Range of competitiveness of road FEV: mobility of passengers and freight transport analysis, performances and possible solutions

Original

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Session

The development of electric mobility in Italy: plan and government incentives, the most advanced experiences and new trends in supply

Range of competitiveness of road FEV:

mobility of passengers and freight transport analysis, performances and possible solutions

Ambito di competitività dei veicoli elettrici su strada: analisi di mobilità di persone e del trasporto merci, prestazioni e possibili soluzioni.

Torino - I, Thursday - 26th of September 2013, p.m.
eCo-FEV

Eco-FEV EU project working group, Politecnico di Torino
Torino - I, Lingotto, 26th of Sept. 2013
Aims

1. Analysis of typical travels of vehicles (passengers/freight), on the basis of the international mobility beside specific national or local
2. Area of competitiveness of FEV on the base of the analysis of demand
3. Performances and limitations on the supply side: autonomy, batteries, power, performances, consumptions
4. Recharging possibilities most suitable on the bases of the previous items
5. Consequent choices, with examples of di UC (use case) of the EcOFEV
6. Possible technical solutions.
Some figures, at European level (EU White Book on transports of 2001 [COM/2001/0370 def.]) estimated dependence on black oil at the 98%; in the USA it was estimated at 96% in the same period, reduced to 93.2% in 2010 [US Transportation Energy Data Book 2011, Ed30]). The White book on Transport Systems of 2011 reports a figure of 96% in EU.

Demand of motorised mobility is nearly constant the last 2-3 years, but expressed in different ways in the last decades (urban contexts).

The electrification of road transport is considered a key element in EU and worldwide for reducing the near-monopoly of black oil in this field and, consequently, local greenhouse gas (GHG) emissions generated by internal combustion engines, largely used at present for the whole travels.
"17. The challenge is to break the transport system’s dependence on oil without sacrificing its efficiency and compromising mobility."
Primary energy sources include Fossil fuels (Crude oil, Natural gas, Coal, Nuclear sources (Uranium, Plutonium)), and Renewable sources (Wind, Hydroelectric, Sun, Geothermal, Biomass).

Fuels can be primary energy carriers, including Diesel, gasoline, cherosene, Gas, Fuels from synthesis, and Hydrogen.

Internal combustion engines (ICEs) can use road vehicles, locomotives, installations, ships, and jet engines.

Electric power can be generated from Power production plants using Electric motors (Batteries, Fuel cells (electrochemical)).

Other uses include Diesel, gasoline, cherosene, and Fuels from synthesis.

(Source: elaboration from ERTRAC, 2011)
Analysis of typical travels of vehicles (passengers/freight), on the basis of the international mobility beside specific national or local
Starting from different samples, the following studies individuate comparable results:

### AVERAGE DAILY VEHICLE DISTANCE [km]

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>ISFORT</td>
<td>35,1</td>
</tr>
<tr>
<td>PoliTO(1)</td>
<td>34,8</td>
</tr>
<tr>
<td>«5T» (Turin ITS centre)</td>
<td>32,1</td>
</tr>
<tr>
<td>CNIT/MIT 2004(2)</td>
<td>33,8</td>
</tr>
<tr>
<td>PoliMI(3)</td>
<td>38,7</td>
</tr>
</tbody>
</table>

### AVERAGE VEHICLE TRIP LENGHT [km]

<table>
<thead>
<tr>
<th></th>
<th>URBAN</th>
<th>EXTRA URBAN</th>
</tr>
</thead>
<tbody>
<tr>
<td>ISFORT</td>
<td>4,7</td>
<td>25</td>
</tr>
<tr>
<td>PoliTO(1)</td>
<td>6,2</td>
<td>14,4</td>
</tr>
<tr>
<td>5T</td>
<td>4,6</td>
<td>11,9</td>
</tr>
</tbody>
</table>

Sources:

1. POLITECNICO DI TORINO, Dept. DIATI-Transport. Eng., Indagine su mezzi di trasporto e mobilità motorizzata per il personale del Politecnico di Torino, Risultati salienti, 2013
2. MINISTERO DELLE INFRASTRUTTURE E DEI TRASPORTI, Conto nazionale delle infrastrutture e dei trasporti, 2004
Distribution of daily travels (working days)

Average vehicle trip length distribution

Distance range [km]

Part of the sample

Average vehicle trip length distribution

Distance range [km]

Part of the sample
Comparison between Italy and USA trends

After a period of continuous growth of the road transports, a period of stabilisation or inflection of the demand is showed also in the USA

![Graph showing vehicle travel per capita from 1970 to 2010.](image)

