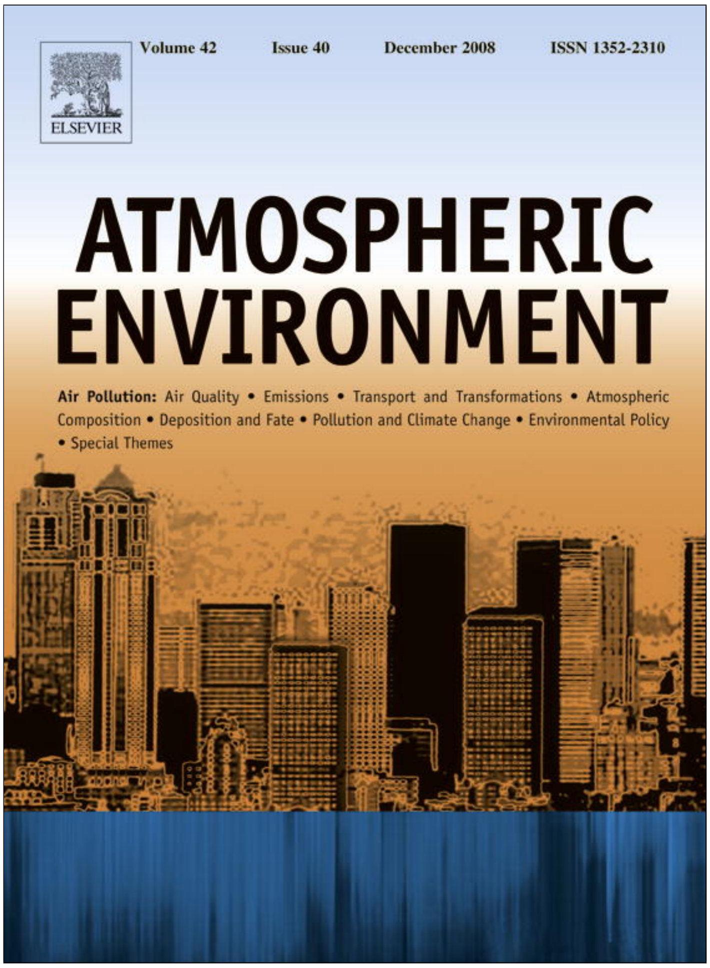
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Air quality effects of an urban highway speed limit reduction

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ABSTRACT

A speed limit intervention on part of the Amsterdam ring highway, adjoined with apartment buildings, was implemented.

The objective of this study was to assess whether, and to what extent, a lowering of the maximum speed limit from 100 to 80 kph had reduced traffic related air pollution in the direct vicinity of a highway. A monitoring station of the Amsterdam Air Quality Monitoring Network is situated adjacent to the intervened road section. Daily mean concentrations (PM_{10}, PM_1, Black Smoke and NO_x) in the first year since the intervention were compared with measured concentrations in the prior year. The intervention effect was adjusted for daily traffic flow, congestion and downwind exposure. The concentration changes were compared with those observed at a section of the same ring highway where the speed limit had not been reduced.

Since the intervention, the adjusted traffic contribution to PM_{10} concentrations has decreased by 2.20 $\mu g\,m^{-3}$ (95%-CI: 1.43–2.98), PM_1 0.42 $\mu g\,m^{-3}$ (95%-CI: 0.01–0.82) and Black Smoke 3.57 $\mu g\,m^{-3}$ (95%-CI: 1.50–5.65). At the not intervened highway section the adjusted traffic contribution to PM_{10} and Black Smoke concentrations has also decreased by 0.97 and 2.43 $\mu g\,m^{-3}$ respectively. However, decreases were significantly greater for PM_{10} and PM_1 at the intervention site. In conclusion, this study demonstrates a significant reduction of PM_{10} and PM_1 as a result of reducing the speed limit at an urban ring highway.

1. Introduction

Air pollution and associated health effects have been the subject of extensive research for many years (Brunekreef and Holgate, 2002; Pope and Dockery, 2006). More recently, health effects of traffic related air pollution have gained importance. Living near busy roads or attending school there has been shown to be associated with a reduction in lung-function growth (Gauderman et al., 2007) and an increase in chronic respiratory symptoms in children (Gehring et al., 2002; Janssen et al., 2003; Van Vliet et al., 1997). Other studies show that adults living near busy roads suffer more from respiratory symptoms (Bayer-Oglesby et al., 2006) and heart disease (Hoek et al., 2002; Hoffmann et al., 2006; Maheswaran and Elliott, 2003), compared to adults living further away from busy roads.

