03.11 Traffic-related Air Pollution – NO_2 and PM10 (Edition 2008)

Overview

Original Situation

In the past, the reduction of emissions from industrial and domestic heating was the main focus of clean air planning. In these segments, sizeable reductions of airborne pollutant emissions could be achieved through extensive rehabilitation programmes and plant closures. Improvements could also be achieved in the area of traffic, but nonetheless, **traffic is the largest single source** of both current and future air pollutants - not only in Berlin - and is the determining factor for the course of action in clean air planning.

Due to historical development conditions, the spatial residential structure of Berlin and Brandenburg is "traffic-efficient". No other region in Germany has anywhere near such favourable conditions. Especially characteristic of Berlin are the clearly polycentric structures and the intensive utilisation of limited space in the inner city, as well as in the centres on the outskirts if the city, with intensive large and small scale multiple uses resulting in a lower degree of suburbanisation than in other large cities. Only 20% of the population lives in the surrounding area. Certainly this is in part due to the fact that large sections of the urban peripheral area are within the administrative borders of Berlin, as a result of the establishment of the amalgamated municipality of "Greater Berlin" in 1920.

Since 1990, the city and its immediate metropolitan area in Brandenburg have experienced considerable changes in their spatial structure, in terms of the distribution of the population, businesses, and jobs. Moreover, significant locations for shopping and leisure activities have been established, especially in the eastern part of the city and in the surrounding areas. The dynamics of change is continuing, but at a reduced rate.

Since reunification, the city of Berlin has been confronted with a considerable **increase in traffic**. The number of the motor vehicles registered in Berlin increased by 23% between 1989 and 2002, when a high point of 1,440,000 was achieved. This number has dropped continuously since then, and is now at 1,291,000 motor vehicles (as of 30 June 2008). The volume of traffic on Berlin's road network has not decreased, however, since the number of commuters from the surrounding areas, and the distances covered per vehicle, have increased. The future is expected to bring a further increase in traffic, especially in the pollution intensive segment of freight transport on the roads.

These far-reaching changes have not ended yet. The increase in traffic is caused, among other things, by the continuing expansion of the joint Berlin-Brandenburg residential and commercial area; the intensification of international economic interdependence; and, especially in Berlin, the increasing interdependence with Eastern Europe.

The Contribution of Motor Vehicle Traffic to Air Pollutant Concentrations: Origins and Trends

Berlin's motor vehicle traffic has for some years now been the cause not only of considerable noise immission in significant problem areas (see Map 07.05.1 & 2, Strategic Noise Maps of Road Traffic; 2008 Edition), but also of air pollution, especially since other categories that originally contributed to **air pollution** have been substantially reduced. Table 1 shows the combined emissions of all of Berlin's sources of major pollutants since 1989.

Since the fall of the Berlin Wall in 1989, many industrial enterprises have been rehabilitated or shut down, and the use of coal for fuel for the furnaces to heat Berlin's residences has been replaced with heating oil, natural gas, or district heating (cf. Map 08.02.1 Predominant Types of Heating; 2009 Edition, in preparation). In 1989, domestic heating and industry were significant sources of sulphur dioxide and particulate pollutants, but these have been reduced substantially. Between 2000 and 2005, total emissions of oxides of nitrogen were reduced by almost 30%, and of particulate matter by over 20%.

Table 1: Emissions in Berlin, by emission category						
	Data in tonnes per year (t/a)					
	1989	**1994**	**2000**	**2002**	**2005**	**Trend 2015**
Sulphur dioxide	**70801**	**17590**	**8868**	**7158**	**4666**	**3900**
Facilities requiring authorisation	60470	10870	5683	4433	2899	2580
Home furnaces	8526	4890	2500	2400	1513	1120
Small commercial	75	70	60	60	50	43
Traffic (only motor vehicles)	1440	1400	400	55	16	15
Traffic (other)	140	140	75	75	68	41
Other sources	150	220	150	135	120	102
Nitrogen oxide	**69971**	**42417**	**25981**	**21913**	**20312**	**16011**
Facilities requiring authorisation	41757	16172	8331	6499	6034	5913
Home furnaces	2704	3120	2860	2860	2945	2739
Small commercial	1200	700	190	185	160	124
Traffic (only motor vehicles)	21410	19025	12400	10455	9558	5833
Traffic (other)	1400	1300	1000	900	652	554
Other sources	1500	2100	1200	1014	963	847
Carbon monoxide	**293705**	**203948**	**94928**	**76133**	**69106**	**65197**
Facilities requiring authorisation	32443	3888	2028	1581	1521	1369
Home furnaces	68712	41560	8000	8000	5305	4934
Small commercial	1500	800	200	193	168	131
Traffic (only motor vehicles)	182050	144200	76500	51259	47767	46000
Traffic (other)	4000	3500	3100	3100	2945	2503
Other sources	5000	10000	5100	12000	11400	10260
Particulate matter (PM10)	**17580**	**8804**	**4729**	**4199**	**3769**	**3494**
Facilities requiring authorisation	9563	3161	960	650	384	376
Home furnaces	2693	1148	131	132	96	77
Small commercial	250	220	160	153	149	134
Traffic (only motor vehicles,exhaust)	1736	1135	667	394	355	166
Abrasion and dust from traffic stirred up by wind	1200	1150	997	1050	1024	1100
Traffic (other)	238	190	124	130	105	73
Other sources	1900	1800	1690	1690	1656	1568
Organic Gases	**103351**	**73703**	**32814**	**24251**	**21873**	**16455**
Facilities requiring authorisation	11801	3473	2554	1966	1596	1564
Home furnaces	5250	2340	550	550	502	351
Small commercial	15500	15000	6500	6484	5511	3858
Traffic (only motor vehicles)	49800	33890	12500	5661	5188	3500
Traffic (other)	3000	2000	1710	1710	1590	1193
Other sources and Households	18000	17000	9000	7880	7486	5989

Tab. 1: Emissions in Berlin by emission categories, 1989 to 2015 (trend)

Particulate emissions from motor vehicle exhausts also decreased by more than 80%. between 1989 and 2002. This finding agrees substantially with the measurements of diesel soot in so-called "canyon streets" - the major component of motor vehicle exhaust emissions: the measured soot concentration on Frankfurter Allee, in the Berlin neighbourhood of Friedrichshain, at measurement point 174 of the Berlin Air Quality Measurement Network BLUME has dropped by almost 40 % within the past 6 years. However, since particulates from street traffic caused by abrasion and stirred up by the wind have decreased only slightly during this period, **road traffic remains the second major source of particulate matter (PM10)** in Berlin, after "Other sources". Road traffic accounts for 34 % of particulate emissions in Berlin, while "Other sources" cause 40 %.