Average daily vehicle distances are higher than Italian and generally European ones, on values next to 30 miles (about 48 km)

<table>
<thead>
<tr>
<th>Year</th>
<th>Number of daily vehicle trips (per driver)</th>
<th>Average vehicle trip length (miles)</th>
<th>Daily vehicle miles of travel (per driver)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1990</td>
<td>3.3</td>
<td>8.9</td>
<td>28.5</td>
</tr>
<tr>
<td>1995</td>
<td>3.6</td>
<td>9.1</td>
<td>32.1</td>
</tr>
<tr>
<td>2001</td>
<td>3.4</td>
<td>9.9</td>
<td>32.7</td>
</tr>
<tr>
<td>2009</td>
<td>3.0</td>
<td>9.7</td>
<td>29.0</td>
</tr>
</tbody>
</table>

Source: FRONTIER GROUP and U.S. PIRG EDUCATION FUND, Transportation and the new generation – Why young people are driving less and what it means for transportation policy, 2012

# Freight transport in Italy

## Average Daily Distances [km]

<table>
<thead>
<tr>
<th></th>
<th>Own Account</th>
<th>For Hire</th>
<th>Global</th>
</tr>
</thead>
<tbody>
<tr>
<td>CONFETRA(^{(1)})</td>
<td>48,8</td>
<td>165,1</td>
<td>118,6</td>
</tr>
<tr>
<td>Ministero dell’Ambiente(^{(2)})</td>
<td>36,6</td>
<td>133,2</td>
<td>102,5</td>
</tr>
<tr>
<td>Autostrade per l’Italia(^{(3)})</td>
<td>-</td>
<td>-</td>
<td>100,6</td>
</tr>
</tbody>
</table>

Data from “Autostrade per l’Italia” indicate that almost half of the heavy vehicles (48%) covers a distance less than 50 km

Sources:
(1) CONFETRA, Trasporti interni ed internazionali per titolo di trasporto e classe di percorrenza, 2003
(2) MINISTERO DELL’AMBIENTE E DELLA TUTELA DEL TERRITORIO E DEL MARE, Il trasferimento modale sui grandi assi di scorrimento, 2013
(3) Autostrade per l’Italia, Il traffico sulla rete del gruppo autostrade, valori a consuntivo, 2012
Mobility demand trend in Italy (2000-2012)

The urban mobility has a weight of approx. 60.1% on total trips.
## Motorized mobility in Italy

### Trips distribution for motorized vehicles in URBAN mobility (% values)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Public transport</td>
<td>15,1</td>
<td>13,5</td>
<td>12,9</td>
<td>11,5</td>
</tr>
<tr>
<td>Car</td>
<td>79,7</td>
<td>79,4</td>
<td>80</td>
<td>81</td>
</tr>
<tr>
<td>Motorcycle / moped</td>
<td>5,2</td>
<td>7,1</td>
<td>7</td>
<td>7,6</td>
</tr>
</tbody>
</table>

### Trips distribution for motorized vehicles in EXTRA-URBAN mobility (% values)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Public transport</td>
<td>13,0</td>
<td>14,8</td>
<td>13,9</td>
<td>12,6</td>
</tr>
<tr>
<td>Car</td>
<td>84,7</td>
<td>83,0</td>
<td>83,0</td>
<td>83,9</td>
</tr>
<tr>
<td>Motorcycle / moped</td>
<td>2,2</td>
<td>2,2</td>
<td>3,1</td>
<td>3,4</td>
</tr>
</tbody>
</table>

Source: ISFORT, ANAV, ASSTRA, *Una leva per la ripresa – 10° rapporto sulla mobilità in Italia*, 2013
• Area of competitiveness of FEV on the base of the analysis of demand
• Performances and limitations on the supply side: autonomy, batteries, power, performances, consumptions
• Recharging possibilities most suitable on the bases of the previous items
• Area of competitiveness of FEV on the base of the analysis of demand
• Performances and limitations on the supply side: autonomy, batteries, power, performances, consumptions
• Recharging possibilities most suitable on the bases of the previous items
Full electric cars energy consumption range according to three driving cycles
[elabor. by Politecnico di Torino, Filidoro, 2013]
The calculation does not take into account the limits caused by the batteries' admissible size though. The two types of charging methods would need respectively a 30 kWh and a 60 kWh battery pack. Recalling the Li-ion batteries' characteristics, that would correspond to 200–300 kg and 400–600 kg respectively. Definitely it would not be possible to afford 500kg-heavy batteries in a vehicle with a total mass of 1000 kg. Small to medium electric cars are typically featured by a 20–30 kWh battery pack. As a consequence is possible to notice that the limit on the maximum driving range between charges is not imposed by the charging methods, even if fast charging is not considered, but from the size of the batteries.