Abbreviations: AAQMN, Amsterdam Air Quality Monitoring Network; AVH, additional vehicle hours, the total extra hours needed to complete the specified road stretch, for all vehicles passing, in comparison to a usual average speed of 70-kph; BS, Black Smoke; kph, kilometers per hour; NO_x, nitrogen oxides; PM_1, particulate matter with an aerodynamic diameter less than 1 µm; $PM_{2.5}$, particulate matter with an aerodynamic diameter less than 2.5 µm; PM_{10}, particulate matter with an aerodynamic diameter less than 10 µm.

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Because of the great public-health impact, Künzli et al. (2000) concluded that traffic related air pollution should be a key target in public-health in Europe.

To reduce general exposure to air pollution, the European Union has set air quality standards. In Amsterdam (730,000 inhabitants), air quality standards for PM_{10} and NO_2 are exceeded on many locations, especially along busy roads. All over Europe, many policy measures are taken to reduce traffic emission and thereby improve air quality. The effectiveness of such measures, however, has rarely been quantified. As stated by Int Panis et al. (2006), it is hardly ever feasible to directly measure the effect of a policy measure on vehicle emission and air pollution concentrations. To study these effects, emission- and dispersion modelling are often combined. In February 2003, a congestion charge was implemented in central London. Based on detailed traffic data and a local road traffic emissions model, an estimated emission reduction of 12% NO_x and 11.9% PM_{10} was achieved within the charging zone (Beevers and Carslaw, 2005). Using more extensive air pollution concentration modelling and exposure–response relationships from literature, Tonne et al. (2008) modelled the resulting life expectancy impact of the London congestion charge. A modest benefit was found.

In the Netherlands, dispersion models (Eerens et al., 1993) suggest that traffic related emissions at highways being substantially affected by the maximum driving speed. More strict speed limits on highways with many people living in close proximity are set to reduce exposure and related health effects. However, speed limitation measures taken elsewhere raised concern about air pollution concentrations which may increase due to delay and congestion (Coelho et al., 2005).

Starting November 2005 the Dutch National Department of Transport limited the maximum speed from 100 to 80 km per hour (62–50 miles per hour) on some specific stretches of urban highway. All over the country, the maximum speed for heavy duty vehicles already was 80 kph.

The Amsterdam ring highway (A10) is one of the busiest highways in the Netherlands. It typically consists of six lanes, three in both directions. During rush hours, congestion appears on every working day. Along the western section of the ring highway, apartment buildings are located at less than 20 m on either side of the road (<20 m), creating a situation resembling a street canyon. This road section, which covers 6 km (3.7 miles), is where the 80-kph speed measure was implemented (Fig. 1). Drivers are informed of this speed limit by many road signs, no additional devices causing traffic interruptions, such as speed control traffic signals, are used. This speed limit, however, is automatically adhered to through monitoring of vehicle specific trajectory driving speed and stringent fines. Approximately 40,500 people live within close proximity that is within 500 m of the road section where the intervention was taken.

The Dutch National Transport Research Center conducted calculations prior to taking the policy measure. Estimated emission reduction on the Amsterdam highway was 14% for PM_{10} and 10–15% for NO_2. According to the Dutch National Department of Transport, this would lead to a concentration decrease of 0.5–1% for PM_{10} and 2–4% for NO_2 adjacent to the road (Ministerie van Verkeer en Waterstaat, 2004).

The objective of this study is to assess whether, and to what extent, the policy to lower the maximum speed limit from 100 to 80 kph on part of the Amsterdam ring highway has reduced measured traffic related air pollution in the direct vicinity of the highway.