By the beginning of the 1990s, road traffic had replaced industrial plants as the main source of nitrogen oxides in Berlin. As of 2005, street traffic produced 53 % of the nitrogen oxides in Berlin, whereas industrial plants accounted for 30 % of total emissions.

Especially high in relative terms is the pollution from motor vehicle traffic in the inner city, where over one million people live in an area of 100 sq. km. Especially here, if current trends for use of and competition for space continue, motor vehicle traffic will increase. If current conditions continue, especially freight transport will encounter increased bottlenecks in the streets.

- the Urban Development Plan for Traffic; and
- the Berlin Clean Air Maintenance and Action Plan, 2005 -2010.

With the **Urban Development Plan for Traffic**, the Berlin Senate in a resolution of 8 July 2003 presented an action plan which combines the possible and necessary steps for the further development of the Berlin traffic system for the coming years with a long term strategic orientation. The core of the action plan is a catalogue of measures that were previously analysed in detail and coordinated for effectiveness, acceptability and fundability. With regard to the future development of traffic in Berlin and the surrounding area, the investigations for the Berlin Clean Air Maintenance Plan are based on this long term action concept.

"Health and Safety", one of the key strategic components of the Urban Development Plan for Traffic, includes a number of important strategies to limit the increase of motor vehicle traffic and its associated effects, with the goal of a reduction of air and noise pollution in the primary road network. The implementation of the measures of the Urban Development Plan for Traffic is expected to be completed by 2015.

The standardised **Clean Air Maintenance Plan** mandated by the EU was adopted by the Berlin Senate in August 2005.Under Europe-wide standards, the Clean Air Maintenance Plan data must include information on:

- pollution measurements;
- the causes of high air pollution levels;
- the frequency and degree of instances in which the limits are exceeded;
- pollution immission and the proportions of the immission for each causative factor (e.g. industry, commercial activity, home heating, traffic);
- planned measures, and a schedule for implementation; and
- a prognosis of the goals to be achieved by such measures.

The present Clean Air Maintenance Plan provides information about the legal framework and the prevailing situation, and describes the causes of air pollution. The measures take into account future developments of the condition of the air through 2010. The focal point is the presentation of a range of potential measures and their evaluation. Based on the effectiveness of these measures, a strategy will be developed for the Berlin Clean Air Maintenance Plan. The Clean Air Maintenance Plan documents that Berlin, like many other large German and European cities, faces a major challenge to meet the new EU limits.

The essential results can be described summarily as follows: the locally generated segment of the pollution, which can only be reduced by Berlin measures, accounts for about half of the particulate pollution; it is caused by the urban background and other local sources. Urban background pollution is caused mostly by road traffic (16 % of the total pollution of PM10). The rest (11 %) consists of approximately equal shares of the emissions form Berlin Residential heating, Industry/ power plants, Construction, and Other sources in the city.

The results of the measurements of recent year and the model calculations carried out for 2005 lead, among other things, to the following conclusions:

- The multi-year trend of particulate and nitrogen dioxide pollution shows only a very slight decline. The high PM10 values in 2005 and 2006, and the drop in 2007 and 2008 are largely due to the weather.
- In 2005 and 2006, the 24-hour values for particulates and the annual values for nitrogen oxide were exceeded at all measurement points located close to traffic. The calculations for 2005 show widespread instances of exceeding the limits in the entire primary road network, especially in the inner city.

These investigations indicate that the two most problematic pollutants in Berlin are NO_2 and PM10. Because of their physical effect, strict limit values for these substances must be upheld in the European Union and in Germany.

Effects

Nitrogen oxides are acidifiers. They are harmful to human health, cause damage to plants, buildings, and monuments, and contribute significantly to the excessive formation of ground level ozone and various noxious oxidants during summer heat waves.

Nitrogen oxides, especially nitrogen dioxide, lead to irritation of the mucus membranes of the respiratory passages in people and animals, and can increase the risk of infection (see Kühling 1986). Cell mutations have also been observed (BMUNR 1987). Various epidemiological studies have shown a correlation between the deterioration of the functions of the lungs, respiratory tract symptoms, and increased nitrogen dioxide levels (see Nowak et al. 1994).

Diesel soot is a major component of **particulate matter (PM10)** in motor vehicle exhaust. It is a carrier for polycyclic aromatic hydrocarbons (PAH), a carcinogen, but also on its own, it is a possible cause of lung and bladder cancer (see Kalker 1993). Moreover, such ultra-fine particulate as diesel soot, smaller than 0.1 µm, is suspected to increase the risk of cardiovascular disease.

Legal Stipulations and Limit Values

An evaluation of air pollution from motor vehicle traffic has only become concretely possible for immission control authorities since 1985, since the European Community, in the Directive of the Council of 7 March 1985 on Air Quality Standards for Nitrogen Dioxide (Directive 85/203/EWG), specified limits and goals for this pollutant. In addition, it stipulated that measurements be taken of concentrations of nitrogen dioxide on "canyon streets" and major intersections.
In 1996, due to a multiplicity of new findings regarding this and other air pollutants, "Directive 96/62/EG On Ambient Air Quality Assessment and Management (the so-called "Framework Directive ") was drafted and brought into force.
In this Directive, the Commission is called upon to submit, within a specified time period, so-called "subsidiary directives" stipulating limits and details for the measurement and assessment of a specified list of components.

Since then, four subsidiary directives have come into force:

- on July 19, 1999, Directive 99/30/EG, with limits for sulphur dioxide, particulate matter (PM10), nitrogen dioxide and lead;
- on December 13, 2000, Directive 2000/69/EG, with limits for benzene and carbon monoxide;
- on February 9, 2002, Directive 2002/3/EG, for comparing ozone at ground level to the data and level of excess over the limits; and
- on December 15, 2004, Directive 2004/107/EC, with limits for arsenic, cadmium, mercury, nickel and PAH.

Germany had two years to enact the first two subsidiary directives into national law, a deadline it missed substantially, as the Seventh Amendment to the Federal Immissions Protection Law (BImSchG), which addressed the first subsidiary directive, was not enacted until September 2002. The new Ozone Directive has now also been enacted into German law with the new 33rd Ordinance of the BImSchG.

