15th ETH-Conference on Combustion Generated Nanoparticles
June 26th – 29th 2011

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Title: Do Low Emission Zones reduce the burden of particulates?

- Extended Abstract -

1. Introduction

More than 40 low emission zones (LEZ) have been established in Germany. Also other European countries such as the Netherlands, the United Kingdom or Sweden have set up LEZ [1] or similar systems like congestion charges, which reduce the amount of traffic and/or aim at traffic restrictions for certain categories of vehicles with high exhaust emissions (e.g. diesel vehicles according to the EURO1 standard or below). Bearing in mind that traffic bans can cause considerable cost for the owners of high polluting vehicles, the public expects a net improvement of air quality. However, the studies published so far on the effects on air quality are equivocal. Whereas studies in Munich [2], Berlin [3] and Cologne [4] showed a decrease of the burden of particles and NO_2 in the order of several percent, other studies in London (congestion charge [5]), several German cities [6] or Hannover [7] gave little or no evidence for improvements of air quality which could be related to LEZ or similar systems.

In the following, we report on two recent evaluations of the changes of the particulate burden before and after the introduction of LEZ in the Ruhr district (8 zones comprising 230 km²) and Berlin (88 km²). Berlin is the biggest Germen city with about 3,4 million inhabitants. The Ruhr district (5 million inhabitants) belongs to the 5 biggest conurbations in Europe.

2. Results

The first stage of the LEZ was introduced in 2008 in both regions (January 1st in Berlin and October 1st in the Ruhr district). Diesel vehicles labeled as EURO1 or before and gasoline vehicles without regulated catalytic converters were forbidden to enter the LEZ. In Berlin, stage 2 of the LEZ scheme operates since January 1st, 2010 (diesel cars: EURO4 or better or EURO3 retrofitted with particulate filters).

Studies examining the effects of LEZ on air quality have to use approximations, as the ideal case – one area at the same time period (fixed meteorology and background pollution) with and without LEZ – can only be modelled, but cannot be ob-

served. Our study (as most of the others) uses the approximation of the same area, but different time periods and after the introduction of LEZ. As background levels, meteorological conditions and other factors can change from one year to another, any observed differences in the pollution burden within the LEZ must be adjusted by differences measured at reference stations outside the LEZ. Only improvements of air quality in the LEZ exceeding those observed outside the LEZ can be counted.

Our study in the densely populated Ruhr district is based on a network of 5 traffic stations inside the LEZ and 3 traffic stations and 27 background stations outside the LEZ measuring PM10 and NO_2 levels. Data from 2007 (before the LEZ) and 2009 (LEZ fully operating) were compared. The monitoring data from stations with the same type (for example traffic stations) were pooled and annual characteristics were calculated as averages from these stations in order to raise the statistical power of the data. Within the LEZ, PM10 levels showed a net decrease of 3,2 µg/m³ (annual means) and 19 days with daily means above 50 µg/m³ (days in exceedance according to EC directive 2008/50/EC) at traffic exposed sites, which was larger than the decrease of background levels (1,1 µg) or at traffic stations (-0,8 µg/m³) outside the LEZ in the same time period. Consequently, a decrease of 2,1 – 2,4 µg/m³ (annual means, about 7 %), and 16 days above 50 µg/m³ can be assigned to the effect of the LEZ after adjustment. Also NO_2 levels (annual means) decreased by 1,2 µg/m³ in relation to traffic stations outside the LEZ.

In Berlin the PM10 burden (annual means) decreased at traffic exposed sites within the LEZ by around 2 µg/m³ (7 %) from 2007 (before the LEZ) to 2010 and by 10 days above daily means of 50 µg/m³. This value can be derived from a PM2.5 source apportionment study for the traffic exposed site Frankfurter Allee in 2007 and the reduction of exhaust emissions by the LEZ from 2007 to 2010. About 78 % of the PM10 burden stems from sources outside of Berlin, other PM10 sources or resuspension and abrasion, which cannot be controlled by the LEZ. Consequently, PM10 levels are a rather insensitive parameter to describe the effects of traffic related measures. Components directly related to traffic exhaust emissions such as soot (elemental and organic carbon) are more sensitive indicators. This can be demonstrated by measurements of total carbon (elemental +1,2 organic carbon) at 10 mini samplers inside and 12 mini samplers outside of the LEZ. Compared to total carbon (TC) levels in 2007, the local increment of soot concentrations at traffic exposed sites within the LEZ (soot background levels substrated) were 50 % lower in 2010. One of the most toxic components of PM10 could thus be significantly reduced.

The effect of the LEZ in the Ruhr district was also examined by model calculations ($IMMIS^{luft}$ [8], HBEFA3.1, background concentrations from EURAD and background monitoring stations). The calculated decreases at traffic exposed sites within the LEZ of 0,5 – 1 µg/m³ (PM10) and 1 – 2,5 µg/m³ (NO_2, both annual means) are in the same range as the observations.

3. Fleet composition and traffic volume

The traffic restrictions introduced by LEZ are aiming at a faster modernization of the car fleet, as the oldest and most polluting vehicles are excluded. This acceleration could indeed be observed in Berlin as well as in the Ruhr district. Compared to the general trend before 2007, the most polluting vehicles (without sticker) were reduced

by 70-90 % from 2007 to 2009 in Berlin, and 60.000 vehicles were upgraded by particulate filters. In the Ruhr district, the number of vehicles with the worst emission standards decreased by 25 % from 2008 to 2009, whereas the decrease in North western Germany was only 16 %.