2. Methods

2.1. Traffic

About 92,000 vehicles day^{-1} pass the western section of the Amsterdam ring highway (current speed limit: 80 kph), while about 140,000 vehicles pass the southern section (current speed limit: 100 kph, no intervention). Road

	Distance to nearest highway	PM_{10} µg/m^3 TEOM	PM_1 µg/m^3 TEOM	BS µg/m^3 SX-200	NO_x ppb EcoPhysics
A10W	6.7 m	■	■	■	■
A10S	8.0 m	■	■	■	■
BN	1.4 km	-	-	■	■
BC	1.7 km	■	■	■	■
BW	1.7 km	■	-	-	-

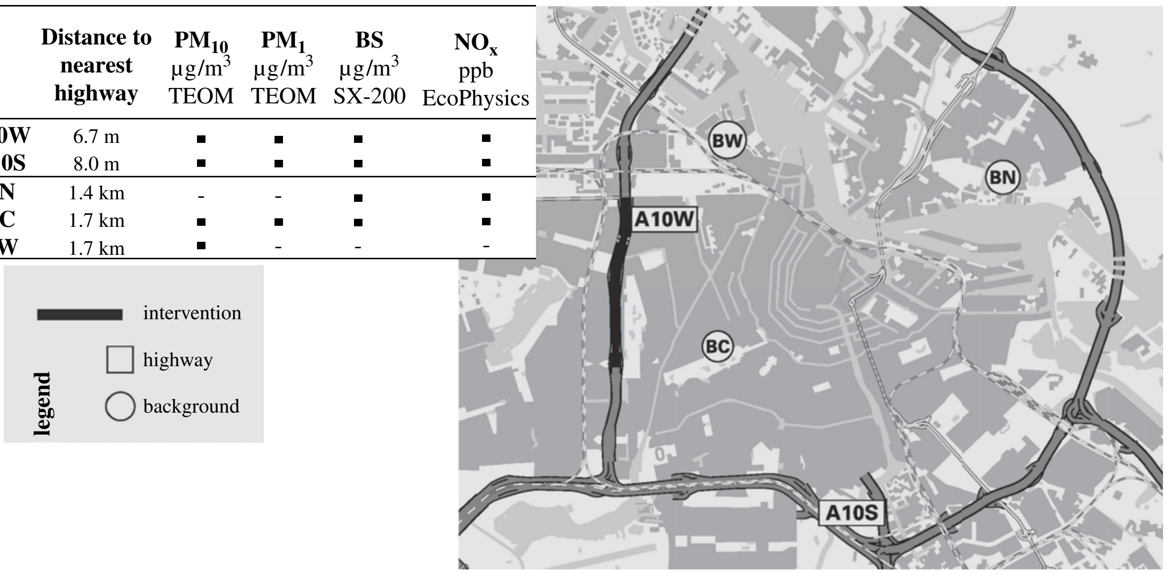

Fig. 1. Location of the speed limit intervention road section, the monitoring stations in Amsterdam Air Quality Monitoring Network, and monitored components.

management and continuous traffic monitoring are performed by the Dutch National Department of Public Works. Daily mean traffic flow, congestion parameters, as well as information on road closure and road works were obtained from this department.

Traffic flow measurements included all vehicles. Unfortunately, no data on heavy duty vehicles or other vehicle types were available. Daily mean intensities were available for analysis. As a parameter for traffic congestion, additional vehicle hours (AVH) were used. This parameter, commonly used by the Dutch National Department of Public Works, is the total of extra hours needed to complete the specified road stretch, for all vehicles passing, relative to the time it would take at a normalised driving speed. For this specific road section, the National Department of Public Works decided on a normalised driving speed of 70-kph. The provided AVH was calculated from minute to minute data on driving speed and traffic flow per lane. A daily total of AVH, referred to as traffic congestion, was used for analysis.

2.2. Air pollution

Within the Amsterdam Air Quality Monitoring Network, particulate matter (PM_{10}, $PM_{2.5}$ or PM_1), nitrogen oxides (NO_x) and a proxy of soot (Black Smoke, BS) are continuously monitored at urban background and roadside locations in the Amsterdam city area. One of the roadside stations is located along the western section of the ring highway (Fig. 1). This is where the speed limit intervention measure was taken. The inlets of this monitoring station are located at 2.7 m elevation at 6.7 m East of the edge of the highway. The fixed site monitoring station was not specially configured to study the speed limit intervention.

Another roadside station is located at the southern part of the ring highway. The southern station has a slightly different positioning; the inlets of this monitoring station are located at 2.7 m elevation at 8.0 m north of the edge of the highway. Fig. 2 shows pictures of both monitoring stations. There are no buildings adjoining this road section. Furthermore, the monitoring network has three background stations (west, north and central), located at least 60 m from major roads. For most components, data on urban background concentrations are available from at least two urban background monitoring stations; PM_1 is available from one station only. Fig. 1 shows locations of the air quality monitoring stations and monitored components.