The core elements of the Air Quality Directives are the immission limit values, which are "to be attained within a given period and not to be exceeded once attained". The pollution concentrations, and the time in which the limits must be met, are stipulated in the subsidiary directives, and in the 22nd Ordinance to the BImSchG (22nd BlmSchV).

Table 2 shows the stipulated limits for the two air pollutants which pose the greatest potential problem for Berlin: PM10 and nitrogen dioxide.

Tab. 2: EU-wide emission limit values and deadlines for PM10 and nitrogen dioxide			
Substance	**Mean for**	**Limit value**	**Deadline**
PM10	24 hrs.	50 µg/cu.m 35 transgressions/yr.	01 January 2005
	1 year	40 µg/cu.m	01 January 2005
NO2	1 hr.	200 µg/cu.m 18 transgressions/yr.	01 January 2010
	1 year	40 µg/cu.m	01 January 2010

Tab. 2: EU wide immission limit values and deadlines for PM10 and nitrogen dioxide stipulated in the 22nd BlmSchV

In the new EU Directive 2008/50, new limit and reference values have been established for very fine particulate PM2.5 (i.e., with a particle diameter of less than 2.5 µm), and the compliance deadline for the NO2 and PM10 limit values is extended by up to 5 years, under certain circumstances.

Under Paragraph 1 of the 22nd BlmSchV, Berlin is a metropolitan area in which the air quality must be evaluated annually and, if necessary, measures must be taken to comply with the limits. The entire city was designated as a planning area for the possible establishment of a plan to preserve air quality. Exceeding of the limits occurs throughout the city, especially on primary roads. It therefore makes no sense to limit the planning area to parts of the city, or to divide the city into distinct planning areas.

Problems in Applying Directive 99/30/EC and the 22nd BImSchV, Using the Example of PM10 Pollution in the City

In the proximity of high pollution immission, such as on canyon streets, high concentrations of immission occur. Unlike in most industrial areas, there are many people on traffic filled streets, be they residents, customers or workers, who face increased exposure to pollution. In order to meet the EU Directives for emissions at the locations of the highest concentrations, quantification of harmful pollutants must be as accurate as possible. For this purpose, such measurements have in Berlin been supplemented by model calculations for all high-traffic streets in which limits could potentially be exceeded.
However, even on a high-traffic canyon street, the proportion of pollution stemming from other sources in the city or transported in from outside , is an important factor. Therefore, for the planning of measures to improve air quality in Berlin, a system of models was used, which can calculate the effect of pollution from the surrounding area as well as the effect of all emitters within the city, even on high-traffic canyon streets. The model uses the levels:

- "canyon streets"
- city wide background pollution, and
- regional background pollution.

The simplified diagram shown in Figure 1, which shows the spatial distribution of PM10 concentrations in Berlin and the surrounding area, was developed from these investigations of the source of particulate matter pollution in Berlin.

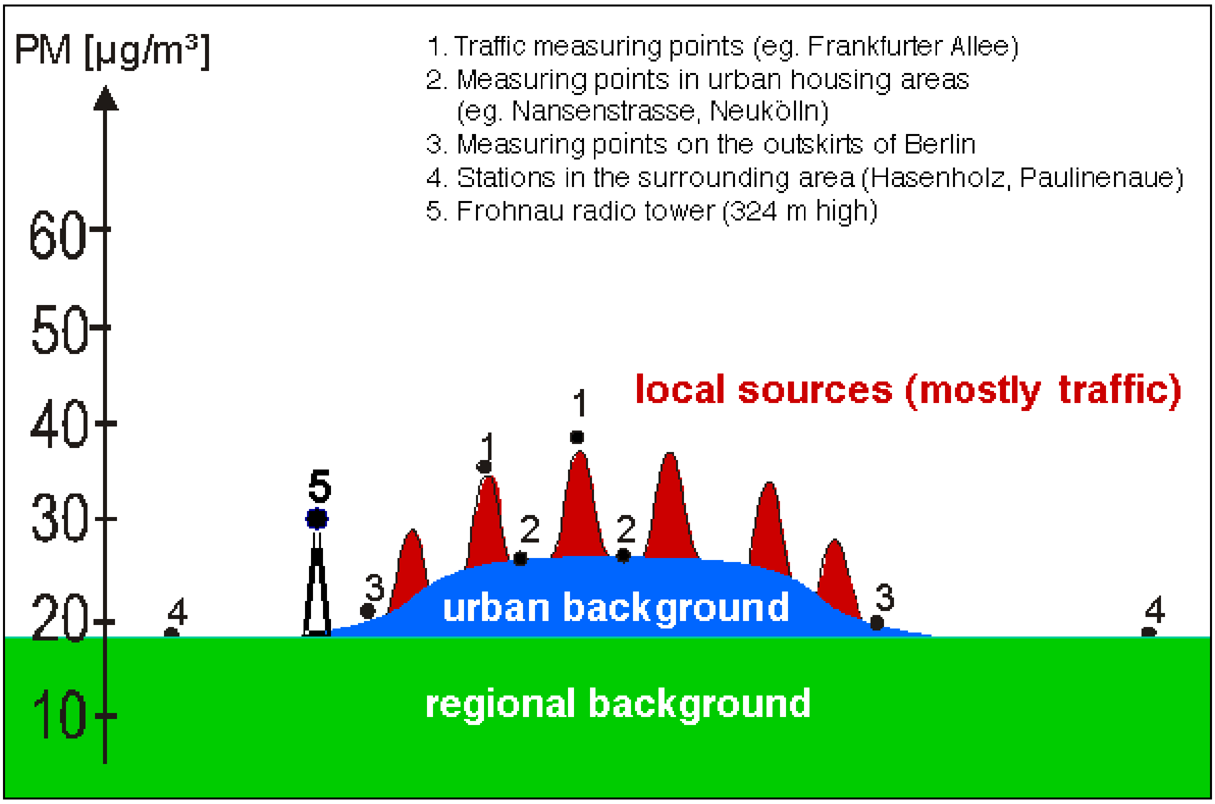

Fig. 1: Diagram showing the concentration of particulate (PM10) pollution in Berlin and the surrounding area (SenStadt 2005b)

There is a broadly distributed background level (green area of chart) which, according to measurements taken at several rural stations in Brandenburg in 2002, amounts to almost 20 µg/cu.m. The component, known as the "regional background pollution", is distributed relatively evenly outside of the city, as the results of the large-scale model show. Added to that is the proportion of PM10 pollution caused by local Berlin-based sources. It includes:

- that portion obtained by the combination of all of the emissions form all Berlin sources: power plants, industry, residential heating (blue area). Together with the regional background, this equals the particulate concentrations measured in the residential areas of the city remote from traffic and industry;
- an additional portion caused by local emitters in the immediate area of the source, such as motor vehicle traffic on Frankfurter Allee (red peaks).

