AIR QUALITY ASSESSMENT IN THE EUROPEAN MEGA CITY RUHR AREA: EFFECTS OF A LOW EMISSION ZONE

Diegmann Volker,[1] Florian Pfäfflin[1] and Sabine Wurzler[2]

[1]IVU Umwelt GmbH, Freiburg, Germany
[2]NRW State Agency for Nature, Environment, and Consumer Protection, Recklinghausen (LANUV), Germany

Abstract: The Ruhr area is the biggest German megalopolis, a conglomerate of several intertwining major cities, with more than 3.5 million inhabitants. In spite of many efforts in recent years to improve the air quality in the Ruhr area, especially residents in street canyons with a high traffic density are still exposed to poor air quality, and meeting the limit values of European air quality directives for PM_{10} and NO_2 remains a challenge. In this study, the hot spots in the area have been identified by a combination of measurements and modeling. Shares of industry, shipping, rail traffic, off-road traffic and heating were calculated. The road network of the Ruhr area was mapped with housing data in order to identify road sections with possibly affected inhabitants. The concentrations caused by local road traffic were then calculated with the screening model IMMIS^{luft}. Such, a road network of more than 3000 km in length and with over 8000 inhabited sections was investigated. In quite a large number of these sections, air quality was identified to be rather poor and measures have to be taken to improve the situation. One possible measure is the implementation of low emission zones. In the study, effects on air quality have been calculated for different scenarios of low emission zones. Due to the methodology, source apportionments for hot spots are easily available.

Key words: *air quality, screening, modeling, EC Directives, road traffic, low emission zone, environmental zone, PM_{10}, NO_2, source apportionment*

1. INTRODUCTION

Basically, five Mega Cities can be found in Europe: Île-de-France, Moscow, Greater London, Istanbul and the Ruhr area. The Ruhr area is the biggest German megalopolis with a population of more than 3.5 million occupying an area of more than 1800 km². It is a conglomerate of several intertwining major cities. The main European centre of integrated steel production with the world's biggest inland port is located in the area at Duisburg. Figure 1 shows the Ruhr area together with the major road network of about 3000 km in length.

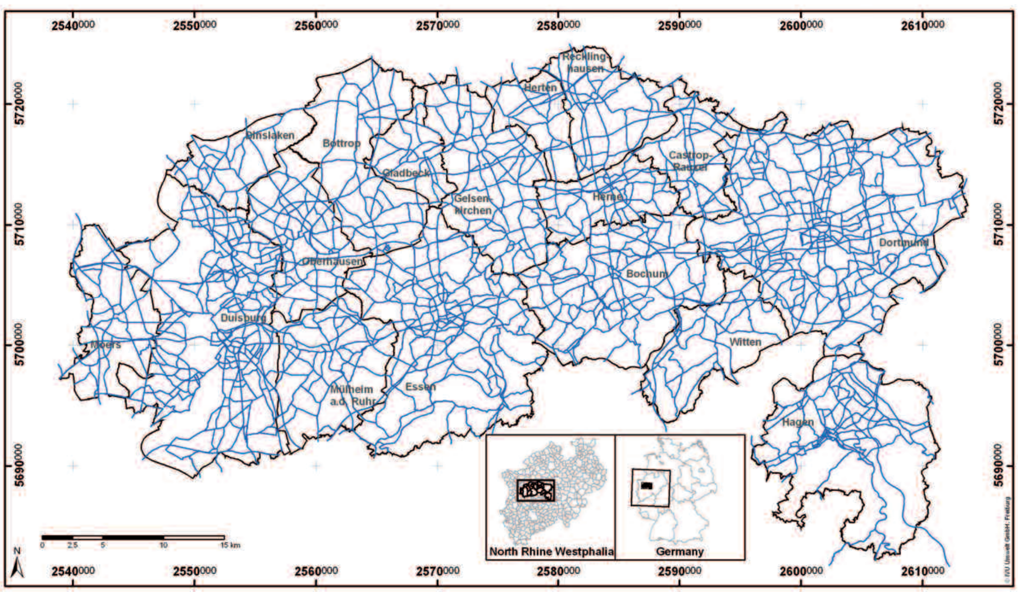

Figure 1. Study area "Ruhr" with major road network.