Daily mean concentrations ($\mu g\,m^{-3}$) of PM_{10} and PM_1 were derived from continuous monitoring using tapered element oscillating microbalance (TEOM) as described in detail by Roemer and van Wijnen (2001). The reported concentrations are measured concentrations, so no additional correction for volatile components (Thorpe et al., 2007), obligatory for legal purposes, was done. $PM_{2.5}$ was not available at the western roadside station. BS concentrations in $\mu g\,m^{-3}$ were obtained using SX-200 continuous monitors (Roemer and van Wijnen, 2001).

Nitrogen oxides are measured using chemiluminescence monitors (EcoPhysics, Switzerland, type CLD 700AL). For NO_x daily mean concentrations in ppb were available for analysis.

Fig. 2. Monitoring stations A10W and A10S.

The Amsterdam Air Quality Monitoring Network complies with the accreditation criteria ISO/IEC 17025:2005 for test laboratories. Also, PM_{10} monitoring is in accordance with A 3580.9.8/NEN EN 1234 1, NO_x with NEN-ISO 7996. For PM_1 and BS no accreditation is available. PM_1, however, is measured using a monitor identical to that for PM_{10}, only using a different inlet. BS monitoring and quality procedures are performed according to the manufacturer's recommendations (ETL, Hereford, England).

2.3. Meteorology and long range air pollution

Daily air pollution concentrations are also determined by factors other than local sources, such as meteorology and long range air pollution. In several studies, the contribution of traffic was studied by subtracting background concentrations (Harrison et al., 2004; Thorpe et al., 2007). In this study, Spearman's correlations between concentrations measured at three background sites in the same urban area (Fig. 1) were high (PM_{10} 0.91, BS 0.75, NO_x 0.84), as were correlations between mean background and roadside concentrations (PM_{10} 0.86, PM_1 0.91, BS 0.64, NO_x 0.71). These coefficients reflect that meteorology (i.e. rainy days, warm and dry summer months or periods with specific predominant wind directions) and other long range atmospheric processes affect the concentrations over the whole city in a similar way. For both roadside monitoring

Table 1
Roadside and background concentrations[a] of air pollutants in Amsterdam, one year prior to the intervention[b] (November 2004 to November 2005).

		Roadside			Traffic contribution[c]		
		N	Mean	Range (min–max)	*N*	Mean	Range (min–max)
PM_{10} ($\mu g\,m^{-3}$)	Highway West	331	29.72	(12.60–85.50)	331	8.18	(−2.40–23.95)
	Highway South	330	25.20	(6.60–80.40)	330	3.67	(−9.60–13.20)
	Background (mean)	334	21.52	(9.35–82.45)			
PM_1 ($\mu g\,m^{-3}$)	Highway West	332	14.78	(4.50–61.40)	322	3.72	(−11.80–12.10)
	Highway South	320	13.31	(4.60–58.40)	310	2.28	(−16.20–9.90)
	Background (mean)	324	11.03	(2.80–54.90)			
Black Smoke ($\mu g\,m^{-3}$)	Highway West	288	23.83	(0.43–104.06)	287	17.36	(−8.82–76.77)
	Highway South	330	20.12	(0.33–93.24)	329	13.66	(−1.82–54.75)
	Background (mean)	333	6.49	(0.43–41.49)			
NO_x (ppb)	Highway West	328	90.00	(8.80–334.40)	328	63.96	(2.80–157.00)
	Highway South	302	68.65	(8.00–322.40)	302	42.36	(−1.80–132.00)
	Background (mean)	334	26.10	(5.60–202.80)			

[a] August data were excluded.
[b] Intervention: maximum driving speed reduced from 100 to 80 kph.
[c] Traffic contribution: concentration at roadside minus daily mean background.

stations, daily 'traffic contribution' concentrations were derived by subtracting same day mean background concentrations.

As the air quality monitoring stations are located next to the ring highway, wind direction may affect the measured concentrations in addition to the meteorological conditions corrected for using 'traffic contribution' concentrations. When the monitoring station is located downwind from the road, traffic emission is directed towards the monitoring station. When the wind is coming from the opposite direction, the opposite might occur. Wind direction data were not available for the exact monitoring locations. Instead, daily wind direction data from measuring site Schiphol (Amsterdam Airport) were obtained from the Royal Netherlands Meteorological Institute. If the daily mean predominant wind direction was within 180° from parallel to the road (in both directions) to directly towards the monitoring station that day was considered downwind.