In sum for Berlin, barely half the PM10 pollution measured at stations near traffic in the inner city comes from the regional background and the other locally caused particulate pollution. That portion is equally divided between the amounts produced by local traffic and the pollution sources in the remainder of the city. Only this last share can be influenced by local measures in Berlin.

Statistical Base

Motor Vehicle Traffic Emissions Registry

The Motor Vehicle Traffic Emissions Registry was compiled anew on the basis of traffic counts for 2005, because according to experience to date, this category of polluters contributes significantly to particulate and nitrogen oxide pollution. Traffic counters have been installed at many locations on the primary roads of Berlin since 2001. This data serve to make the current traffic patterns in Berlin accessible, and to incorporate them into traffic management. This information is evaluated in the **Office of Traffic Management (VMZ)**, and is used to inform the populace (especially drivers) of traffic conditions and provide routing recommendations to avoid traffic jams via radio broadcasts, the internet, and centrally located sign boards.

Ascertainment of Traffic Volume

Since 2002, the data from approx. 400 detectors at about 300 locations within the Berlin primary road network have been available at the VMZ. Many of these detectors distinguish between cars and lorries, and can be used for approximate annual traffic counts.

In addition for 2005, traffic count figures for cars and lorries from an official count by trained persons at many intersections ordered approximately every 5 years by the Senate Department for Urban Development were available. Compared with counts by detectors, this official traffic count has the advantage of being better able to distinguish between lorries of more than 3.5 t and other motor vehicles. Therefore, this traffic count was selected as the basis for the Emissions Registry for 2005, as the 1999 and 1994 counts had been.

The exhaust emissions were then ascertained as follows:

- The extrapolation of the point-related intersection counts to the entire Berlin primary road network with a traffic-flow computational model (VISA) by the Senate Department for Urban Development yielded the results showing the mean daily traffic figures (DTV) and the proportions of lorries for all major streets.
- The ascertainment of the segment-related pollution of the primary road network with regular bus traffic of the Berlin Transit Company (BVG) is calculated from the bus schedule data for 2005.
- The calculation of the emissions with the emission factors from the UBA manual for emissions factors (Edition 2.1, 2004) with consideration for the type of road and its function, was ascertained with the aid of the programme IMMIS$^{em/air}$.

Ascertainment of Emissions

The pollution emissions from motor vehicle traffic include exhaust and abrasion emissions from moving traffic, evaporation emissions from standing traffic, and evaporation emissions from fuel stations. Figure 2 provides an overview of the survey system. Emissions at fuel stations are assigned to "small business".

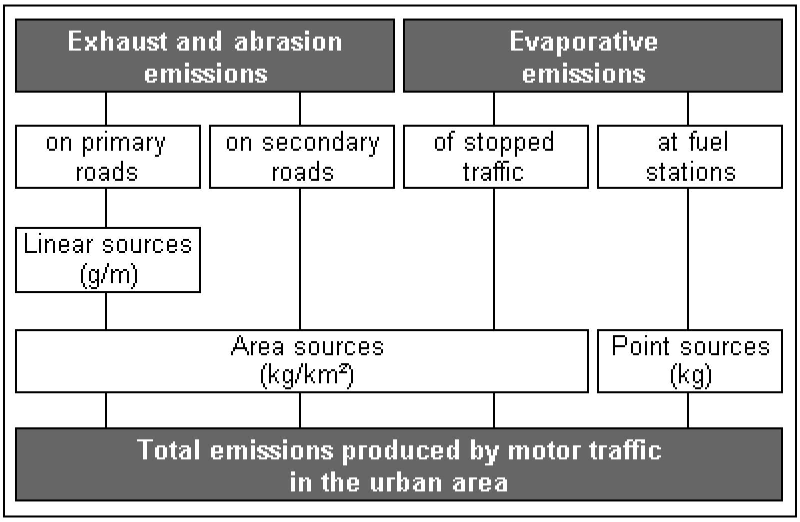

Fig. 2: Survey systems for the Traffic Emissions Registry, 2002

The pollution and CO_2 emissions of linear sources (primary roads) and area sources (secondary road networks and evaporation emissions) are calculated with the aid of emission models.

The exhaust and abrasion emissions appear as linear sources on primary and secondary roads. However, they are only calculated as linear sources for the primary road network, because the aforementioned DTV traffic counts are only available for those streets. The emissions from the linear sources are then assigned to the grid network as area sources. The emissions from the secondary road network are, however, derived directly from estimates of traffic volume and lorry shares for each grid.

The Emissions Models Primary Roads (Linear Sources) and Secondary Road Networks (Area Sources)

Exhaust emissions from motor vehicle traffic depend on factors which can be summarised as traffic-specific and motor vehicle-specific quanta.

Traffic-specific quanta are described by traffic density, i.e. the number of vehicles moving on a given section of a street (source), and their driving style (driving mode). Driving style is determined according to different street types (city centre street, secondary road, primary road with or without traffic lights, freeway), and function (shopping street, residential street, or access street).

The **motor vehicle-specific quanta**, generally expressed by exhaust emissions, are determined by:

- the type of engine (four-stroke, two-stroke or diesel)
- the type of carburetion (carburettor or fuel injection)
- the type of fuel (two-stroke mixture, gasoline, diesel)
- the type of purification system, if any (regulated or unregulated catalytic converter, recycling of exhaust gases); and
- other factors pertaining to the technical condition of the engine.

Emissions also depend on the driving style (driving mode), and are therefore stated for various driving styles. Cold weather starts, which lead to increased emissions during the warm-up phase of the engine, together with evaporation emissions, are considered important vehicle specific quanta.

The emissions factors are provided in the UBA Emissions Factors Manual (Version 2.1, April 2004) for each year from 1990 through 2020. It lists the emission factors for all relevant emitted substances for each vehicle group (passenger cars, light commercial vehicles, motorised two wheeled vehicles, busses and heavy commercial vehicles), for currently at least five reduction levels (1980s ECE cycle, Euro I, Euro II, Euro III, Euro IV, Euro V - only for heavy commercial vehicles), and for each type of street.