While air quality has improved significantly in the Ruhr area during the last decades, the combination of high population, traffic density and heavy industry makes it difficult to meet the limit values of the EC air quality directives (EC, 1996 and 1999), and air quality management remains still a challenge. Mainly the high number of exceedance days for PM_{10} and the annual average NO_2 concentrations well above the limit values endanger the health of the inhabitants of cities. As the assessment of air quality for a large area with measurements only is both impracticable and unaffordable, a model-based approach is required. The present paper focuses on the methods developed, applied and implemented to carry out such a task and the findings. The main sources for the high levels of air pollution in densely populated areas and in street canyons are the regional background concentrations, road traffic and, dependent on the infrastructure, industry. Air quality can be assessed by combining the contribution of these sources. The total concentration of a pollutant in a street canyon is the sum of the "regional background" caused by sources outside the study area, the "local background" caused by sources within the study area, and the "additional concentration" caused by the road traffic in the street canyon itself. The latter is influenced mainly by the traffic load of and the building situation along the street.

2. BASE SITUATION

Background concentration

The local background caused by sources within the study area was calculated with a resolution of 1x1 km² using IMMIS^{net} (IVU GmbH, 1996), a Gaussian multi-source dispersion model, taking into account emissions of industry, shipping, rail traffic, off-road traffic and domestic combustion for the entire Ruhr area. The regional background caused by sources outside the study area and long-range transport includes natural sources, agriculture and most of the gas to particle conversion processes. It was determined by combining the calculations of the chemistry transport model EURAD (1995) for North Rhine Westphalia with a resolution of 5x5 km² with the observations of more than 40 stations of the air quality monitoring network of the LANUV NRW (Diegmann and Wiegand, 2000), and taking out the local background from the IMMIS^{net} calculations. This resulted in an air quality map of the regional background with a resolution of 5x5 km², which, due to the methodology, to a certain extent also includes sources within the study area that are simply not known or cannot be quantified. Combining the regional and the local background leads to the overall background concentration for the Ruhr area. Figure 2 shows the regional and the overall background concentrations for NO_X for the study area. Additionally, a specific overall background value was calculated for each analyzed street section, considering all the sources but the analyzed section itself.

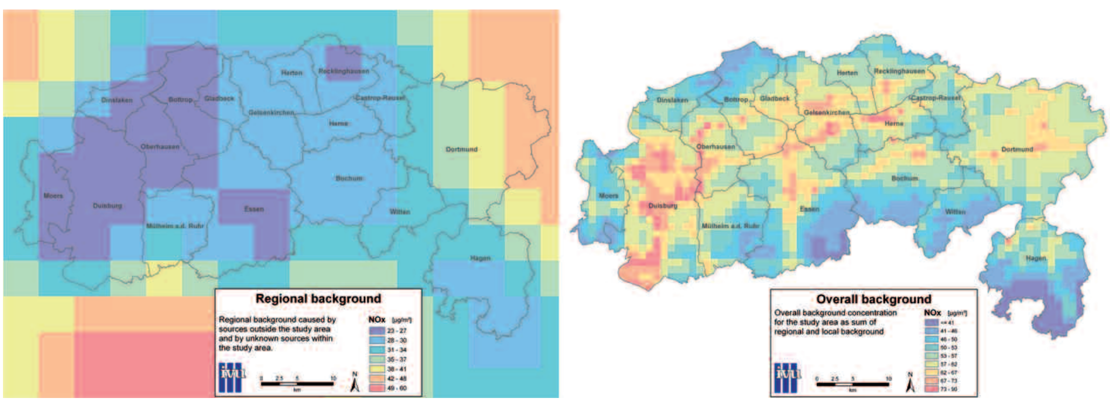

Figure 2. NO_X concentrations for the regional background and the overall background in the study area as annual mean values.

Additional concentration

The additional concentration caused by road traffic in the street canyon itself is influenced mainly by the traffic load of and the building situation along the street. The screening model IMMIS^{luft} (IVU Umwelt, 2005) uses a parameterized description of the street canyon, considering length and width of the canyon, average height of the buildings and building density along the street. In order to calculate the additional concentrations for all built-up streets in the Ruhr area, the road network had to be transformed into sections which are homogenous with respect to these parameters, and the numeric values of the parameters had to be derived. This was done using a semi-automatic GIS-based approach based on the road network and building data consisting of footprints and heights of the buildings (LoD1 model). Thus, over 8000 inhabited street sections were derived from the road network for further analysis. Based on the traffic data and the building parameters, the additional concentration in the street canyon was calculated for each section.