One objection often raised against LEZ in the public discussion concerns the assumed increase of traffic volume outside the LEZ (excluded vehicles are assumed to circumvent the LEZ), so that the net effect on air quality in the whole region would be zero or even negative. No such effects could be observed in Berlin and the Ruhr district. Traffic counts in the Ruhr district at more than 80 street segments showed the same slight decrease of 1,5 % for passenger cars in and outside the LEZ and a somewhat larger decrease for heavy duty vehicles of 5,7 % inside and 4,4 % outside the LEZ.

4. Conclusions

It can be concluded that LEZ reduce the PM10 burden by about 2 – 3 µg/m³ both in Berlin and in the Ruhr district mainly by a faster modernization of the car fleet and by incentives for retrofitting older vehicles with particle traps. This slight decrease is difficult to detect, as there are numerous PM sources not related to exhaust emissions. Total carbon (soot) is not only one of the most dangerous ingredients of particulate matter, but also by far a more sensitive parameter for traffic related measures. According to the measurements in Berlin, the local soot increment (urban background substracted) could be reduced by 50 % within the LEZ. In a nutshell, LEZ as single measure are often not sufficient to meet the European limit values, but are an effective means to reduce the impact of traffic exhaust on air quality particularly in combination with other measures.

Literature

[1] An up to date survey is available in the internet under www.lowemissionzones.eu.

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[7] Staatliches Gewerbeaufsichtsamt Hildesheim: Bewertung der Auswirkungen der Umweltzone Hannover auf Basis von Messwerten. Hildesheim, Juli 2010.

[8] Morfeld, P., M. Spallek, D. Groneberg: Zur Wirksamkeit von Umweltzonen: Design einer Studie zur Ermittlung der Schadstoffkonzentrationsänderung für Staubpartikel (PM10) und andere Größen durch Einführung von Umweltzonen in 20 deutschen Städten. Zentralblatt für Arbeitsmedizin, Arbeitsschutz und Ergonomie (2010), accepted for publication.

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DO LEZ reduce the burden of particulates?

- Evidence from monitoring difficult
- 2 case studies:
  - Ruhr (PM10)
  - Berlin (PM10, soot)
- Traffic volume, fleet composition
- Evidence from modelling

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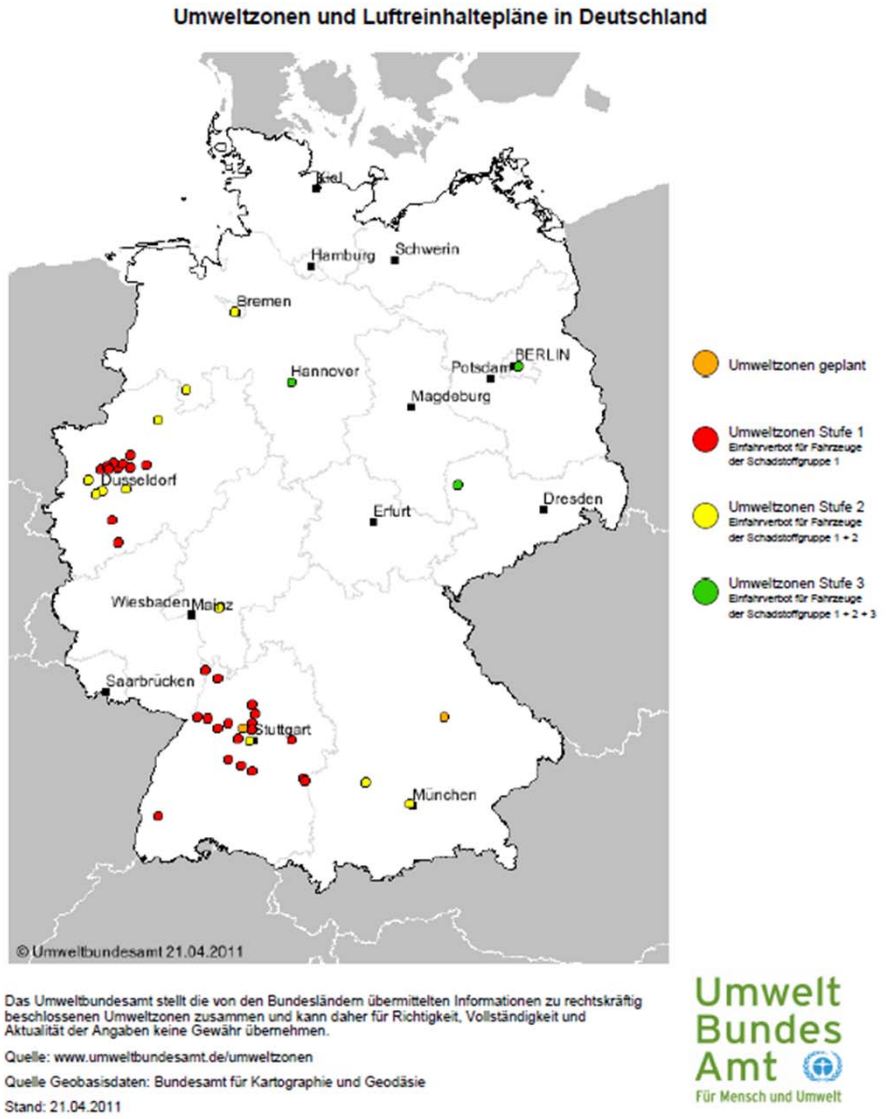
> 40 LEZ in Germany

- Traffic restrictions according to exhaust emissions and EURO classes
- 3 labels (red, yellow, green)
- Green:
  - petrol: EURO 1
  - diesel: EURO 4 (or EURO 3 + filter)



Problems with an impact analysis of LEZ based on measurements

Ideal, not realistic:	**Same area and time period**
1st approximation:	**Same time period, but different areas (cities) with and without LEZ**
2nd approximation:	**Same area, but different time periods with and without LEZ**

