TRAFFIC-INDUCED AIR POLLUTION TRENDS IN URBAN AREAS OF GERMANY

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ABSTRACT

In the European Union, revised air quality standards have been introduced and some traffic-induced pollutants, such as NO_2, PM_{10} and benzene, now sometimes exceed the planned regulatory limits near heavily-used roads in urban areas. Therefore the question arises whether expected emission reduction will be sufficient to ensure that the limits will met soon. For Germany, emission forecasts predict a mean reduction of traffic-induced NO_x- and benzene release between 1990 and 2020 of 81% and 95% respectively (IFEU, 2000). This decrease is expected despite a traffic increase of 44%. It is not clear if this predicted reduction also will occur in urban areas because the emission decrease there might show a different trend in comparison to the German mean. To determine if the predicted trend is correct, it is necessary to compare recent emission forecast with observed immission trends. NO_x and benzene inner-city emission was therefore modelled between 1995 and 2000 and compared with measurements near heavily-used urban streets in the same time interval. The decrease of benzene immission in urban areas agrees well with the emission forecast. For NO_x, the immission decrease between 1995 and 2000 in urban areas is smaller than expected. And for NO_2, in contrast to prediction, no significant reduction of pollution can be observed during the 6 years between 1995 and 2000. Therefore it can be assumed that, in urban areas, further NO_x and NO_2 immission decrease will be less than expected.

Key words: traffic induced immission, air pollution, environmental impact of traffic, benzene, nitrogen dioxide, verification of emission prediction

1 INTRODUCTION

The European Union has introduced new air quality regulatory standards and in future a maximum annual mean concentration of 40 µg/m³ for NO_2 and of 5 µg/m³ for benzene must be observed. Now the question is whether the emission reduction expected in the next few years will be sufficient to ensure that regulatory limits are met. The forecast for Germany predicted a reduction of traffic-induced NO_x- and benzene emission between 1990 and 2020 of 81% and 95% respectively (IFEU, 2000). This decrease is expected despite a traffic increase of 44%. It is not clear if this reduction will also occur in urban areas. There, emission trends may differ strongly from the German average due to vehicles starting cold, deviant traffic patterns and different car/truck ratios. Measurements near heavily-used streets in urban areas showed that, during the 6 years between 1995 and 2000, the annual mean NO_2 concentration was nearly constant. This is surprising because NO_x emission was predicted to decrease. It is not clear whether this difference between expectation and observation is caused by deviant emission factors, differing traffic volume trends or other reasons. But it is necessary to examine this disagreement, because urban air quality forecast is only credible as a basis for environmental and traffic policy if the recent past can be explained by the same assumptions and methods as the forecast uses.

2 METHOD

The aim of this study was to analyse

- how much the traffic-induced emission of benzene and NO_x in urban areas decreased between 1995 and 2000 and
- if this reduction agrees with the observed immission decrease.

In order to do this

- the benzene- and nitrogen oxide immission time series at 80 measuring sites in 5 German states were analysed between 1995 and 2000
- the emission trend of NO_x and benzene was modelled for the same time interval in urban areas.

In principle, it is not possible to compare an immission concentration [g/m³] time series and an emission strength [g/s] time series directly. Therefore both of them were standardised in respect to the year 1995. The relative reductions of both quantities thus obtained could be compared. This also has the advantage that the trend at several stations with different concentration levels could be averaged in order to get better statistical reliability.

3 MODELLING TRAFFIC-INDUCED EMISSION IN URBAN AREAS

First, traffic-induced NO_x and benzene emission trends in urban areas between 1995 and 2000 have to be assessed. The emission calculation was done for warm engine conditions and cars starting cold using *the Handbuch für Emissionsfaktoren, version 1.2* (Keller et al., 1999), published by the German environmental protection agency and abbreviated below as *HB*.

3.1 Emission under warm engine conditions

In cities, HB distinguishes 18 different driving patterns for motor vehicles. This study includes only heavily-used inner-city streets. Therefore only 6 driving patterns remain. It is interesting that, although the emission factors for the 6 driving patterns are different, the percentage decrease between 1995 and 2000 is the same for all of them. As can be seen from Table 1, the emission reduction per vehicle for warm engine conditions, i.e. with catalytic converter, is between 20% and 70% for the 6 year period.