Results

The additional concentrations were added to the specific overall background concentration of the respective section, leading to the total NO_X- and PM_{10}-concentrations in the inhabited street sections. Total NO_2-concentrations were derived from NO_X-values using a statistical approach (IVU Umwelt, 2002). LUA (2006) states that the daily PM_{10} limit value according to the EC guideline, i.e. a maximum of 35 days with a daily mean above 50 μgm^{-3}, is possibly violated for annual means of 29 μgm^{-3} and above and violated with a high probability for annual means above 32 μgm^{-3}. According to IVU Umwelt (2006), the daily limit value of 35 days above 50 μgm^{-3} is reached at an annual mean of 30 μgm^{-3}. For PM_{10}, the results were classified according to these annual mean values and for NO_2 according to the limit value for the annual mean of 40 μgm^{-3} and 48 μgm^{-3} (limit value + tolerance for 2006). Comparison with measurement data for four hot spots within the study area showed a good quality of the modeled data being well within the data quality objectives of EC (1999). Modeled PM_{10} concentrations deviate between 0 and 9% from the measured data and modeled NO_2 concentrations between 0 and 17%.

The data was analyzed statistically, leading e. g. to the total length of inhabited street sections affected by violations of the respective limit values and displayed cartographically in colors green (good), orange (intermediate) and red (poor), the so-called „traffic light maps". Figure 3 and Figure 4 show the results for the base case for PM_{10} and NO_2.

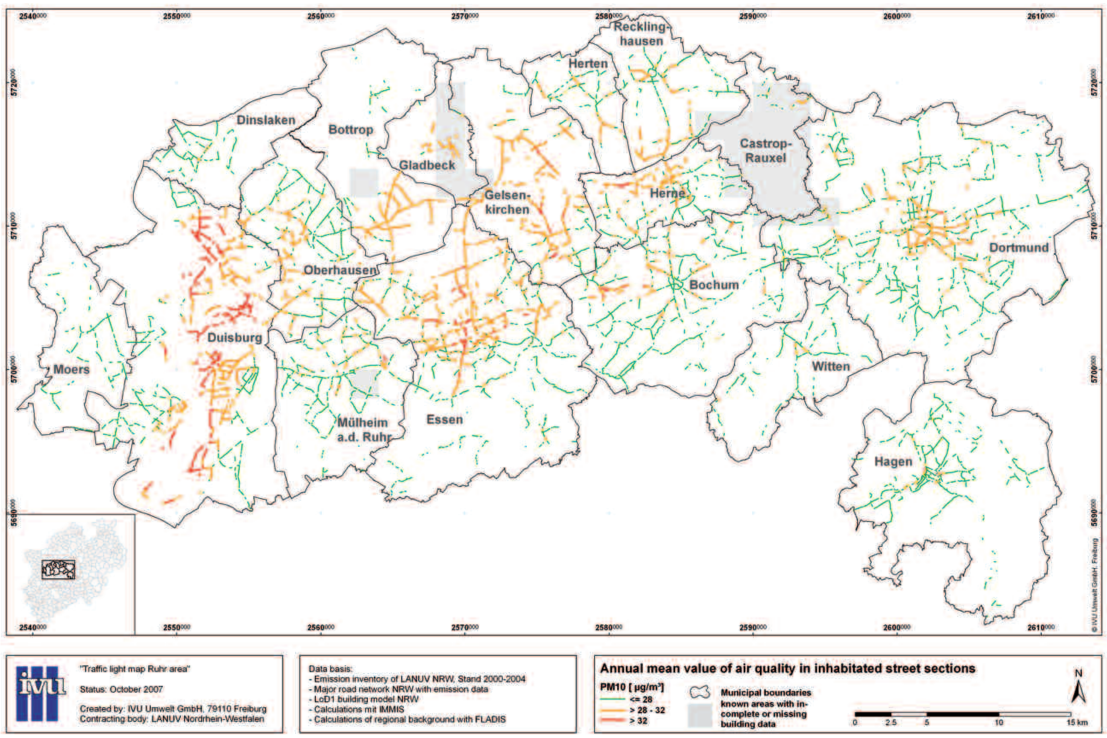

Figure 3. PM_{10} annual mean values in inhabited street sections in the Ruhr area.