Problems of 2nd approximation

High variability of PM levels due to meteorology, uncertainty of measurements	⇒	**Longer time periods, aggregated monitoring data (e.g. annual characteristics)**
Different meteorological conditions, trend of background concentrations	⇒	**Adjustment by reference stations outside LEZ**

$$\Delta_{LEZ} = (C_{withoutLEZ,\ T1} - C_{LEZ,\ T2}) - (C_{Ref,\ T1} - C_{Ref,\ T2})$$

Studies on the impacts of LEZ on air quality published so far (1)

Study	Impact	Source
London, congestion charge (22 km²): Monitoring data from 2001/2 vs 2003/4 in zone compared to stations outside; modelling (background levels)	Little evidence of CCS related changes at roadside monitoring sites; modelling (Background): PM10 -0,8 µg/m³	Kelly, Atkinson et al., 2011
Berlin, Mannheim, Stuttgart, Tübingen, Ludwigsburg: Monitoring data from cities with LEZ compared to similar cities without LEZ (problem: traffic flow and volume not equal)	none	Niedermaier, 2009
Hannover: Monitoring data from traffic station, corrected by changes of background levels 2008: red LEZ, 2009: yellow LEZ	PM10 (annual mean): -1 µg/m³ authors: not significant	Staatliches Gewerbeaufsichtsamt Hildesheim, 2010

Studies on the impacts of LEZ on air quality published so far (2)

Study	Impact	Source
München: Monitoring data from 2 traffic stations, corrected by background-ref. stations. 4 months	PM10: -9,8 % - -12,3 %	Cyris et al., 2009
Berlin: „red“ LEZ (2007 → 2008) monitoring data, corrected by background stations (annual means)	EC: -14 – 16 % PM10: within uncertainty. Calculated from changed fleet composition: -4,5 % (-6 – 7 days > 50 µg/m³)	Lutz et al., Rauterberg-Wulff et al. (2008)
Köln: „red“ LEZ (2007 → 2008) monitoring data from traffic stations, corrected by background stations (annual means)	PM10: -2 µg/m³ (7 %), (-10 days > 50 µg/m³)	Bruckmann et al.
LEZ in 20 German cities: Monitoring data (hourly means), corrected by ref. stations	in progress	Morfeld et al.

LEZ Berlin

Stage 1: since 1.1.2008

- Diesel vehicles: at least Euro 2 or Euro 1 & retrofit
- Gasoline vehicles: at least Euro 1
- 7% of vehicle fleet affected

Stage 2: since 1.1.2010

- Diesel: Particle emission Euro 4:
- cars: Euro 3 + particle filter or better
- commercial vehicles: also retrofit of Euro 1-3 towards Euro $4_{Particle}$
- 10% of the vehicle fleet affected

Area:

about 88 km²
(Berlin total area: 892 km²)

Inhabitants:

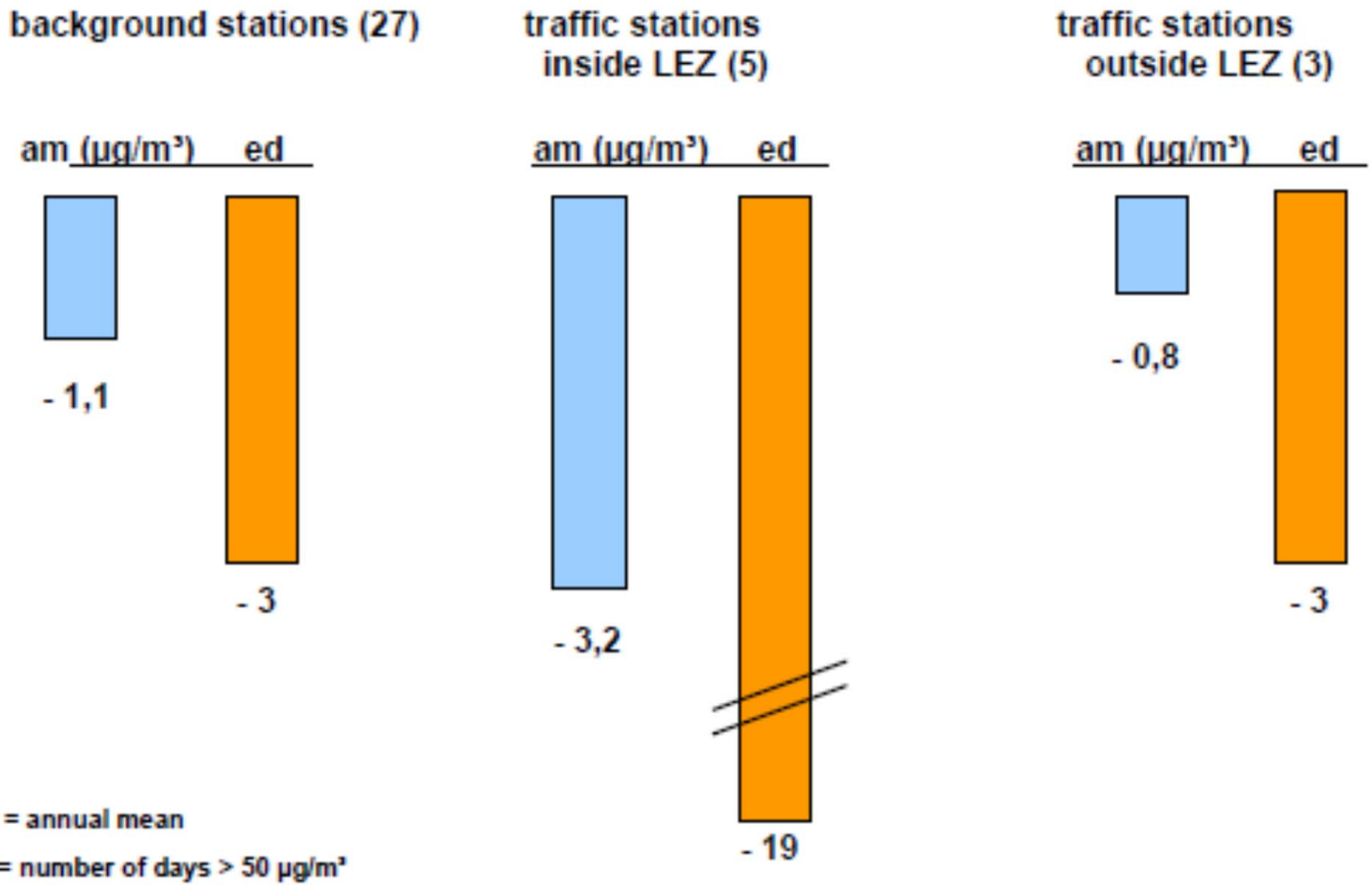
about 1 Million

(Berlin total: 3,4 Mio)

LEZ Ruhr area

- Area: 8 LEZ (230 km²)
- Traffic ban for vehicles without labels ("red" LEZ) from Oct 1st, 2008
- Time periods: 2007 (without LEZ) and 2009 (with LEZ)
- Monitoring data: annual PM10 characteristics 2007, 2009, averaged over several monitoring stations with identical classification:
  - 5 traffic stations inside LEZ
  - 27 background stations outside LEZ
  - 3 traffic stations outside LEZ

Change of PM10 burden 2007 – 2009
(averages of stations with identical classification)



am = annual mean

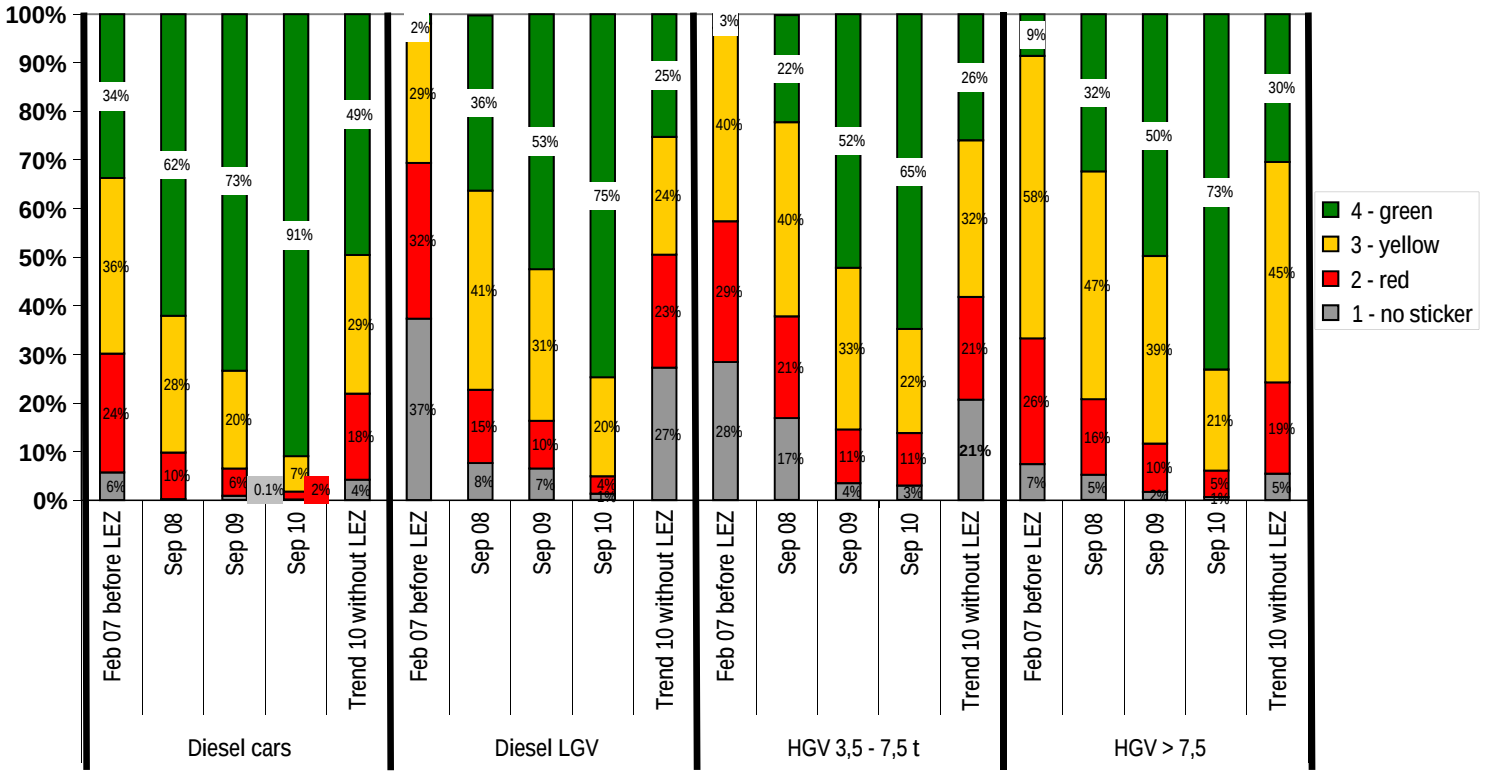
ed = number of days > 50 µg/m³

Impact of LEZ Ruhr (Δ 2007 – 2009) corrected by reference stations

PM10:	**averages:**	
	- 2,4 µg/m³ (annual means) **- 16 days > 50 µg/m³**	**based on traffic stations outside LEZ**
	- 2,1 µg/m³ (annual means) **- 16 days > 50 µg/m³**	**based on background levels outside LEZ**
	individual stations:	
	range from -8 µg/m³ to +1 µg/m³ (annual means)	

