3 Smart-AC</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Small size car</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>d: 0.44</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>m: 13.51</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Medium size car</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>d: 0.52</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>m: 16.24</td>
<td></td>
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</tr>
</tbody>
</table>

⇒ between ½ and 1 per day ⇒ 15 and 30 per month
⇒ between 8% and 16% SOC per recharge ⇒ 2.3 kWh and 3.8 kWh per recharge

**Energy stored per recharge**

<table>
<thead>
<tr>
<th>Strategy</th>
<th>EV type</th>
<th>Data</th>
<th>Str. 1 Long-Stop R-AC</th>
<th>Str. 2 Short-Stop R-DC</th>
<th>Str. 3 Smart-AC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small size car</td>
<td>ΔSOC 0.173</td>
<td>ΔEn. [Wh] 2764.6</td>
<td>0.144</td>
<td>2304.4</td>
<td>0.189</td>
</tr>
<tr>
<td>Medium size car</td>
<td>ΔSOC 0.159</td>
<td>ΔEn. [Wh] 3816.0</td>
<td>0.133</td>
<td>3192.0</td>
<td>0.160</td>
</tr>
</tbody>
</table>

⇒ > 80% vehicles have a SOC > 80%
Results: Impact on the electricity grid

- Long-stop R-AC
- Short-stop R-DC
- Smart AC

Electricity demand of the sample [MWh]

Electricity demand scaled-up to Italy [GWh]

Medium-size vehicle
Fleet share capable to drive only electric

Total demand between 35 and 331 GWh (from 0.1% to 1.2% of the national demand, i.e. 27 TWh)
Results: GIS-based spatial distribution

**Small size** vehicle – Smart-AC recharges

- 7400 km² analysis terrain window
- Circles placed at 5, 10, 15, 20, and 30 km from Modena
- 65% of the events within 15 km from Modena

**Medium size** vehicle – Smart-AC recharges

- Parking events [%]
- Latitude [deg]
- Longitude [deg]
- Dist. From Modena
- 65% of the events within 15 km from Modena
Small size vehicle – Smart-AC energy request integrated over 250 m/edge squared terrain tiles
Medium size vehicle – Smart-AC energy request integrated over 250 m/edge squared terrain tiles
Conclusions

• Large-scale analysis of travel behaviour has been carried out deriving:
  – Fleet share in motion at the same time < 11.5 % (private), <15.2% (commercial);
  – 50% of the sample < 20 trips/week, < 200 km/week. Only 3% > 150 km/day;

• EVs usability results show that 80% of the trips can be driven with a small/medium sized electric vehicle and that a fleet share between 10% and 25% can drive 100% of the trips by small/medium sized EVs, increasing to 50% by accepting to shift < 5 trips/month.

• The impact on the electricity demand derived is rather limited, with no. of recharges between 15 and 30 per month, and 2.3 kWh to 3.8 kWh of energy per recharge, (max. 1.2% of the monthly demand of Italy).

• GIS-based analysis shows how the electric energy demand is distributed over the province area, highlighting how to design/size recharge infrastructure network.