The stricter exhaust standard Euro 5 for cars is stipulated as mandatory for new vehicles as of September 2009. However, the planned stricter standard Euro VI for heavy commercial vehicles and Euro 6 for cars will very likely become effective only as of 2013. These exhaust standards cannot be taken into account with the present version of the UBA manual, so that realistic forecasts of motor vehicle emissions are only possible through 2010, and to a limited degree through 2015.

Ascertainment of Emissions from Abrasion and Air Movement Caused by Street Traffic

With today's knowledge, it is assumed that a large part of traffic related PM10 emissions do not originate from vehicle exhaust, but rather from the wind stirring up the particulate matter lying on the street surface, and from tyre and brake abrasion.

The calculations of these emissions with $\text{IMMIS}^{\text{em/air}}$ are based on the modified EPA formula from corresponding investigations. This formula was developed from measurements taken on Schildhornstrasse and on Frankfurter Allee, and is based on the finding that approximately 50 % of the measured additional particulate in canyon streets in not attributable to motor vehicle exhaust, but is rather caused by motor vehicle related abrasion (braking and street/tyre abrasion) and air movement. Since exhaust emissions have since been further reduced by improved engine technology, the proportion of additional pollution due to non-exhaust-caused emissions is today considerably higher than 50 %.

Figure 3 shows each output quantum for the calculation of exhaust and abrasion emissions from traffic, such as driving style factors, "stop and go" supplement, cold weather start factors etc., as well as the results.

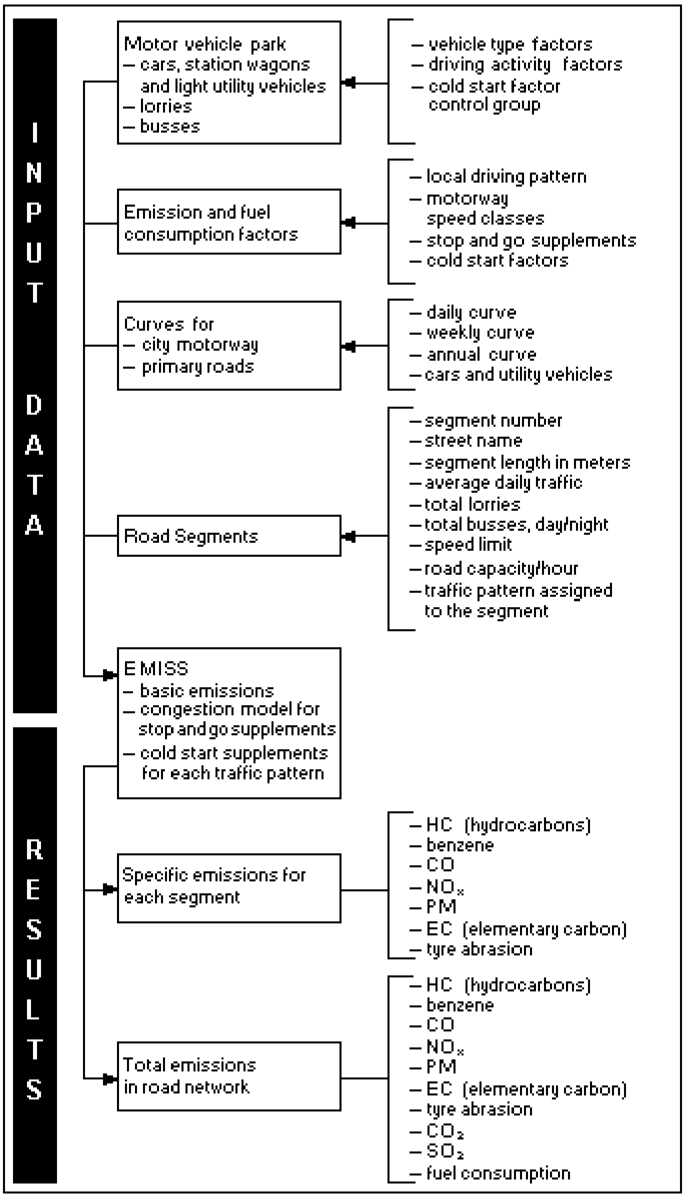

Fig. 3: Emission model for the calculation of quantities of emitted pollutants on primary roads (Liwicki, Garben 1993)

Emissions from motorised two wheeled vehicles cannot be shown due to a lack of traffic counts on the primary road network. Their contribution to the total is determined on the basis of the average traffic load in Germany and available emissions data.

For areas with distinct orography, the street sections should be arranged in longitudinal categories. However, this is not necessary for Berlin.

Emission Model Secondary Roads Networks (Area Sources)

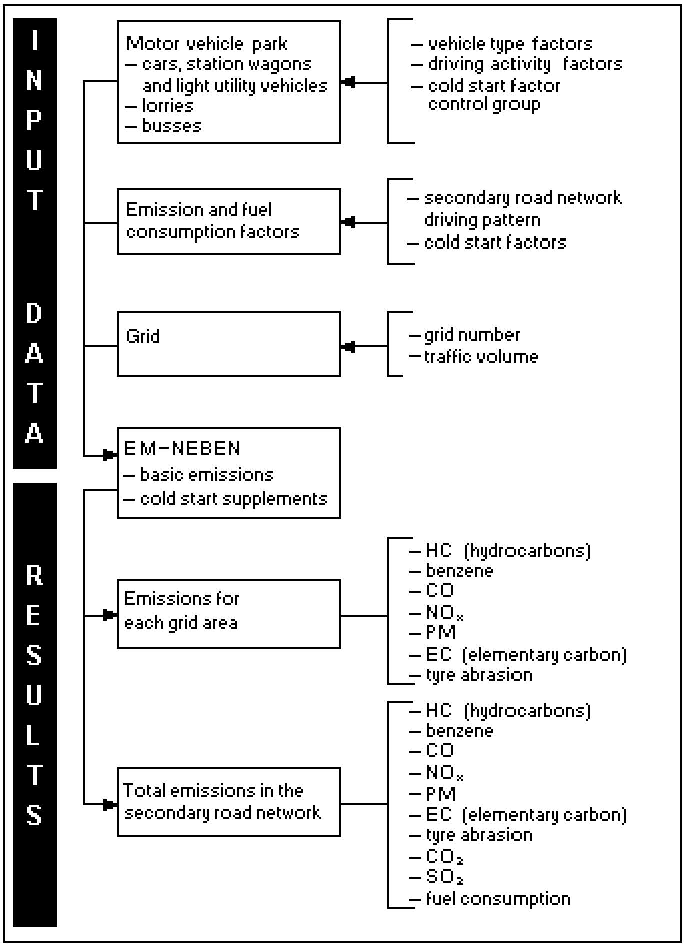

Fig. 4: EM-NEBEN - Emission model for the secondary roads networks (Area Sources) (Liwicki, Garben 1993)

The traffic pollution on secondary roads for 2005 was calculated with the aid of the traffic routing programme VISUM, based on the underlying source-goal relationship. The resulting total driving performance and the proportion of heavy commercial vehicles was assigned to traffic cells in the city. The emissions from exhausts, ,and from dust stirred up by wind and from abrasion in secondary roads, was determined using the IMMIS$^{em/air}$ emissions module.