Berlin LEZ impact on vehicle fleet composition on the road

(retrieved from number plate recognition)



decrease: cat.1 (no sticker) by 70-90 %; Cat 2 (red) by 50-80 %

increase: category 4 (green) by factor 1,5 to 3

60.ooo vehicles upgraded through DPF retrofit

☞ faster fleet modernisation also in Ruhr LEZ

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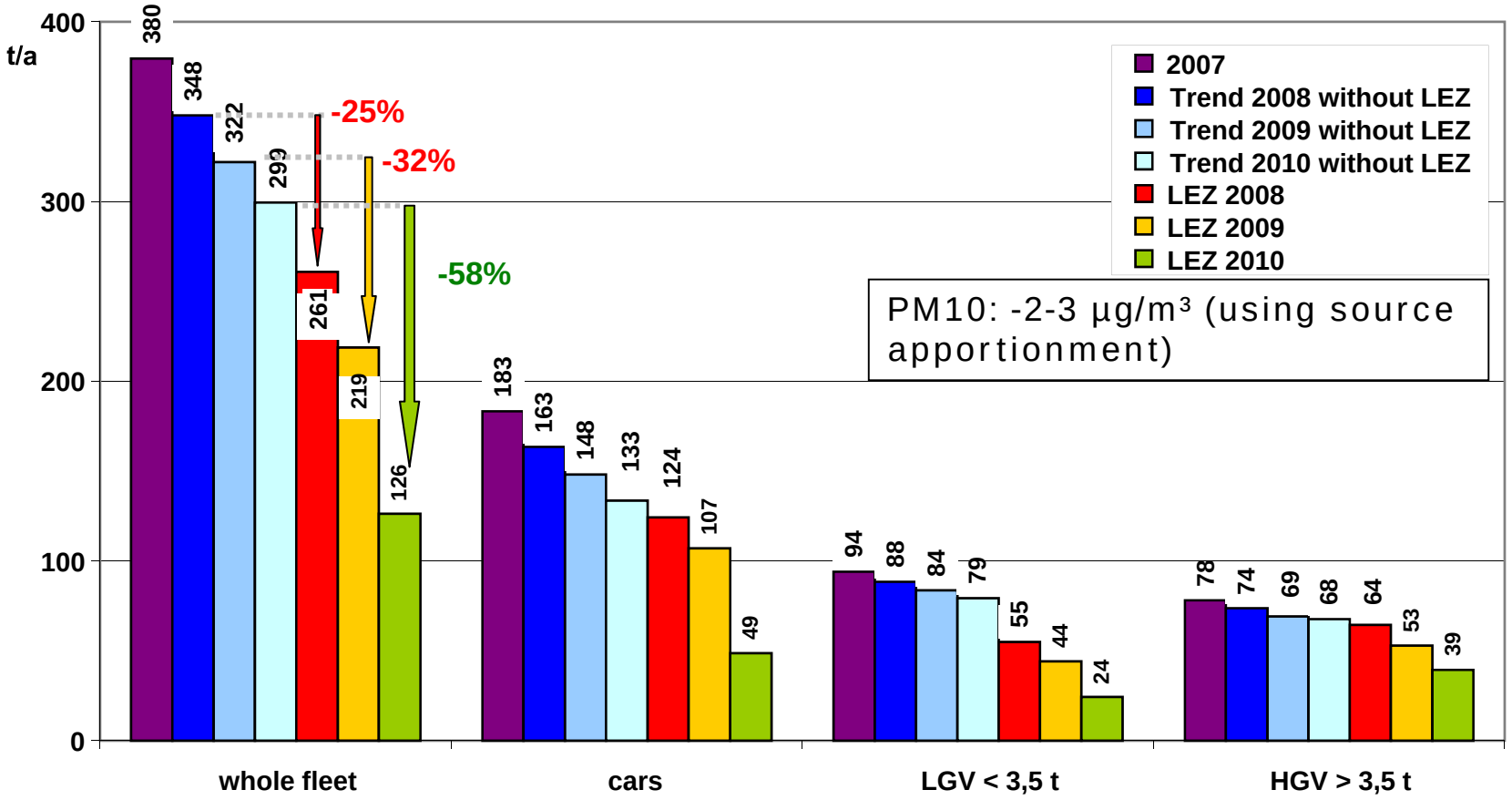
Berlin LEZ impact on particle exhaust emissions