<table>
<thead>
<tr>
<th>Curb mass [kg]</th>
<th>Energy consumption [Wh/km]</th>
<th>Slow charging: 220 V, 16 A, maximum power≈3.5 kW</th>
<th>Mode 2 charging: 220 V, 30 A, maximum power≈7kW</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000</td>
<td>150</td>
<td>187</td>
<td>373</td>
</tr>
<tr>
<td>1500</td>
<td>170</td>
<td>165</td>
<td>329</td>
</tr>
<tr>
<td>2000</td>
<td>190</td>
<td>147</td>
<td>295</td>
</tr>
<tr>
<td>2500</td>
<td>210</td>
<td>133</td>
<td>267</td>
</tr>
</tbody>
</table>
Road tests performed by specialized magazines always show real consumptions to be higher than the one obtained through standard driving cycles, particularly NEDC.

There is no direct way of measuring the State Of Charge of a Li-Ion battery indeed. There are indirect ways of estimating it, but each suffers from limitations.

The electric cars designed in recent years show that is affordable to have approx. up to 20% of the curb weight given by batteries.
<table>
<thead>
<tr>
<th>Curb mass [kg]</th>
<th>Energy consumption [Wh/km]</th>
<th>3.5 kW</th>
<th>7 kW</th>
<th>AC three-phase charging: 400 V, 30 A, max. power≈20 kW</th>
<th>DC fast charging: 400 V, 125 A, maximum power≈50kW</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000</td>
<td>150</td>
<td></td>
<td></td>
<td>67</td>
<td>167</td>
</tr>
<tr>
<td>1500</td>
<td>170</td>
<td></td>
<td></td>
<td>59</td>
<td>147</td>
</tr>
<tr>
<td>2000</td>
<td>190</td>
<td></td>
<td></td>
<td>53</td>
<td>132</td>
</tr>
<tr>
<td>2500</td>
<td>210</td>
<td></td>
<td></td>
<td>48</td>
<td>119</td>
</tr>
</tbody>
</table>

Obtainable driving range, **half-hour charging**

[elabor. by Politecnico di Torino, Filidoro, 2013]
Charging time [min] given the charging speed specified in the line below

<table>
<thead>
<tr>
<th>Curb mass [kg]</th>
<th>Energy consumption [Wh/km]</th>
<th>3.5 kW</th>
<th>7 kW</th>
<th>20 kW</th>
<th>50 kW</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000</td>
<td>150</td>
<td>90</td>
<td>45</td>
<td>16</td>
<td>6</td>
</tr>
<tr>
<td>1500</td>
<td>170</td>
<td>102</td>
<td>51</td>
<td>18</td>
<td>7</td>
</tr>
<tr>
<td>2000</td>
<td>190</td>
<td>114</td>
<td>57</td>
<td>20</td>
<td>8</td>
</tr>
<tr>
<td>2500</td>
<td>210</td>
<td>126</td>
<td>63</td>
<td>22</td>
<td>9</td>
</tr>
</tbody>
</table>

Charging time needed to obtain a 35 km driving range
[elabor. by Politecnico di Torino, Filidoro, 2013]
BATTERY RE-CHARGING

A. Conductive charging

B. Inductive contactless charging (contactless implicit)

both of them can be

1. either motionless or in motion (e.g. inductive charging in motion);
2. either driverless or while driving (e.g. inductive charging while driving).
The development of electric mobility in Italy,
B. Dalla Chiara - Politecnico di Torino, Torino, 26.09.2013
Free driving assistance

Charging facilities accessibility monitoring

1. check relevance of event (traffic, weather)

2. event()

3. driver request monitoring()

At [event="driver explicit ad hoc trip request"]

Ad-hoc trip assistance

At [event="autonomy issue" or event="driver explicit drive to charging facility request"]

Ad hoc drive to charging facility assistance

At [event="POI" or event="driver POI explicit request"]

POI notification
**sdCWD charging management**

For private car, eCo-FEV traveller

For private car, not present and relevant steps should be deleted

: Fleet operator driver : FEV Delivery Fleet Operator

**eCo-FEV Backend**

**OBU**

**Charging infrastructure**

---

Loop [Charging infra is operating]

1. get vehicle charge info()
   - ID, charging parameters, time

---

alt [EVSE is ready, FEV is approaching a selected EVSE]

2.1: Approaching instructions(Lane, speed, position)

2.1.1: Implement instructions()

2.1.2: EVSE turn on request()

2.1.2.1: Turn on request()