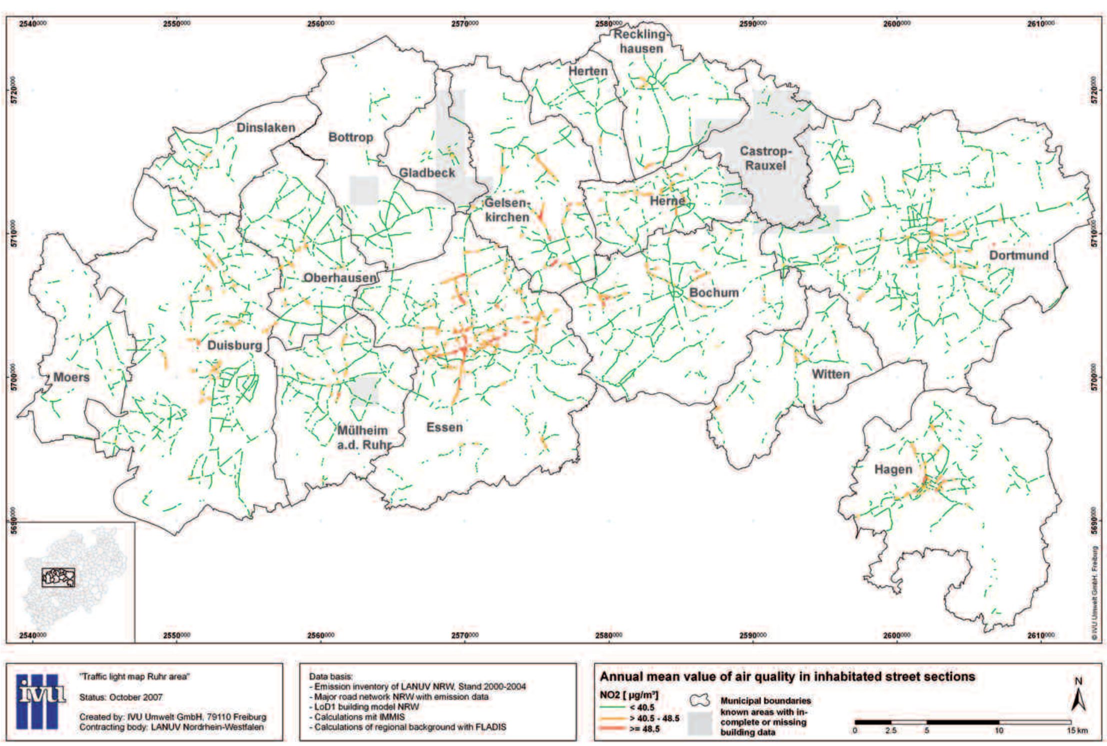

Figure 4. NO_2 annual mean values in inhabited street sections in the Ruhr area.

Source apportionment

As each source group was modeled separately, source apportionments for hot spots are easily available.

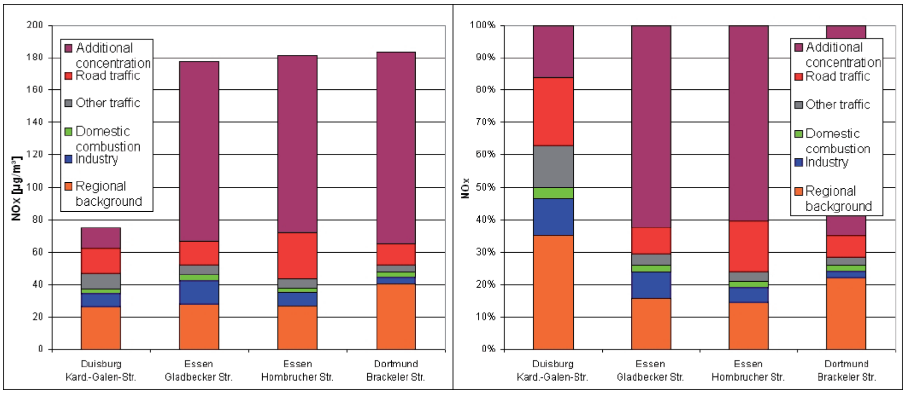

Figure 5. NO_X source apportionment with absolute (left) and relative (right) contributions for four hot spots in the study area.