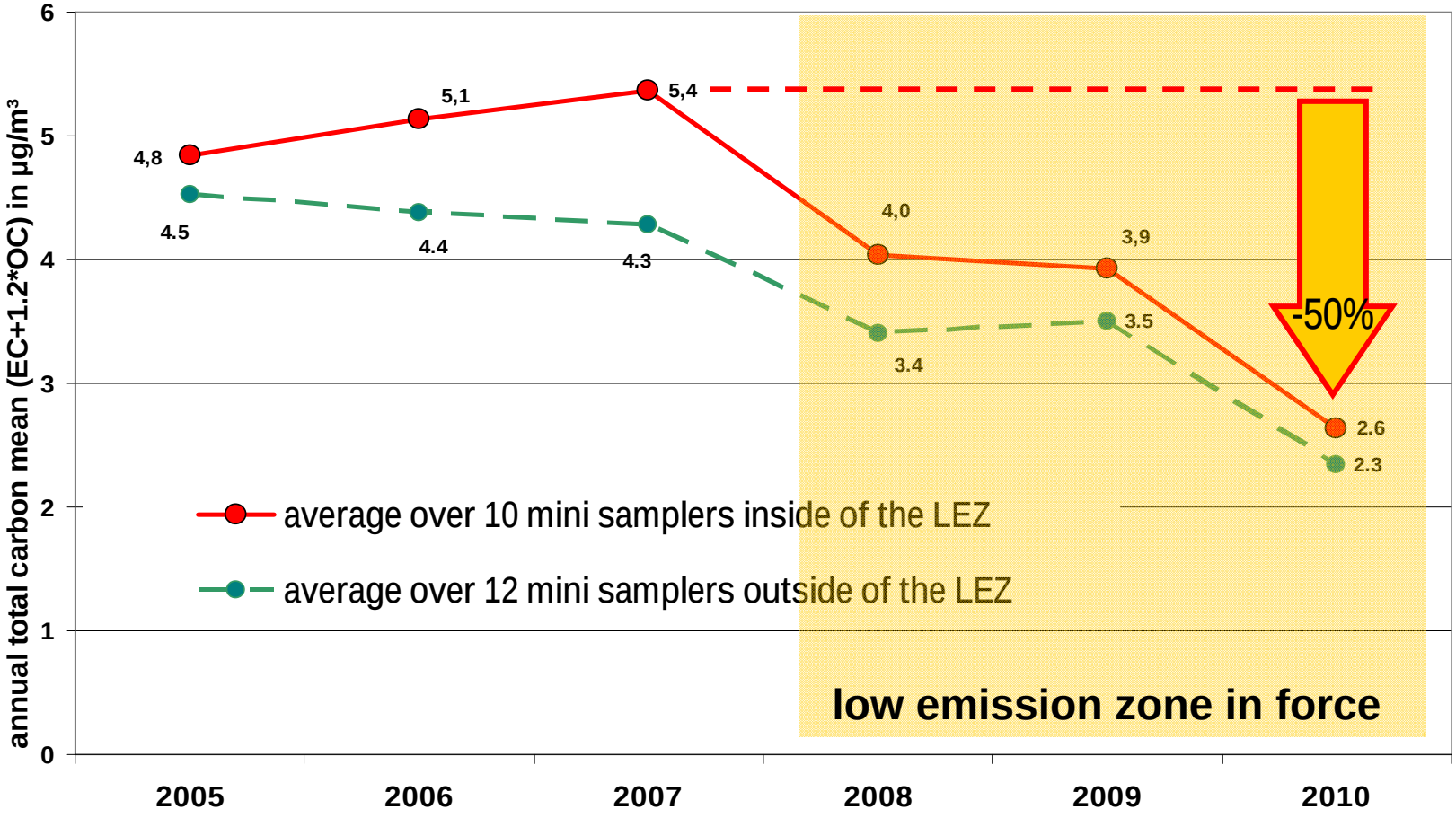
new results **based on fleet composition at Frankfurter Allee** (new emission factor data base HBEFa 3.1)



emissions extrapolated to the entire main road network based on the fleet composition at Frankfurter Allee (with DPF-retrofit, only warm emissions, no cold start impact)

Berlin LEZ impact on black carbon¥ concentration

new results until 2010



¥ local increment (minus urban background) of total carbon (EC+1.2*OC) at traffic sites, adjusted to traffic volumes trend relative to 2007 pre-LEZ figures

lanuv NRW.

Conclusions

- Difficult to derive impact of LEZ on PM levels from monitoring:
  - Small difference of large figures, no exactly comparable settings
- LEZ Ruhr: Impact from monitoring data, relative to ref. stations:

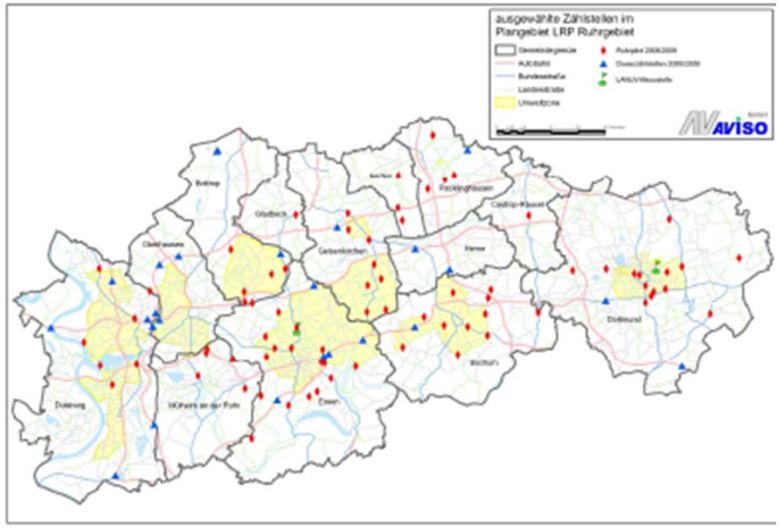
  PM10: -2 µg/m³ (annual mean); -16 days > 50 µg/m³
- LEZ Berlin: Impact from fleet measurements, calculated emissions, applied on results of pre-LEZ source apportionment study in 2007 :

  PM10: -7%, -2-3 µg/m³ (annual mean); -10 days > 50 µg/m³
- Soot (EC, OC) more sensitive to traffic related measures

  LEZ Berlin: EC&OC: -2.8 µg/m³ (annual mean) or -50% of traffic-related concentration

  ☞ decrease of the most toxic PM component
- Similar results from modelling
- Faster modernization of fleet in Berlin and Ruhr
- No observed increase of traffic outside LEZ Ruhr, Berlin

Trend of traffic volume within Ruhr area 2008 to 2009



	inside LEZ (AVISO)	outside LEZ
pass. cars	-1,5 %	-1,5 %
HDT*	-5,7 %	-4,4 %
traffic system Ruhrpilot (77 stations):		
	inside LEZ	outside LEZ
HDT*	-7 %	-4 %
* without busses		

