Does Electric Vehicle Introduction in the Car Fleet Improve the Air Quality?

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May 9, 2013
Among the main pollutant sources in urban areas the traffic can be considered one of the more dangerous. Emissions from vehicles contribute to the photochemical pollution involving ozone and nitrogen oxides. New technologies allow reducing the NOx emission thanks to the electric engines. For this reason, it is very important to evaluate the degree of pollution reduction related to hypothetical scenarios, which account for the introduction of the electric vehicle in the car fleet.
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We need to estimate the plume secondary pollutants like \( \text{NO}_2 \) or other reactive pollutants for regulatory purposes. Estimating short term non-equilibrium concentrations in a plume with chemical reactions is a critical aspect.

The Lagrangian particle model is particularly suitable to simulate the dispersion at the small scale. One critical point: how to consider the segregation in real atmosphere?
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LSM limits

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- Theoretical limit!
An hybrid model

The Eulerian scheme is included inside the Lagrangian model as follows:

**Lagrangian Model (Thomson, 1987)**
- Particles emission
- Lagrangian particles displacement

**Eulerian scheme (Alessandrini & Ferrero, 2009)**
- Concentration computation on a 3D grid
- Chemical reactions on the same grid
- New particles mass of each species computation
We developed a model able to estimate a secondary pollutant like $NO_2$ due to the oxidation reaction (the segregation effect is considered):

$$NO + O_3 \rightarrow NO_2 + O_2$$

The model considers the photolysis of $NO_2$ due to solar radiation:

$$NO_2 + O_2 + h\nu \rightarrow NO + O_3$$
Chemical reactions (II)

For each cell we have:

\[
< C_{NO} > = < C_{NO}^* > - k \Delta t < C_{NO}^* C_{O3}^* > + j < C_{NO_2}^* >
\]

where \( C^* \) are the concentrations after the turbulent displacement, \( k \) the reaction rate and \( j \) the photolysis constant and

\[
< C_{NO}^* C_{O3}^* > = < C_{NO}^* > < C_{O3}^* > + < c_{NO}^{'} c_{O3}^{'} >
\]

(\( c' \Rightarrow \) fluctuations)

being \( < c_{NO}^{'} c_{O3}^{'} > \) unknown we look for a parameterization.
Segregation parameterization

Based on the Brown and Bilger (1986) wind tunnel data, we found:

\[
\alpha = \frac{< c'_{NO} c'_{O3} >}{< C_{NO} > < C_{O3} >} = -0.71 e^{-0.106 \frac{x}{N_D x_s}}
\]

where \(x\) is the downwind distance, \(N_D\) the Damkhöler number and \(x_s\) the stechiometric distance

- \(x_s\) is calculated for a line source
- Alessandrini et al, IJEP, 2012 (H14-188), *Evaluation of the segregation effect in the dispersion from a urban highway*, shown that the segregation effect may be not negligibile
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References:

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- \( C_{\text{def}} \) is carried by the particles of the plume

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- new scalar $C_{\text{deficit}} = C_{\text{background}} - C$
- $C_{\text{def}}$ is carried by the particles of the plume
- Concentration $C$ in the plume is calculated as the difference between $C_{\text{background}}$ and $C_{\text{deficit}}$

During the period 15 December 2010-25 January 2011 were collected Hourly average concentrations of NO, NO₂, and O₃. Meteorological measurements of wind speed and direction and solar radiation were also performed. The air quality measurements were performed within the area where is located the headquarters of RSE at about 400 m from the east highway of Milan. Lambro and Limito quality stations concentration measurements, carried out by ARPA (Regional Environment Protection Agency) Lombardia, were taken into consideration. They are respectively located at about 600 m and 5000 m from the highway.
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Emission trend from the highway

The traffic flows for the period, required for estimating the emission, were determined from movies recorded by a webcam.

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- Present scenario (NEV), a car fleet without electric vehicle.
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- Future scenario (EV) in which an introduction of 25% of electric vehicle in the light vehicle fleet
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**Figure**: Emission trend ($\mu g \ h^{-1} \ m^{-1}$)

- Present scenario (NEV), a car fleet without electric vehicle
- Future scenario (EV) in which an introduction of 25% of electric vehicle in the light vehicle fleet
- This brought an emission reduction to about 8%, 10% and 8% for $NO$, $NO_2$ e $NO_x$ respectively
Meteorological input

The meteorological input to the dispersion model was provided by RAMS60. Initial and boundary conditions from large-scale analysis of the European Centrum for Medium range Weather Forecast (ECMWF). Furthermore the local measurements were assimilated into the model.
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3. Furthermore the local measurements were assimilated into the model.
4. Turbulence model, Mellor and Yamada 2.5
NO concentration differences between NEV and EV scenarios at the Lambro (PL) and RSE stations

Figure: top: absolute difference, bottom: relative difference
$NO_2$ concentration differences between NEV and EV scenarios at the Lambro (PL) and RSE stations

*Figure*: top: absolute difference, bottom: relative difference
Quantifying the pollution reduction

NO: except for a few episodes the differences do not exceed the value of about 2 \( \mu g/\text{m}^3 \) and the relative difference is below the 2%.

NO\(_2\): differences are small, generally below 0.5 \( \mu g/\text{m}^3 \) and the 1% for the relative one.

High background concentrations make the additional contribution of the highway evident only in a few situations, when the meteorological conditions are favourable for the dispersion from the highway to prevail respect to other diffuse sources.
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Statistical analysis of the difference between the two scenarios

<table>
<thead>
<tr>
<th></th>
<th>NOX</th>
<th>NO2</th>
<th>NO</th>
</tr>
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<tbody>
<tr>
<td>NMSE (RSE)</td>
<td>0.017</td>
<td>0.017</td>
<td>0.018</td>
</tr>
<tr>
<td>NMSE (PL)</td>
<td>0.022</td>
<td>0.023</td>
<td>0.022</td>
</tr>
<tr>
<td>FB (RSE)</td>
<td>-0.022</td>
<td>-0.022</td>
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The difference between the two scenarios are very small, even including the episodes which show peaks in the difference trend, and comparable for the two stations.
Conclusions

1. The Lagrangian Stochastic Chemical/Dispersion Model
   - Background concentrations are simulated as "deficit"
   - Segregation is parameterized

2. The effect of the EV introduction is limited to a mean concentration decrease of less than 1% for $NO_2$, and of about 2% for $NO$ (400-600 m from the highway)

3. To achieve further improvements on air quality, may be not sufficient to limit the emissions of light transport vehicles, but it is necessary to reduce also emissions from commercial transport