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Modeling the effects of a speed limit reduction on traffic-related elemental carbon (EC) concentrations and population exposure to EC

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ABSTRACT

Despite the scarce effect of speed limit reduction measures on total mass PM_{10} and $PM_{2.5}$ concentrations, it is shown that the effect on the probably more hazardous component elemental carbon (EC) is more important which means that, from the viewpoint of health benefit, speed reductions during smog episodes may well be justified. Especially in the very dense highway network in Flanders with a 60% share of diesel cars (the highest in Europe) a speed limit reduction from 120 to 90 km/h during winter smog episodes on selected sections of Flemish highways leads to a significant decrease of the EC concentrations near those highways. Key findings are that the decrease in EC depends on the distance from the highways. In the direct vicinity of the highways, a decrease compared to the base-line scenario where no speed limit changes were implemented of up to 30% of the EC concentrations is modeled. Within a distance of 1500 m of the concerned highway sections there is an average decrease in EC of 0.18 $\mu g\,m^{-3}$ affecting about 1 million people living in these areas. When the speed limit reduction measure is in force, the EC exposure of about 300,000 people decreases by at least 5% and 7500 people experience a decrease of 15% or more.

1. Introduction

The European Commission, in its strategy to protect the health of the European citizens, introduced the air quality directive 2008/50/EC with limit values for particulate matter (PM_{10} and $PM_{2.5}$). The daily limit value to protect the population against the short-term impact of particulate matter (PM_{10}) is 50 $\mu g\,m^{-3}$, not to be exceeded more than 35 times in a calendar year. According to Article 23 of the directive 2008/50/EC, EU member states have to establish action plans specifying which type of actions are taken in case limit values are likely to be exceeded, in order to diminish the risk and/or to limit the duration of the exceedances. Within this context the Flemish Government decided to introduce speed reducing measures (maximum 90 $km\,h^{-1}$ instead of 120 $km\,h^{-1}$ on certain sections of highways) during PM_{10} smog episodes. The sections of highways (see Fig. 1) on which the measure are taken consist of the major highways in the areas where they cross densely populated regions. Between May 2006 and December 2009, the measure entered into force during five smog episodes.

Although the measure was taken in relation to the forecasted PM_{10} concentrations, there were strong arguments to assess the influence of the measure on elemental carbon (EC) concentrations.

First of all, it was found that the effect of the speed limit reduction measures on the total mass concentrations of PM_{10} and $PM_{2.5}$ was small (Janssen et al., 2010), with maximum decreases up to 5% for PM_{10} and up to 8% for $PM_{2.5}$ close to the highways. The decrease in total mass PM_{10} and $PM_{2.5}$ becomes quickly smaller, once the distance to the affected highways increases. Averaged over Flanders the decrease in PM_{10} and $PM_{2.5}$ amounts respectively to 0.12 and 0.22%. This concurs with the findings of Gonçalves et al. (2008) who discussed a reduction of the speed limit to 80 $km\,h^{-1}$ during a high ozone pollution period over the Barcelona Metropolitan area. The effects on the city air pollution were found to be relatively small with decreases up to 0.8% for daily averaged NO_2 and 0.2% for both PM_{10} and $PM_{2.5}$ and increases of 0.1% for the 8-h averaged ozone, averaged over the Barcelona area. The changes close to the motorways have been found to be more significant. Furthermore Dijkema et al. (2008) discussed the effect of a speed limit reduction from 100 to 80 $km\,h^{-1}$ on an Amsterdam motorway

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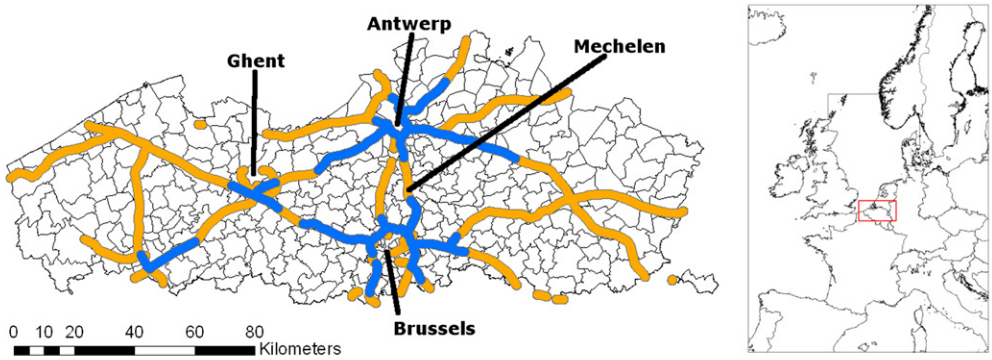

Fig. 1. In blue: areas within 1500 m of highway sections where speed limit reductions from 120 to 90 km h^{-1} are imposed during smog episodes (scenario 1, 1,026,071 inhabitants concerned). In orange: areas within 1500 m of highway sections where no speed limit reductions are imposed during smog episodes (scenario 2 = orange and blue, 1,760,445 inhabitants concerned).

and showed significant but small decreases of the PM_{10} (up to 7.4% along roadside) and the PM_1 (up to 2.8% along roadside) levels in the close vicinity of the affected highway.