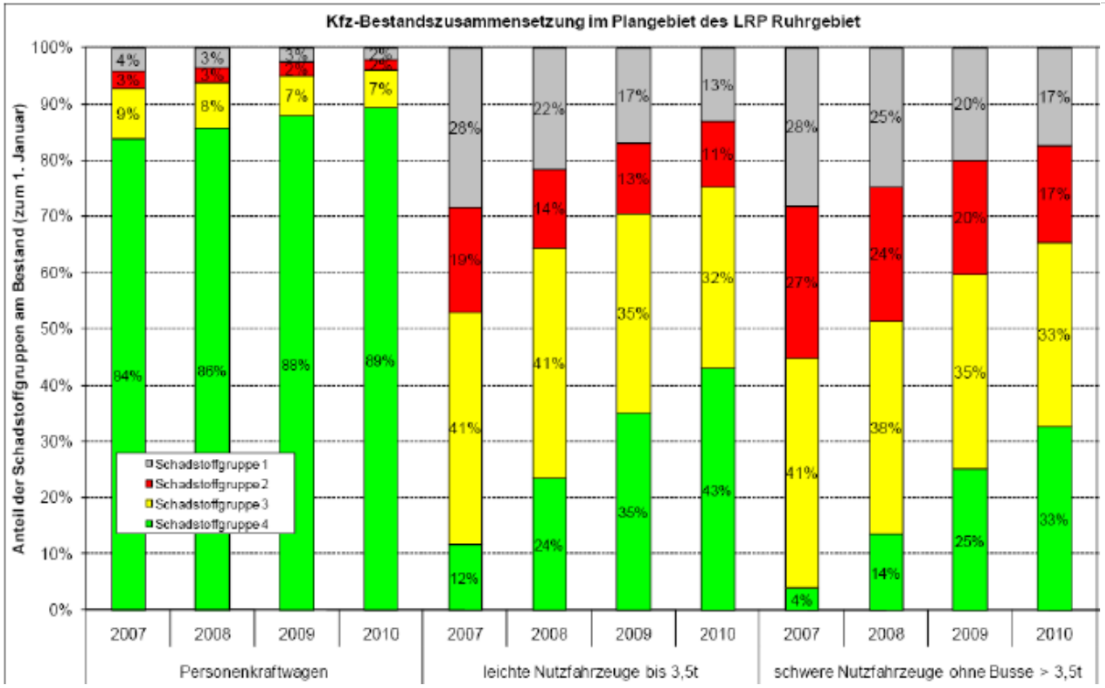
Monitoring stations of traffic volume in the Ruhr area

☞ **no increase of traffic outside Ruhr LEZ**

☞ **same result in Berlin**

Trend of fleet composition within Ruhr area from 2007 – 2010

(source: KBA)