In secondary roads networks, emissions are not calculated for specified sections of streets, but rather as grids per square kilometre. The driving performance for the grids is determined on the basis of:

- predominate use of the area, either
  - residential areas in the outskirts;
  - commercial and industry; or
  - inner city and sub centres
- the number of residents and jobs is categorised as
  - trade and service jobs, or
  - manufacturing,
- the results are in source/goal matrices of motor vehicle traffic.

Further inputs for determining total emissions of each pollution component for each area correspond to those for the calculations in the primary roads network.

Exhaust and Abrasion Emissions in the City

Table 3 breaks down the driving activity caused by motor vehicle traffic in the city of Berlin (millions of vehicle kilometres per year); fuel use (t) and the exhaust and abrasion emissions of vehicular traffic (t/year), by type of vehicle, for the reference year 2005.

Table 3: Traffic volume (million vehicle km per year), fuel consumption (tonnes) and exhaust and friction emissions (tonnes per year), by motor vehicles type, in the city of Berlin - reference year 2005

	Total	Cars and station wagons	Heavy lorries	Light commercial transport	Transit busses	Motorized two wheelers
Primary streets						
Driving activity	10.630,4	9.229,7	419,3	771,7	82,1	127,6
Fuel consumption	840.896,5	625.458,8	106.753,4	70.859,0	29.372,2	8.453,1
Hydrocarbons	2.506,4	1.899,5	217,8	145,3	77,3	166,5
Benzene	143,2	119,3	5,0	9,1	1,3	8,5
Carbon dioxide	2.669.846,9	1.955.253,6	383.911,3	224.977,3	93.256,6	12.448,1
Carbon monoxide	35.326,4	30.915,9	1.022,0	1.640,4	258,2	1.489,9
Nitrogen oxide	7.799,8	3.062,8	3.088,0	648,8	984,1	16,2
Particulate matter (PM10) (total)	1.162,4	606,5	298,5	168,7	83,2	5,6
from exhaust	290,0	108,1	97,7	58,7	23,5	2,0
from tyre abrasion, stirred up by wind, etc.	872,4	498,4	200,8	109,9	59,7	3,7
Elemental carbon (exhaust and tyre friction)	346,7	213,0	70,2	43,5	19,3	0,7
Benzo(a)pyrene	0,023	0,008	0,010	0,003	0,002	0,0
Sulphur dioxide	12,4	9,3	1,5	1,0	0,5	0,1
Secondary streets						
Driving activity	2.010,9	1.791,7	61,7	140,1	7,6	9,8
Fuel consumption	190.782,1	147.908,1	19.891,9	14.619,6	7.730,6	631,9
Hydrocarbons (also from tank respiration)	2.681,4	2.436,2	94,4	129,0	10,2	11,6
Benzene	54,5	51,6	0,4	2,3	0,0	0,2
Carbon dioxide	569.872,6	437.302,4	56.296,5	48.130,8	26.403,3	1.739,6
Carbon monoxide	12.440,8	11.667,8	97,0	598,1	26,3	51,6
Nitrogen oxide	1.638,0	917,5	490,5	130,4	98,7	0,9
Particulate matter (PM10) (total)	186,6	98,0	57,0	23,8	7,6	0,2
from exhaust	65,3	22,7	25,0	13,7	3,8	0,1
from tyre abrasion, stirred up by wind, etc.	151,6	94,1	40,0	12,6	4,8	0,1
Elemental carbon (exhaust and tyre friction)	33,5	14,2	11,5	6,2	1,6	0,0
Benzo(a)pyrene	0,008	0,004	0,002	0,001	0,0	0,0
Sulphur dioxide	3,5	1,7	1,0	0,6	0,2	0,0
Entire City						
Driving activity	12.641,3	11.021,4	481,0	911,8	89,7	137,4
Fuel consumption	1.031.678,7	773.366,9	126.645,3	85.478,7	37.102,8	9.085,0
Hydrocarbons	5.187,7	4.335,6	312,2	274,3	87,5	178,1
Benzene	197,9	171,0	5,4	11,5	1,3	8,7
Carbon dioxide	3.239.719,6	2.392.556,0	440.207,8	273.108,1	119.660,0	14.187,7
Carbon monoxide	47.767,3	42.583,8	1.119,0	2.238,5	284,5	1.541,5
Nitrogen oxide	9.437,8	3.980,3	3.578,5	779,2	1.082,8	17,1
Particulate matter (PM10) (total)	1.191,8	610,9	316,0	170,6	89,2	5,1
from exhaust	355,3	130,8	122,7	72,4	27,3	2,1
from tyre abrasion, stirred up by wind, etc.	1.024,0	592,5	240,8	122,5	64,4	3,8
Elemental carbon (exhaust and tyre friction)	380,2	227,1	81,7	49,7	21,0	0,7
Benzo(a)pyrene	0,031	0,012	0,011	0,005	0,002	0,001
Sulphur dioxide	15,9	11,0	2,5	1,6	0,7	0,1

Tab. 3: Traffic volume (million vehicle km/year), fuel consumption (t) and exhaust and abrasion emissions (t/year) in the municipal area of Berlin, by type of vehicle; Reference year: 2005

The new method of measuring emissions for this registry is also a suitable basis for dispersion calculations to determine the extent of pollution at streets. The extensive reorganisation of calculation methods permits only very limited comparisons with previous emissions increases, because these were based on a much simpler method of calculation.