3.2 Emission for vehicles starting cold

When a car starts cold, the catalytic converter operates inefficiently. As a result, high benzene emissions occur primarily in the first kilometre, and for NO_x also in the second kilometre. Calculating the emission from vehicles starting cold on a given street therefore requires detailed information on the number of moving vehicles in the first, second, third and fourth kilometre. Examples of different driving distance distribution in urban areas depending on traffic strength are given in Friedrich (1999). By combining the emission factors for 1995 to 2000 and the driving distance distribution, the cold start emission on a urban road can be estimated for the time period. The emissions are standardised in respect to the value in 1995 in order to get a percentage reduction. As can be seen in Table 1, for benzene, the calculated reduction of cold start emission between 1995 to 2000 is 60% whereas NO_x emission increases by 10% in this period.

Table 1: Emission decrease per vehicle between 1995 and 2000

Emission reduction between 1995 and 2000	Benzene	NO_x
Truck, warm engine	20%	20%
Car, warm engine	70%	45%
Car, cold engine	60%	-10%

Now the emissions for all vehicles, whether trucks or cars with warm and cold engines, must be summarised. For urban areas it is assumed that 4% to 8% of the vehicles will be trucks. Again, the results between 1995 and 2000 were standardised in respect to the emission calculated for 1995. In fig. 1, the percentage emission decrease relative to 1995 is shown, together with the standard deviation due to different driving distance distributions, urban traffic patterns and car/truck ratios.

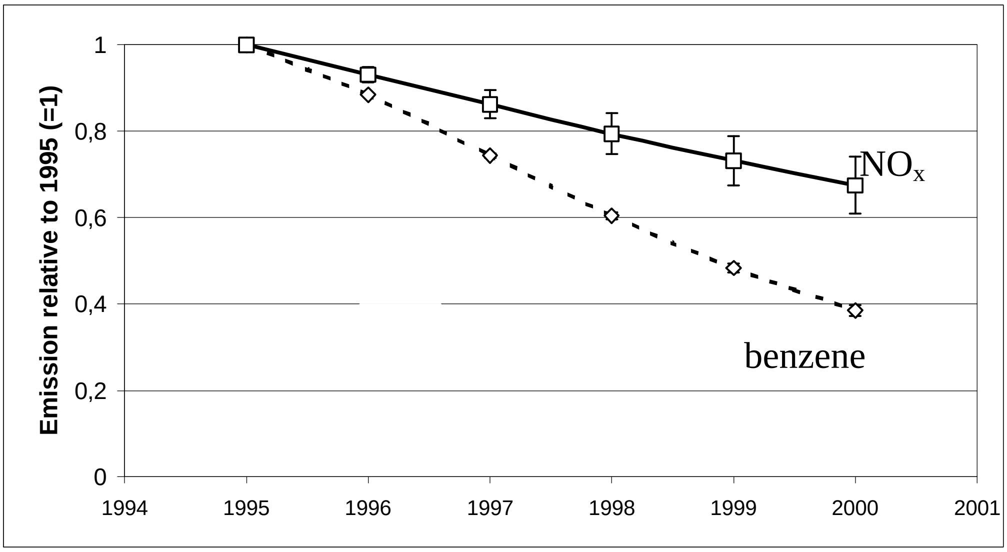

Fig. 1: Percentage decrease of benzene and NO_x emission in urban areas relative to 1995 together with the standard deviation due to different driving distance distributions, traffic patterns and truck percentages of 4 and 8%.

The resulting forecast is that, between 1995 and 2000, traffic-induced NO_x and benzene emission in urban areas should have decreased by 30-40% and 60% respectively. In order to compare this with the results of immission measurements, it is necessary to consider the background concentration due to e.g. industry and domestic fuel. At sites near heavily-used roads and with benzene concentrations of more than 5 $\mu g/m^3$, non-traffic-influenced background benzene concentration is expected to vary between 0% and 10% of the total immission here. This seems quite high, but emission of tank evaporation is also treated here as a background concentration. NO_x non-traffic emission is assumed to be 10% to 25% of the total immission near heavily-used streets. With respect to these background concentrations, the expected immission decrease is 55% - 60% for benzene and 23%– 35% for NO_x. For NO_2, which is toxicologically more relevant than NO_x and therefore subject to regulation, the estimated emission reduction is smaller than for NO_x.

Most of the NO_x is released as NO and subsequently converted to NO_2. The NO_2/ NO_x conversion ratio depends mainly on the ozone, HC and NO_x concentrations and this ratio increases while the NO_x concentration decreases. According to data from Romberg et al. (1996), a NO_2 reduction of 10 to 20% is expected while NO_x concentration decreases by 20% - 35%.