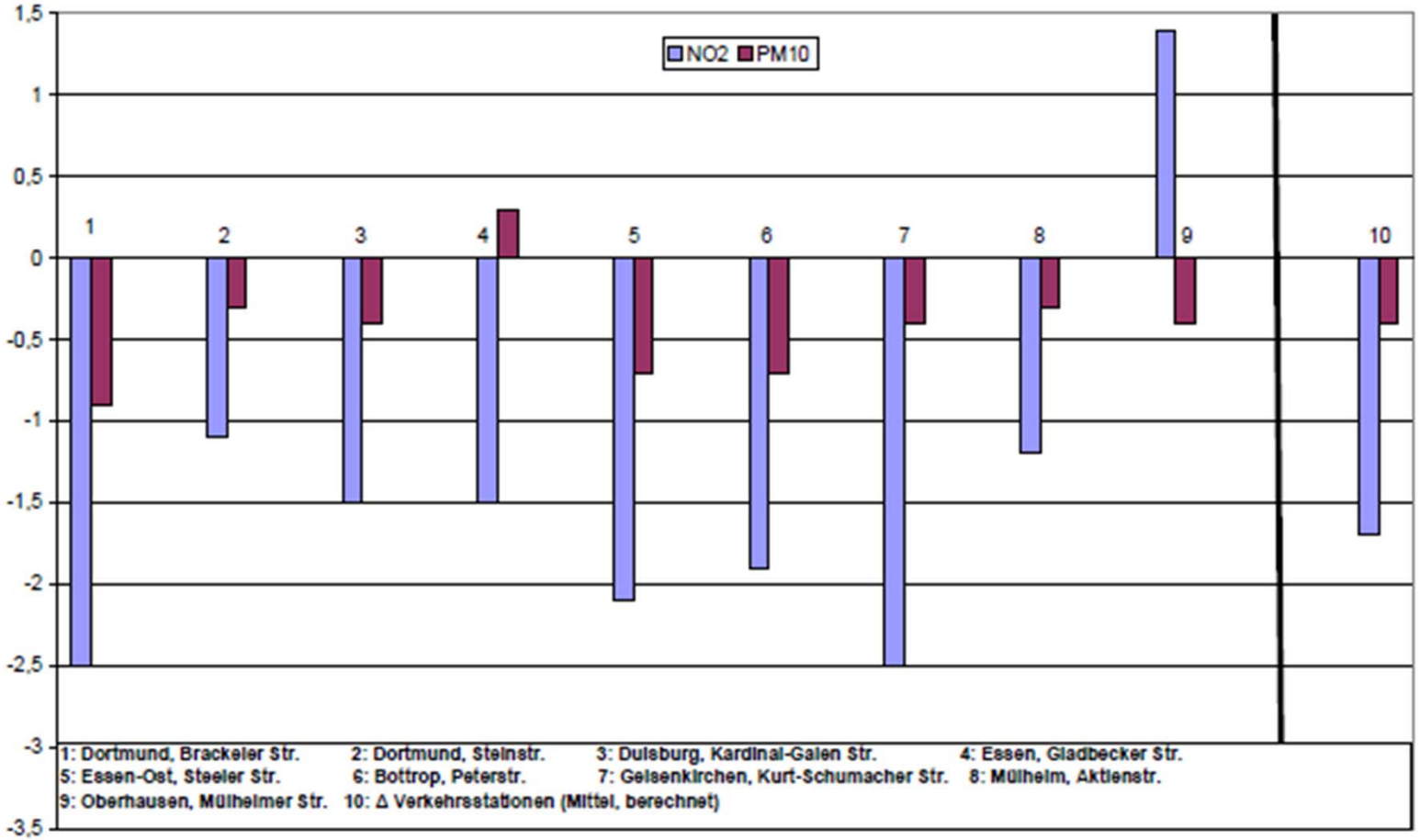


Δ 2008/2009, without label		
	Ruhr	**Northrhine-Westphalia**
pass. cars	**-25 %**	**-16 %**
light DV	**-21 %**	**-16 %**
HDV*	**-20 %**	**-17 %**
*** without busses**		

☞ faster fleet modernization in Ruhr area

Modelled decrease of NO_2 and PM10 burden at characteristic streets from 2008 (no LEZ) to 2009 (LEZ), meteorology and background kept constant

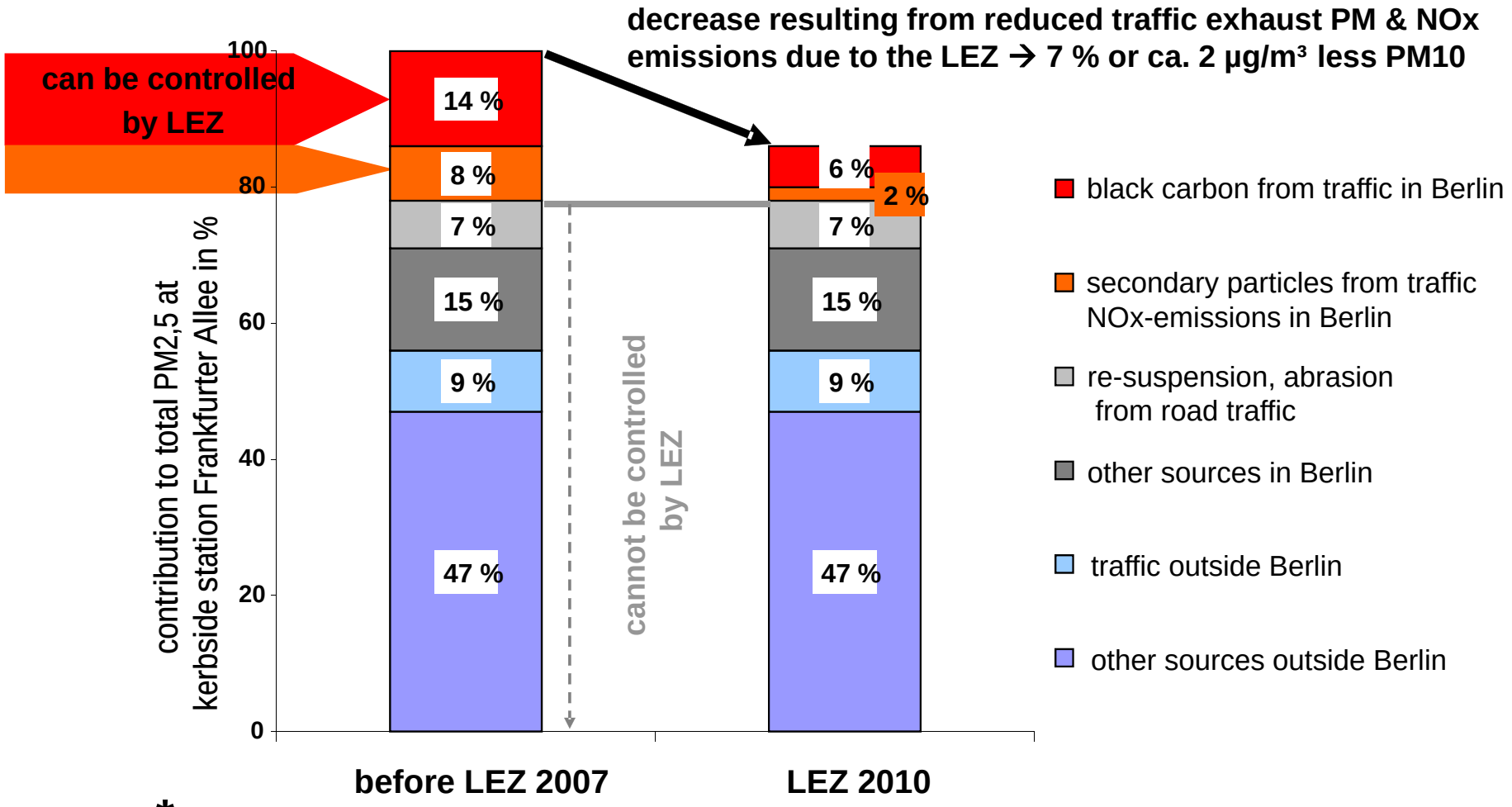
(IMMIS^{luft} (IVU), HBEFA3.1, background from EURAD)



Berlin LEZ impact on PM10 levels in 2010

using results of a PM2.5 source apportionment study in 2007 before the LEZ

☞result largely independent from inter-annual meteo & traffic variation



* related to **PM2,5**-levels in a busy main road in Berlin‘s city centre in 2007 before the LEZ

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