2.1.2.1.1: Turn on EVSE()

EVSE turn on result

2. Charging instructions(Position, speed)

---

3. Charging start notification()

---

4. EVSE status update to busy(ID, status, time)

---

[During charging]
- Area of competitiveness of FEV on the base of the analysis of demand
- Performances and limitations on the supply side: autonomy, batteries, power, performances, consumptions
- Recharging possibilities most suitable on the bases of the previous items

Freight transport
Energy usage – **Freight transport**
From WELL TO WHEEL (electric drive)

Source: Elaboration by Politecnico di Torino (I) on «Energy efficiency in public transport systems: what is the next stop on the line»? (F. Burkhart), Public Transport International n° 5, Sep-Oct 2012
Full electric light commercial vehicles energy consumption estimation, with some examples

*Payload conditions!*
The development of electric mobility in Italy, B. Dalla Chiara - Politecnico di Torino, Torino, 26.09.2013

Maximum driving range [km] obtainable through the charging speed in the line below

<table>
<thead>
<tr>
<th>Gross Vehicle Weight [kg]</th>
<th>Energy consumption [Wh/km]</th>
<th>3.5 kW charging</th>
<th>7 kW charging</th>
<th>20 kW charging</th>
</tr>
</thead>
<tbody>
<tr>
<td>1300</td>
<td>300</td>
<td>93</td>
<td>187</td>
<td>533</td>
</tr>
<tr>
<td>2000</td>
<td>350</td>
<td>80</td>
<td>160</td>
<td>457</td>
</tr>
<tr>
<td>3500</td>
<td>450</td>
<td>62</td>
<td>124</td>
<td>356</td>
</tr>
<tr>
<td>5000</td>
<td>550</td>
<td>51</td>
<td>102</td>
<td>291</td>
</tr>
</tbody>
</table>

Maximum obtainable driving range, eight-hour charging

The calculation does not take into account again the limits caused by the batteries admissible size
The development of electric mobility in Italy,
B. Dalla Chiara - Politecnico di Torino, Torino, 26.09.2013

<table>
<thead>
<tr>
<th>Gross Vehicle Weight [kg]</th>
<th>Energy consumption [Wh/km]</th>
<th>3.5 kW</th>
<th>7 kW</th>
<th>20 kW</th>
<th>50 kW</th>
</tr>
</thead>
<tbody>
<tr>
<td>1300</td>
<td>300</td>
<td>180</td>
<td>90</td>
<td>32</td>
<td>13</td>
</tr>
<tr>
<td>2000</td>
<td>350</td>
<td>210</td>
<td>105</td>
<td>37</td>
<td>15</td>
</tr>
<tr>
<td>3500</td>
<td>450</td>
<td>270</td>
<td>135</td>
<td>47</td>
<td>19</td>
</tr>
<tr>
<td>5000</td>
<td>550</td>
<td>330</td>
<td>165</td>
<td>58</td>
<td>23</td>
</tr>
</tbody>
</table>

Charging time needed to obtain a 35 km driving range

The calculation does not take into account again the limits caused by the batteries admissible size
The development of electric mobility in Italy
• Area of competitiveness of FEV on the base of the analysis of demand
• Performances and limitations on the supply side: autonomy, batteries, power, performances, consumptions
• Recharging possibilities most suitable on the bases of the previous items
Main features:
• Fixed path
• Known distances
• Known and usually necessary stops
• Scheduling of activities (driver’s rest) at terminals/depots

Though:
• Variability of the mass
• Possible aging effects on batteries
• Transport for a public service (no risks, no nearly-empty SOC allowed)
Factors driving change towards electrification of public transport

Global

Environmental issues and oil depletion

Local

Pressure to improve quality of city life

Technical

Sustainable technology with low running costs
Factors limiting change towards electrification of public transport

- Autonomy range
- Charging infrastructure
- Batteries
- Implementation cost
- Flexibility of the operation

Politecnico di Torino - P. Tomlin, with B. Dalla Chiara and F. Deflorio, 23.07.2013
Electric energy storage element

- Specific energy
- Cycle life
- Purchasing costs
- Opportunity charging
- Sizing of the storage element

Most used:
- Li-iron phosphate
- Li-titanate
- Super capacitors
Electric bus typologies and energy consumption

- **Trolley bus**  
  (Non autonomous)

- **Battery bus**  
  (Autonomous, partially autonomous)

- **Capabus**  
  (Partially autonomous)

- Dimensions
  - Number of passengers
  - Avg. energy consumption

- Energy storage element
  - Autonomy range
  - Charging time
  - Purchasing cost