Table 2: Predicted reduction of immission in urban areas between 1995 and 2000, assuming the traffic induced emission decrease and background concentrations as discussed in the text.

Pollutant / Decrease expected	benzene	NO_x	NO_2
Minimum (%)	55	23	10
Maximum (%)	60	35	20

4 IMMISSION TRENDS NEAR HEAVILY-USED INNER-CITY STREETS

Data, exceeding a certain concentration level, from several urban air quality measuring stations[1] in 5 German states were selected in order to analyse the immission trend in urban areas. To derive a general trend, the annual mean immission concentration I_{iS} (j) at station i in the year j was standardised as follows:

$$I_{iS}(j) = 6 \cdot I_i(j) / \sum_{j=1}^{6} I_i(j)$$

$I_i(j)$ = annual mean immission concentration at station i in the year j

$\sum_{j=1}^{6} I_i(j) / 6$ = average concentration at station i

$I_{iS}(j)$ = Immission concentration standardised in respect to 1995-2000 mean.

Because immission is inversely proportional to wind velocity, a further standardisation was used in respect to relative annual mean wind velocity in the particular region. In figs. 2 and 3 the percentage decrease of measured benzene and NO_x immission (an average taken over all stations) is given.

[1] which were made available by local authorities

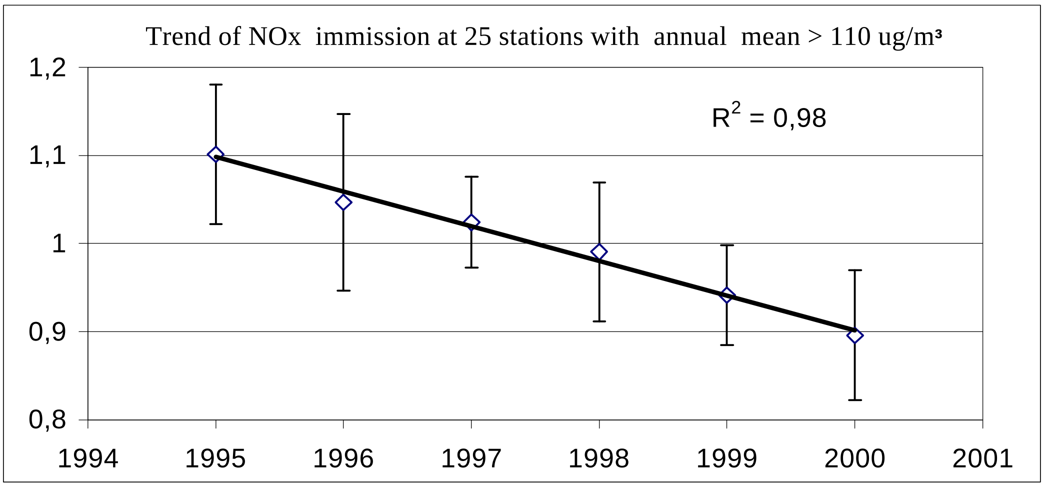

Fig. 2: Mean decrease of NO_x immission in urban areas at stations with an annual mean of more than 110 µg/m³ together with the standard deviation $\pm \sigma$

As can be seen from fig. 2, from 1995 to 2000, NO_x immission in urban areas decreases by about 18 %. Data from 25 stations were used with annual mean NO_x concentrations exceeding a pre-determined limit of 110 µg/m³. The correlation coefficient R^2 of 0,98 for NO_x reduction is surprisingly high, indicating a very uniform trend. The standard deviation σ for the variance between the decreases at different sites in one year is about 7%.