3. LOW EMISSION ZONES

The results of the calculations described above were the basis for defining the planned low emission zones. Other aspects, e. g. accessibility, were considered as well in this political process that led to the low emission zones shown in Figure 6. Federal highways (Autobahnen) were generally set to be without traffic restrictions. For all other roads within the low emission zones, four different scenarios of traffic restrictions were analyzed:

1.) vehicles with Euro I or older exhaust emission technology are banned from the low emission zones and replaced with vehicles with newer technologies
2.) same as 1.) but vehicles with Euro I or older technology are not replaced, i. e. traffic is reduced
3.) same as 1.) but vehicles with Euro I and II or older technology are replaced with vehicles with newer technology
4.) same as 3.) but vehicles with Euro I and II or older technology are not replaced, i. e. traffic is reduced

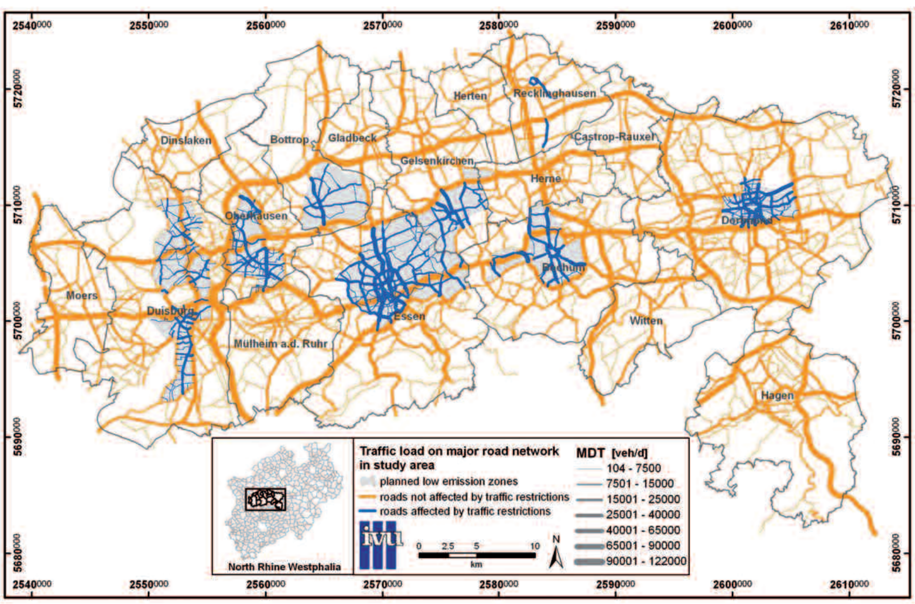

Figure 6. Planned low emission zones in the Ruhr area with mean daily traffic load (MDT) and traffic restrictions (cf. text).

The methodology described in the previous section was used to calculate the effects of the four scenarios for all inhabited street sections within the low emission zones, i.e. the local background and the additional concentrations were re-calculated under the planned conditions. The regional background is not significantly affected by the low emission zones and was kept unchanged. As before, the data was analyzed statistically, leading e. g. to the length of inhabited street sections affected by violations of the respective limit values, and compared with the base situation to assess the effect of the respective scenarios. Table 1 shows the affected length of all inhabited street sections within the planned low emission zones in the respective impact classes for PM_{10} and NO_2 together with the relative changes compared to the base situation. Figure 7 shows the relative changes for the upper two impact classes.

Table 1. Length of inhabited street sections within the low emission zones for the base situation and four scenarios of low emission zones (cf. text)

	Annual mean value (AMV) [µgm^{-3}]	Base situation		EURO I						EURO I+II					
				replacement			traffic reduction			replacement			traffic reduction		
		length [km]	frac-tion	length [km]	frac-tion	delta	length [km]	frac-tion	delta length	length [km]	frac-tion	delta	length [km]	frac-tion	delta
PM_{10}	AMV < 29	81.2	40.3%	87.7	43.5%	7.9%	92.4	45.8%	13.7%	89.1	44.2%	9.7%	103.7	51.4%	27.6%
	29 ≤ AMV < 30	41.0	20.3%	40.1	19.9%	-2.2%	41.7	20.7%	1.73%	40.6	20.2%	-0.9%	41.7	20.7%	1.72%
	AMV ≥ 30	79.4	39.4%	73.8	36.6%	-7.0%	67.5	33.5%	-15.0%	71.9	35.7%	-9.4%	56.2	27.9%	-29.2%
NO_2	AMV ≤ 40	153.2	76.0%	164.7	81.7%	7.5%	171.6	85.1%	12.1%	169.1	83.9%	10.4%	183.9	91.2%	20.0%
	40 < AMV ≤ 48	42.6	21.2%	32.9	16.3%	-22.7%	27.8	13.8%	-34.8%	29.7	14.7%	-30.4%	16.0	7.9%	-62.5%
	AMV > 48	5.8	2.9%	4.0	2.0%	-31.6%	2.1	1.1%	-62.9%	2.8	1.4%	-50.9%	1.7	0.9%	-70.2%