2.4. Analysis

In November 2005 the maximum speed for the western part of the Amsterdam ring highway was limited from 100 to 80 kph. In this study, daily mean concentrations in the year after the intervention were compared to daily mean concentrations in the year before. Due to holidays and maintenance works air pollution and traffic are generally untypical in August, and therefore August data were excluded from all analyses.

All statistical analysis was done using SAS 9.1.3 (SAS Institute Inc., Cary, NC, USA). The analysis consists of three phases:

- First, the effect of the intervention on the roadside concentrations was studied using linear regression.
- Secondly, the effect on 'traffic contribution' was studied using linear regression.

Table 2
Roadside and background concentrations[a] of air pollutants in Amsterdam, one year post-intervention[b] (November 2005 to November 2006).

		Roadside			Traffic contribution[c]		
		N	Mean	Range (min–max)	*N*	Mean	Range (min–max)
PM_{10} ($\mu g\,m^{-3}$)	Highway West	327	27.55	(11.60–59.20)	327	5.75	(−6.00–24.30)
	Highway South	316	24.21	(9.20–54.30)	316	2.63	(−25.55–13.60)
	Background (mean)	334	21.73	(8.35–53.45)			
PM_1 ($\mu g\,m^{-3}$)	Highway West	320	14.23	(4.30–39.90)	313	3.14	(−1.70–14.40)
	Highway South	232	15.23	(4.70–57.00)	228	4.22	(−2.00–34.80)
	Background (mean)	327	11.12	(3.70–38.70)			
Black Smoke ($\mu g\,m^{-3}$)	Highway West	312	19.41	(0.89–92.51)	311	13.46	(−13.04–75.10)
	Highway South	316	15.82	(0.63–53.93)	315	9.99	(−6.22–34.80)
	Background (mean)	332	5.85	(0.32–30.50)			
NO_x (ppb)	Highway West	328	83.99	(8.80–218.40)	328	59.70	(−2.40–162.80)
	Highway South	314	61.60	(4.80–179.20)	314	37.09	(−8.00–103.60)
	Background (mean)	334	24.13	(5.60–100.00)			

[a] August data were excluded.
[b] Intervention: maximum driving speed reduced from 100 to 80 kph.
[c] Traffic contribution: concentration at roadside minus daily mean background.

Table 3
Speed limit intervention effects on concentrations of PM_{10} ($\mu g\ m^{-3}$), PM_1 ($\mu g\ m^{-3}$), Black Smoke ($\mu g\ m^{-3}$) and NO_x (ppb) measured at roadside.

	A10W: with intervention[a]						A10S: without intervention[a]					
	Roadside		Crude		Adjusted[c]		Roadside		Crude		Adjusted[c]	
			Traffic contribution[b]		Traffic contribution[b]				Traffic contribution[b]		Traffic contribution[b]	
	Change	95%-CI	Change	95%-CI	Change	95%-CI	Change	95%-CI	Change	95%-CI	Change	95%-CI
PM_{10}	−2.30*	(−4.00 to −0.59)	−2.34*	(−3.13 to −1.55)	−2.20*	(−2.98 to −1.43)	−1.36	(−2.88–0.17)	−0.63	(−1.41–0.16)	−0.97*	(−1.68 to −0.25)
PM_1	−0.47	(−1.56 – 0.62)	−0.54*	(−0.97 to −0.12)	−0.42*	(−0.82 to −0.01)	1.93*	(0.65–3.22)	2.19*	(1.56–2.82)	2.24*	(1.60–2.88)
BS	−4.15*	(−6.78 to −1.52)	−3.72*	(−5.89 to −1.54)	−3.57*	(−5.65 to −1.50)	−1.99	(−4.12–0.14)	−2.18*	(−3.74 to −0.62)	−2.43*	(−3.80 to −1.05)
NO_x	−5.46	(−13.36 – 2.45)	−3.25	(−9.06–2.56)	−2.13	(−7.25–3.00)	−5.63	(−12.19–0.94)	−0.45	(−5.25–4.35)	−1.87	(−5.68–1.94)

*$p < 0.05$.
[a] Intervention: maximum driving speed reduced from 100 to 80 kph.
[b] Traffic contribution: concentration at roadside minus urban background.
[c] Adjusted for daily traffic flow, congestion (AVH) and wind direction.