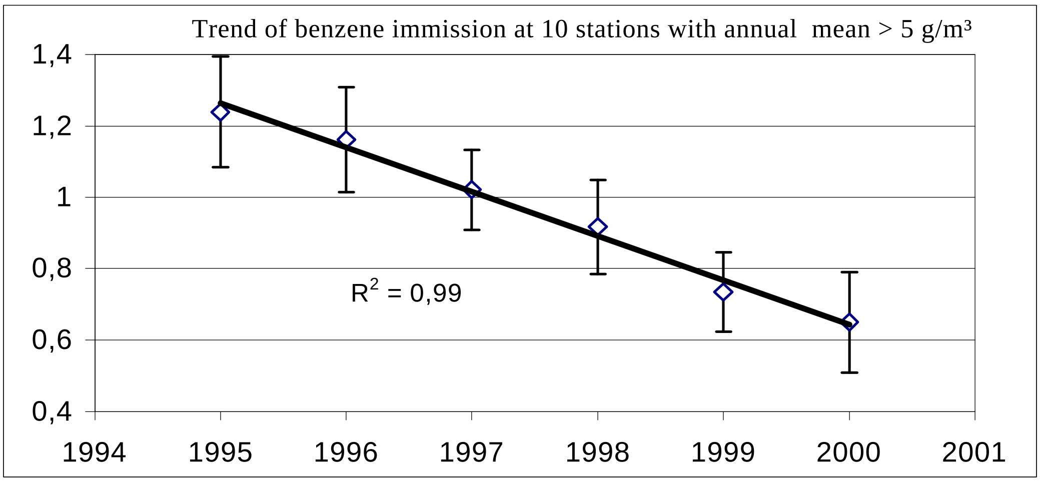

Fig. 3: Mean decrease of benzene immission in urban areas at stations with an annual mean of more than 5 µg/m³ together with the standard deviation $\pm \sigma$

Figure 3 shows the mean decrease of benzene immission in urban areas at stations with concentrations of more than 5 µg/m³. Immission decreases by about 55% in 6 years. Data from only 9 stations were available where benzene was measured for the whole time period and the mean concentration exceeds the pre-determined limits. The standard deviation σ for the variance between the decreases at different sites in one year is about 12%. This is larger than for NO_x due to the smaller data base. Fig. 4 shows the mean NO_2 immission trend observed at 30 measuring stations with a concentration of more than 40 µg/m³. In contrast to time-dependent NO_x and benzene immissions, between 1995 and 1999 no clear decrease of NO_2 concentration in urban areas can be derived. On the basis of the 1995 and 2000 value alone, a maximum reduction of about 10% might be possible within this 6 year period.

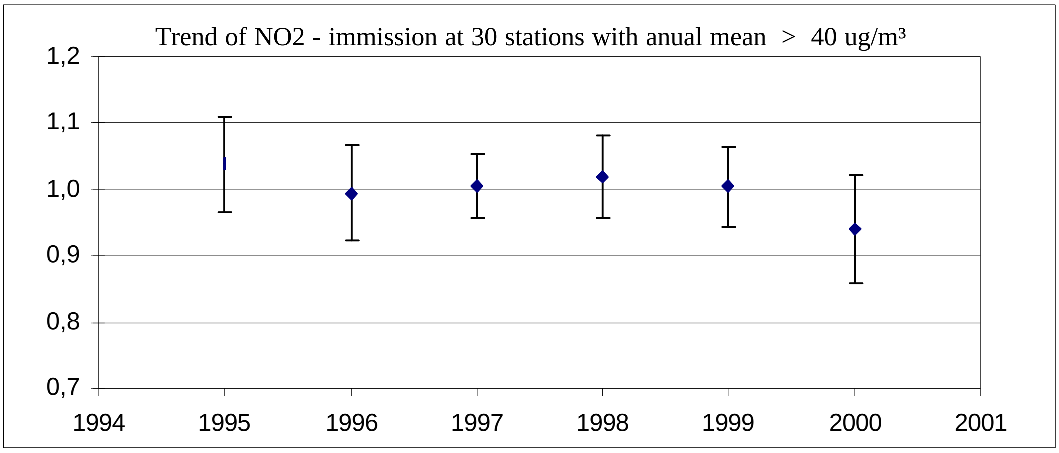

Fig. 4: Mean decrease of NO_2 - immission in urban areas at stations with an annual mean of more than 40 µg/m³ together with the standard deviation $\pm \sigma$

5 COMPARISON

By comparing the results

- predicted by the *Handbuch für Emissionsfaktoren* which is used for traffic-related environmental impact studies in Germany
- and derived from the measurements at traffic influenced air quality stations in urban areas

it can be seen that the mean decrease of benzene immission concentration in urban areas between 1995 and 2000 agrees with the emission forecast. For NO_x, in urban areas the immission reduction for this period is smaller than expected. And for NO_2 no significant decrease can be observed during the 5 years between 1995 and 1999.

Table 3: Results for benzene, NO_x, and NO_2 immission decreases between 1995 and 2000

	Expected decrease (predicted by HB) 1995-2000	Observed decrease (derived from measurements) 1995 – 2000	Agreement
NO_x	23% - 35%	18%	No
NO_2	10% - 20%	0 % - (10 % ?)	No
Benzol	55% - 60%	50% - 60%	Yes

It can be expected that future benzene immission will decrease in accordance with present predictions. But for NO_x and NO_2, it has to be assumed that further immission decreases will be lower than expected.

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