Immission - The Results of Stationary Measurements

Street measurement points are operated to ascertain the pollution caused by motor vehicle traffic, in the framework of the automatic BLUME air measurement **street measurement station** system. In

recent years, some changes have been carried out in the Berlin air quality measurement system, in order to comply with EU Directives and the amendments to the BImSchG and the 22nd BImSchV of 2002, resulting from those directives.
Since the concentrations of sulphur dioxide and carbon monoxide have now been reduced to only a fraction of the limit values, the measurement of these substances has been correspondingly reduced. At the same time, more attention is being directed towards the ascertainment of **particulate matter (PM10)** and **nitrogen dioxide**, particularly in the proximity of traffic.

Measurement of Immission in the Municipal Area

In 2008, air pollutant measurement was conducted at a total of 15 measurement containers (5 at the outskirts, 5 in the inner-city background and 5 at street locations), and at 37 RUBIS measurement points. These small measurement points with active and passive collectors for gathering weekly mean nitrogen dioxide, benzene and soot values have been providing measurements bi-weekly since 2005. The situation of each measurement point is shown in Figure 5. The exact addresses are listed in the monthly reports on air-pollution control of the Senate Department for Urban Development (only in German).

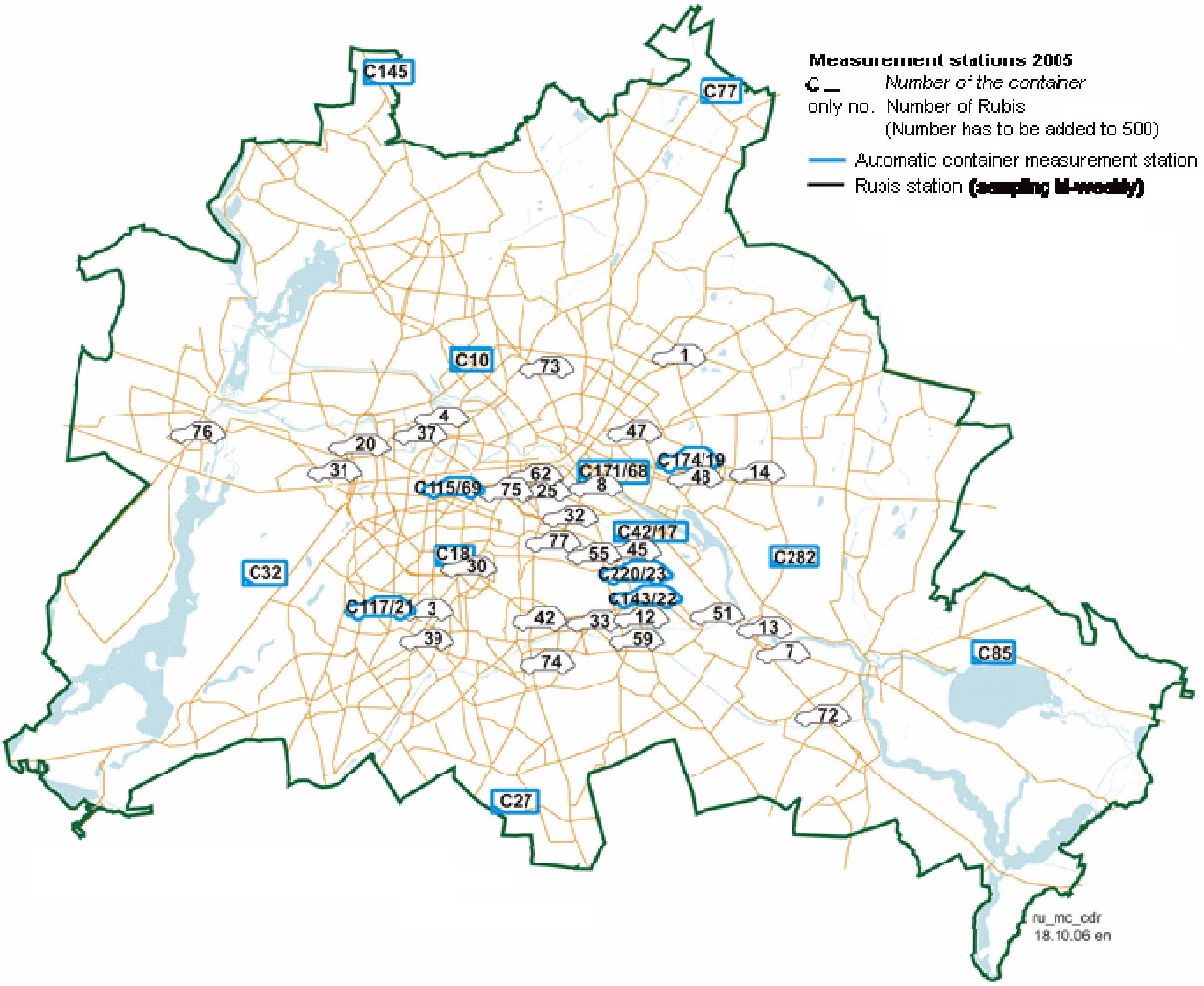

Fig. 5: Locations of the automatic container measurement stations of the BLUME measurement network, as well as the small RUBIS measurement points, 2005

The level of measured concentrations is not solely dependent on the number of motor vehicles and the resulting emissions, but also on the air exchange conditions, which are on the one hand determined by meteorological parameters (e.g. the wind), and on the other by the type and extent of buildings. Thus, there is a high immission impact registered in streets with buildings on both sides (canyon streets), such as on Silbersteinstr. in Neukölln, or Schildhornstr. in Steglitz, while the city motorway, which carries a noticeably higher traffic volume, lower pollution concentrations are found. Figure 6 shows typical pollution distribution in a canyon street. Such distribution develops if the wind direction (over roof level) leads from the measurement point towards the road, resulting in a turbulence formed in the canyon street. This blows the motor vehicle emissions to the side of the road where the measurement point is located.