- Finally, the influence of traffic flow (T), traffic congestion (AVH) and wind direction (D) was taken into account. Linear multivariate regression analysis was performed for the 'traffic contribution' concentrations of all components of air pollution. The multivariate regression equation was

$$\text{'traffic contribution' concentration} = a + \beta_1 T + \beta_2 \text{AVH} + \beta_3 D + \beta_4 \text{ intervention} \quad (1)$$

in which 'intervention' was included as a yes/no variable and β_4 is the intervention effect estimate.

This final, fully adjusted analysis was replicated for data from the southern section of the highway, where no change in speed limit was implemented. This way, explanations for changes in air pollution other than caused by the speed limit intervention could be detected.

3. Results

Table 1 summarizes the measured concentrations of the different components of air pollution in the year prior to the intervention. Concentrations at A10W (intervention highway section), A10S (non-intervention highway section) and mean background concentration are shown. Also the traffic contribution concentrations (daily roadside minus daily mean background) are shown for both highway locations. The data show that despite lower traffic density than at A10S, roadside concentrations of all components were highest at the intervened road section (A10W). Table 2 shows the measured concentrations for the year after the intervention took place.

The regression analysis of the effect of the intervention (Table 3) showed that roadside concentrations of PM_{10} and BS decreased statistically significantly at A10W. The traffic contribution to PM_{10}, PM_1 as well as BS was also found to be significantly reduced after the intervention. Adjustment for daily traffic flow, congestion (AVH) and wind direction made no difference to this finding. PM_{10} concentrations were estimated to decrease by 2.20 $\mu g\ m^{-3}$ since the speed limit reduction, PM_1 concentrations were reduced by 0.42 $\mu g\ m^{-3}$. A reduction of 3.57 $\mu g\ m^{-3}$ BS was achieved. The high variability of daily NO_x concentrations is reflected in the wide 95%-confidence interval of the estimated intervention effect. No statistically significant effect was observed. The estimated reductions mount up to 27%, 11% and 21%, respectively, of the traffic contributions to PM_{10}, PM_1 and BS shown in Table 1. Table 4 shows the speed limitation effect relative to the roadside concentrations in the year before the intervention (Table 1).

Table 5 shows the relation between air pollution concentrations at the two monitoring stations and traffic flow, congestion (AVH) and downwind exposure in the year before the intervention was implemented. The monitoring site being downwind from the freeway was significantly related to all air pollution components at A10S. At A10W this was only so for PM_1. Traffic flow was significantly related to almost all components at both stations, congestion was only related to some components.

Table 4
Speed limit intervention effects, relative to the ambient concentration in the year before the intervention.

	A10W: with intervention			A10S: without intervention		
	Intervention effect[a]	Relative to roadside concentration[b]		Intervention effect[a]	Relative to roadside concentration[b]	
			95%-CI			95%-CI
PM_{10}	−2.20* μg m^{-3}	−7.4%	(−10.0% to −4.8%)	−0.97* μg m^{-3}	−3.8%	(−6.7% to −1.0%)
PM_1	−0.42* μg m^{-3}	−2.8%	(−5.5% to −0.1%)	2.24* μg m^{-3}	16.8%	(12.0% – 21.7%)
BS	−3.57* μg m^{-3}	−15.0%	(−23.7% to −6.3%)	−2.43* μg m^{-3}	−10.2%	(−16.0% to −4.4%)
NO_x	−2.13 ppb	−2.4%	(−8.1%–3.3%)	−1.87 ppb	−2.7%	(−8.3% – 2.8%)

*[a] Traffic flow, congestion and downwind exposure adjusted 'traffic contribution' speed limit intervention effect.
[b] Roadside concentration in the year before the intervention.

Fig. 3 shows the estimated adjusted difference in traffic contribution between the year before and the year after the intervention for both monitoring sites. As the figure shows, there were reductions for PM_{10} and BS but not for PM_1 at the 'control' highway site as well. At both highway sites no statistically significant change in NO_x was seen. For PM_{10} and PM_1 the difference in estimated effect between the intervened and non-intervened road sections was statistically significant. The crude and adjusted effect estimates at the 'control' site (A10S) are shown in Table 3.