- Charging devices on board
  - Adaptation to infrastructure
Electric bus typologies and energy consumption

For given traffic and route, energy consumption is mainly influenced by:

- Vehicle mass
- Auxiliary devices

Exemplary consumption value: 1kWh/km
Investigated charging technologies and infrastructure systems

**Conductive**
- Trolley pole
  - Efficiency >92%
  - High power transfer
- Catenaries, along route or occasional
- Top up at terminus
- Proterra
  - Flash top up at bus stop
- TOSA

**Inductive**
- Linea Star
  - Efficiency <83%
  - Medium power
  - Aesthetic
- WPT at terminus
- Static WPT at bus stop
- Primove
  - In-motion WPT along route
- Olev
Linea Star study case: example
[source: some data were provided by GTT, Spring-Summer 2013]

Current bus characteristics:
- 7.48m, 34 passengers
- 8750-11500 kg
- Pb-gel batteries, 60.4 kWh, 1790 kg
- Three phase asynchronous motor
  (max 120kW, 65kW)

Route:
- Turin city center, 6km
- Total of 120km/day

Inductive charging at terminus:
- Efficiency 70%
- Power transfer ≤40kW
- 10-15 minutes
Linea Star study case - current status

<table>
<thead>
<tr>
<th>Pb-gel batteries</th>
<th>Data given by GTT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full load energy consumption</td>
<td>1.25 kWh/km</td>
</tr>
<tr>
<td>Weight effect on energy consumption</td>
<td>0.094 kWh/km*ton</td>
</tr>
</tbody>
</table>

Verification of energy consumption, Pb-gel

Cycle for verification: 300 m

Speed [km/h] vs Time [sec]

- Pb-gel energy consumption, on cycle
- Pb-gel, energy consumption, Gtt data

minibus loading
minibus weight [t]
Linea Star study case - current state

Energy consumption and range autonomy, Pb-gel

<table>
<thead>
<tr>
<th>Minibus load %</th>
<th>Energy consumption [kWh/km]</th>
<th>Autonomy range [km]</th>
</tr>
</thead>
<tbody>
<tr>
<td>40% loading</td>
<td>1.07</td>
<td>49</td>
</tr>
<tr>
<td>60%</td>
<td>1.13</td>
<td>46</td>
</tr>
</tbody>
</table>

40% loading
- 14 passengers
- 9.56 ton
- 1.07 kWh/km
- 49 km

60%
- 20 passengers
- 10.2 ton
- 1.13 kWh/km
- 46 km
Linea Star study case - current state

- Pb-gel useful SOC: 40-90 %

- 6km route
- 20 journeys
- 19 stops
Linea Star study case - Li-iron phosphate versus Pb-gel batteries

- Weight reduction (778 kg)
- Improvements in regenerative braking

-30% energy consumption

Energy consumption, range autonomy and data verification, Pb-gel versus Li-iron phosphate

Politecnico di Torino - P. Tomlin, with B. Dalla Chiara and F. Deflorio, 23.07.2013
Linea Star study case - Li-iron phosphate versus Pb-gel batteries

Lead-gel vs Li-iron minibus operation for 120 km

- Lead-gel (9.56 ton, 1.07 kWh/km): 20 journeys of 6km each with 19 stops of 11’ for inductive charging

- Li-iron (8.78 ton, 0.75 kWh/km): 10 journeys of 12km each with 9 stops of 5’ for inductive charging

Politecnico di Torino - P. Tomlin, with B. Dalla Chiara and F. Deflorio, 23.07.2013
The development of electric mobility in Italy

B. Dalla Chiara
Politecnico di Torino, Torino, 26.09.2013
Conclusions: FEV

• A market compliant with urban motorised personal mobility and other specific cases (freight distribution, < 5 t – GVW; Public Transport)

• Conditioned by use, with preferences for known paths: actual autonomy and foreseeable SOC, recharging organisation and scheduling (e.g. PT)

• Inductive charging can be a good solution, especially in some conditions

• EV conditioned by flexible use → PHEV

• Heavy masses and long distances → traditional and alternative fuels
Contributions by:
Francesco DEFLORIO, Luca CASTELLO , Ivano PINNA
Paola TOMLIN, Ivan FILIDORO
Bruno DALLA CHIARA (resp.), associate professor, ph.d. eng.

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Dalla Chiara B., Range of competitiveness of road FEV: mobility of passengers and freight transport analysis, performances and possible solutions, Session “The development of electric mobility in Italy: plan and government incentives, the most advanced experiences and new trends in supply“, Green Cars Forum, Lingotto - Torino (I), Politecnico di Torino - Transport Engineering working group, 26.09.2013