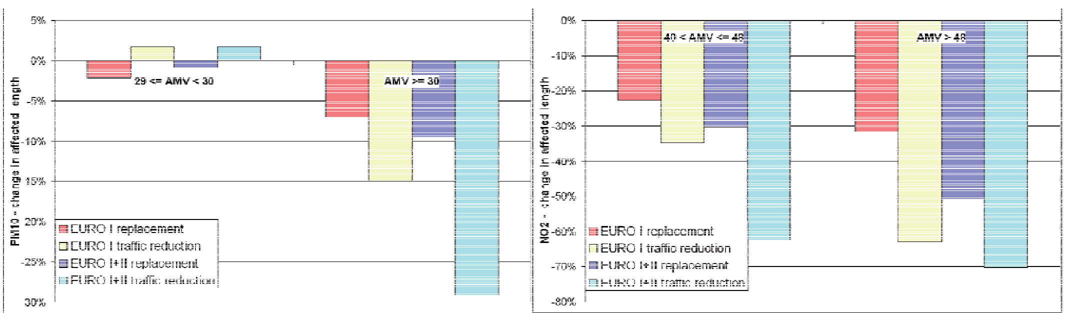

Figure 7. Change in length of inhabited street sections compared to base situation in two impact classes of annual mean values (AMV) for PM_{10} (left) and NO_2 (right) for four scenarios of low emissions zones (cf. text).

4. CONCLUSIONS

This paper presents a model-based methodology to assess the air quality in inhabited street sections and its successful application for the very large Ruhr area. Calculations for the base situation provide a detailed assessment of the current situation which cannot be achieved with measurements alone. Source apportionments give deeper insights into the situation. This provides the basis for the establishment of measures to improve the situation. In this study, low emission zones of different characteristics were introduced. The effects of the different scenarios were calculated and their efficiency assessed, e.g. in terms of the affected length of inhabited street sections, showing considerable improvements of the situation. Thus, a powerful tool and sound arguments are available for policy makers seeking to improve air quality in their cities.

REFERENCES

Diegmann, V. and Wiegand, G., 2000: FLADIS - A system for extending air pollution point data to continuous spatial information. Air Pollution, VIII. WIT Press, 2000. ISBN 1-85312-822-8.

EC, 1996: Council directive 96/62/EC of 27 September 1996 on ambient air quality assessment and management. *Official Journal of the European Communities*, No **L 296/55**.

EC, 1999: Directive 1999/30/EC of 22 April 1999 relating to limit values for sulphur dioxide, nitrogen dioxide and oxides of nitrogen, particulate matter and lead in ambient air. *Official Journal of the European Communities,* No **L 163/41**.

EURAD, 1995: http://www.eurad.uni-koeln.de/modell/eurad_descr_e.html

IVU GmbH, 1996: Entwicklung eines Modellinstrumentariums für § 40 Abs. 2 BImSchG. Teilvorhaben I im Rahmen des Projekts „Entwicklung eines Modellinstrumentariums zur immissionsseitigen Bewertung von Kfz-Emissionen“. FE-Vorhaben FKZ 105 02 812/2. Contracting body: Wuppertal Institut für Klima - Umwelt - Energie GmbH.

IVU Umwelt, 2002: Automatische Klassifizierung der Luftschadstoff-Immissionsmessungen aus dem LIMBA-Meß-netz. FE-Vorhaben FKZ 200 42 265. Contracting body: German federal environmental protection agency (UBA). 2002.

IVU Umwelt, 2005: IMMIS$^{em/luft}$ – Handbuch zur Version 3.2. IVU Umwelt GmbH, Freiburg.

IVU Umwelt, 2006: Maßnahmen zur Reduzierung von Feinstaub und Stickstoffdioxid. FKZ 204 42 222. Published as UBA-Texte 22/07. Contracting body: German federal environmental protection agency (UBA). Under participation of ifeu Heidelberg GmbH.

LUA NRW, 2006: Jahresbericht 2005. Landesumweltamt Nordrhein-Westfalen (now LANUV). Essen, 2006.