4. Discussion

In this study, we have shown that particulate air pollution (PM_{10}, PM_1 and BS) at roadside has decreased since the speed limit reduction on a section of the Amsterdam ring highway. No significant effect on nitrogen oxides was observed.

Although reductions were also observed at a section of the same ring highway without intervention, reductions in PM_{10} and PM_1 at the intervention site were significantly larger. The reductions on the non-intervened highway section might be explained by the governmental stimulation of reduced emission vehicles.

Daily air pollution concentrations are not only determined by traffic, also other local sources and factors such as long range air pollution and meteorology are of influence. The correlations between the background monitoring stations reflect that these processes affect the concentrations over the whole city in a similar way. To correct for these factors, the traffic contribution concentrations were studied. Nevertheless, these processes may potentially influence the transport and dilution of pollution caused by local sources such as traffic as well, leading to both increasing and decreasing local concentrations. In this study no further adjustment was possible as sufficiently detailed information on these processes was not available.

Apart from the difference in speed limit, the two highway sections are not exactly the same in some more features as well. While the western section has adjoining apartment buildings, the southern section is located in a relatively open area next to a river. Also, the embankment elevation of the two sections is different, 4.8 m at the western section, 7.6 m at the southern. These spatial differences are a probable explanation for the higher and more significant effect estimates for downwind exposure (Table 4) at the southern section. The negative association with PM_1 at A10W may be explained by the adjoining buildings (Harrison et al., 2004). Also, the wind direction data were obtained from Schiphol Amsterdam Airport, as no data from the monitoring sites were available. The monitoring sites are located 8 km northeast (A10S) to10 km north (A10W) of the airport. Possibly, local appearing wind directions might differ slightly. However, no change in intervention effect estimates was shown when the downwind exposure variable was excluded from the adjusted model. At the same time, the influence of traffic density on air pollution was much larger on the more enclosed A10W than at the A10S location, leading to higher pollution concentrations at the A10W site despite lower traffic densities.

Since the intervention, traffic flow on the intervened highway was somewhat decreased (intervention effect: −1823 vehicles per 24 h, 95%-CI: −4226 to 581), similar figures appear at the highway section without intervention (−1981 vehicles per 24 h). These changes are small, amounting to no more than 2% of total traffic flow. Congestion was higher at the intervened highway section than at the not intervened section. Since the intervention, daily traffic congestion at the western road section has not changed (intervention effect: 0.12 AVH, 95%-CI: −0.53 to 0.77), at the 'control' highway section, an increase was observed (1.13 AVH, 95%-CI: 0.47–1.80). The previously expressed concern of the speed limit intervention causing additional congestion (Coelho et al., 2005), showed not to be valid at this highway.

About two weeks before the intervention was implemented, a noise-barrier was installed along the western highway section. The screens were installed in the open spaces between the already present high-rise buildings (Fig. 2). Noise screens are known to change the air flow at a road, thereby increasing the concentrations at the road itself, and lowering concentrations in the adjoining neighbourhoods (Bowker et al., 2007). In this study, the air quality monitoring station was situated between the road and the façade of the building (see Fig. 2). Installation of the noise screen therefore could have caused an underestimation of the effect of the intervention on air quality.

Improving air quality by speed limit reduction has been predicted (Eerens et al., 1993; Keller et al., 2008), but has not been demonstrated by real life air quality measurements before. Based on dispersion models, the Dutch National Department of Transport predicted that PM_{10} concentrations at roadside in this specific situation would be reduced by 0.5–1% (Ministerie van Verkeer en Waterstaat, 2004). The observed reduction of 2.20 μg m^{-3} is 7% of the mean concentration measured at roadside.

Table 5
Effects of traffic flow, congestion and wind direction on traffic contribution[a] to air pollution concentrations measured at roadside.