EC however, is only a small fraction of the total particulate matter mass. During a chemical composition measurement campaign, it was found that the mean EC contribution to total mass PM_{10} in Flanders was only 4% (Vercauteren et al., 2011). This campaign was carried out by measuring every 6 days, at 6 different stations (industrial, background, suburb and city areas), the chemical composition of the PM_{10}, from September 2006 until September 2007. However, the ratio EC/PM_{10} for traffic *emissions* is much higher. Although reductions in traffic emissions due to the speed limit do not have a significant impact on the total mass concentrations of PM_{10} and $PM_{2.5}$, they could thus have a more significant impact on the EC concentrations, particularly near the highways where the speed limit is introduced.

Secondly, there is a growing concern about the impact of EC on health. In particular, it is relevant to mention results from studies assessing the relation between the total traffic-related air pollution and health effects. Peters et al. (2001) pointed out that transient exposure to traffic may increase the risk of a myocardial infarction in susceptible persons. A correlation was found (Mills et al., 2007) between a brief inhalation of diesel exhaust and the onset of myocardial infarction one hour afterwards. This points to the ischemic and thrombotic mechanisms, which explain, in part, the general link between combustion-derived air pollution and adverse cardiovascular effects. Local exposure to traffic on a highway had adverse effects on children's lung development which could result in important deficits in attained lung functions in later life (Gauderman et al., 2007). In this study, children were followed up to eight years with a yearly lung-function measurement. Children who lived within 500 m of a highway had substantial deficits in 8-year growth of forced expiratory volume (FEV1) compared with children who lived at least 1500 m from a highway. The impact of traffic-related pollutants on allergic diseases in children was studied in a cohort study (Morgenstern et al., 2008). Strong positive associations were found between the distance to the nearest main road and asthmatic bronchitis, hay fever, eczema and sensitization. A distant-dependent relationship could be identified with the highest impact for children living in less than 50 m from a busy street. Morgenstern et al. (2008) found strong evidence for increased risk of atopic diseases and allergic sensitization when children are exposed to ambient particulate matter. Furthermore, McCreanor et al. (2007) showed that a 2-h exposure to traffic of a busy London street decreases significantly lung capacity and increases biomarkers for neutrophilic inflammation and airway acidification. Finally, Hoek et al. (2002) showed that living close to a major road increases significantly the cardiopulmonary mortality whereas non-cardiopulmonary, non-lung cancer deaths seem to be unrelated to the traffic air pollution, nor with background concentrations. It has not yet been possible to directly connect EC to health problems. However, EC is a good proxy for exposure to traffic and thus we can estimate that a decrease in EC would induce a decrease in traffic-related health effects.

Another purpose for assessing EC is that it is known to be a good measure for diesel exhaust. Particles derived from diesel cars are more abundant in EC (Geller et al., 2005). The studied area, Flanders, is characterized by a high population density and the continuously rising share of diesel cars is the highest in Europe (see Fig. 2).

The objective of this study is to assess the impact of a speed limit reduction on the traffic-related air pollutant EC. Until now, few studies have done this. Dijkema et al. (2008) studied, based on measurements, black smoke (BS), which is closely related to EC, PM_{10} and PM_1 concentrations. No significant difference was found in the annual mean BS concentrations between two monitoring stations, one next to a highway where a permanent speed limit reduction was introduced and a second one near to a highway without any speed limit reductions. In both stations, the BS concentrations decreased, compared to the situation of the previous year, in which on none of the highways adjacent to the stations speed limit reductions were introduced. This study was thus based on local air quality measurements over a period of two years. Recently, Patel et al. (2009) studied the influence of diesel traffic proximity and intensity on ambient concentrations of $PM_{2.5}$ and black carbon (BC) at New York City High Schools. It was suggested that in urban areas with higher levels of diesel traffic, which is also the case for the area examined in this study, black carbon is a more specific indicator to represent exposure to air pollution of the population.

Due to a lack of EC monitoring sites next to highways and to avoid the impact of the meteorological circumstances, model calculations are used to study the differences in EC concentrations, as a result of a speed limit reduction. The difference in EC concentrations is calculated by comparing the modeled concentrations using different traffic emission scenarios (with and without the speed limit). By taking into account the difference of the EC concentrations, possible errors that exist on the absolute EC concentrations are eliminated. Two different speed limit reduction measures are modeled and assessed: in a first scenario the existing measure in Flanders, namely a speed limit reduction from 120 km h^{-1} to 90 km h^{-1} that is introduced during smog episodes on more or less 300 km of highways in densely populated areas (scenario 1) and a second scenario with a speed limit reduction