	A10W						A10S					
	Traffic Flow (per 1000 vehicles)		Traffic congestion (AVH)		Downwind		Traffic Flow (per 1000 vehicles)		Traffic congestion (AVH)		Downwind	
		95%-CI		95%-CI		95%-CI		95%-CI		95%-CI		95%-CI
PM_{10} (μg m^{-3})	1.09*	(0.61–1.56)	0.01	(−0.18–0.20)	0.07	(−1.13–1.26)	0.13	(−0.07–0.34)	0.08	(−0.03–0.19)	3.85*	(3.12–4.59)
PM_1 (μg m^{-3})	0.78*	(0.53–1.03)	0.05	(−0.05–0.15)	−0.72*	(−1.34 to −0.09)	0.36*	(0.22–0.51)	0.07	(−0.01 – 0.15)	1.53*	(1.01–2.05)
BS (μg m^{-3})	2.78*	(1.96–3.60)	0.46	(−0.07–0.99)	1.11	(−2.18–4.40)	1.06*	(0.49–1.63)	0.32*	(0.01–0.63)	7.21*	(5.19–9.24)
NO_x (ppb)	10.78*	(7.58–13.98)	0.07	(−1.22–1.36)	−3.67	(−11.70–4.36)	2.86*	(1.36–4.35)	0.85*	(0.04–1.66)	26.21*	(20.90–31.53)

*$p < 0.05$.
[a] Traffic contribution: concentration at roadside minus daily mean background.

In addition, the monitoring network provided information on PM_1 and BS. Both fine particles (PM_1) and especially soot (BS) (Fischer et al., 2000; Janssen et al., 2001; Wichmann et al., 2005) are known to be directly related to traffic combustion and considered to be of health importance. In a country like the Netherlands, with a very dense population and road network, the observed reductions at roadside of 3 and 15% for PM_1 and BS respectively, are therefore of potential importance to health.

The larger intervention effect on BS than on PM_{10} however, might be artificial. BS monitors are known to produce levels which are not real concentrations (Schaap and Denier van der Gon, 2007). Relative to the traffic contribution concentration in the year prior to the intervention, the reduction in PM_{10} is larger than that in BS (26.8 and 20.6%, respectively).

Also, the relative PM_1 reduction (12.7%) is smaller than PM_{10}. A probable reason for the relatively large effect on the reduction of PM_{10} could lie in the fact that the traffic contribution concentration studied, is not only consisting of exhaust emission, but also of resuspended particulate matter. Along a busy street in London, about 20% of the traffic contribution concentration of PM_{10} is due to resuspension of particles (Thorpe et al., 2007). In Berlin (Lenschow et al., 2001) this was about 50%. Traffic driving speed was one of the influential factors of resuspension, less resuspension occurs at lower driving speeds. Resuspension was dominated by the coarse fraction of PM_{10} (2.5–10 μm), the finer fractions of particulate matter are less influenced by the resuspension of road dust.

In contrast to particulate matter, no clear effects on nitrogen oxides were observed but confidence intervals

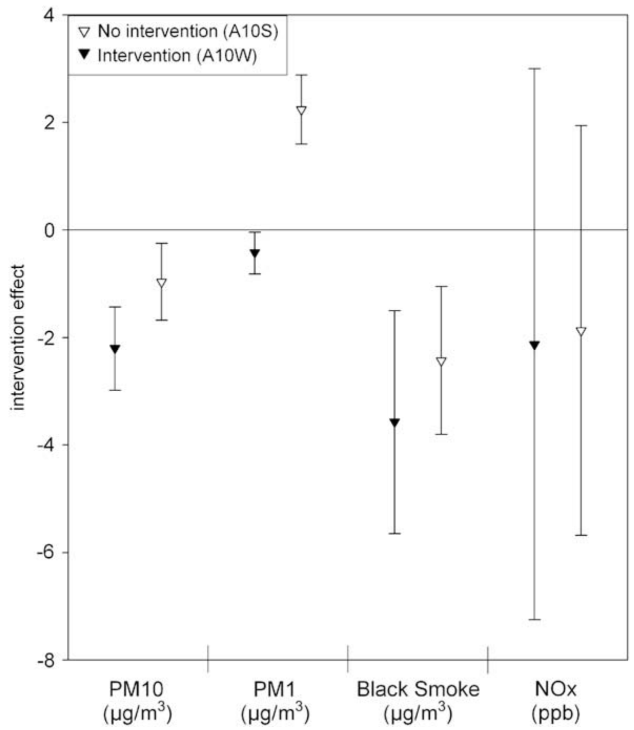

Fig. 3. Speed limit intervention effect on traffic contribution measured at roadside at highway sections with and without intervention. Adjusted for traffic flow, congestion and wind direction.

were wide, owing to the high day-to-day variation of the measured NO_x concentrations.

In conclusion, this study demonstrated a significant reduction of PM_{10} and PM_1 as a result of reducing the speed limit at an urban ring highway.

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