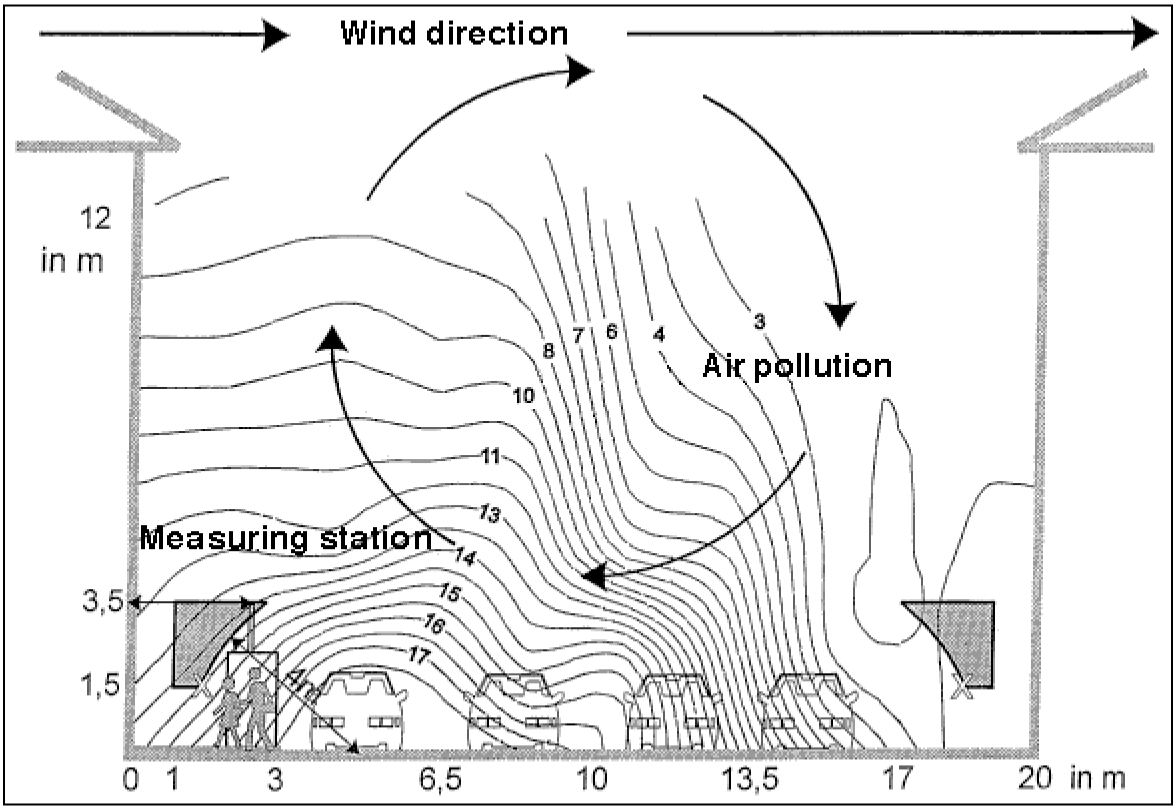

Fig. 6: Pollution distribution in a canyon street with the measurement range as per the 23rd BImSchV, and the receptors used for calculation with the IMMIS$^{em/air}$ canyon street model

Long-term trend of nitrogen dioxide concentration in the municipal area

The results of the measurements carried out through 2007 on major streets indicate the following long-term trend (cf. Figure 7):

- A clear drop in nitrogen dioxide concentrations was achieved around 1995 by equipping the Berlin power stations with denitrification facilities, and the introduction of the regulated catalytic converters for gasoline-powered vehicles.
- NO_2 pollution has hardly changed during the past ten years at any of the three station categories shown. The values of heavily-travelled streets (red curve) are still considerably above the EU annual average limit value of 40 µg/cu.m.
- The expected reduction in nitrogen oxide emissions due to the improvement in exhaust gas technology in vehicles has not achieved any reduction in nitrogen dioxide pollution.

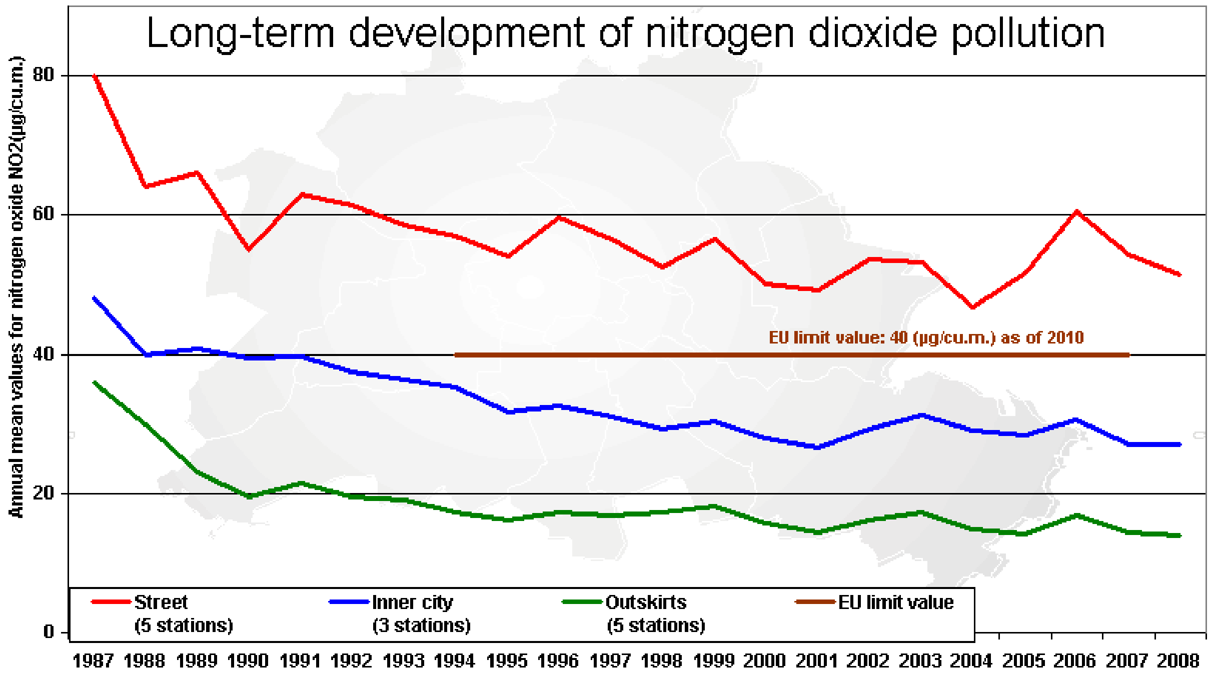

Fig. 7: Long-term trend of nitrogen dioxide values in Berlin
(more information provided under Long-Term Development of Air Quality)

Long-term trend of the PM10 concentration in the municipal area

Figure 8 shows the development of PM10 and total particulate concentrations in Berlin and the surrounding areas over the past twenty years (in 1997, the measurement system was changed from total dust to particulates [PM10]).
The red curve shows pollution at three measurement points near traffic, while the blue and dark-green lines show the concentrations at three measurement points in populated areas of the inner city, and at five measurement points on the outskirts of the city, respectively. The measured soot levels at eight traffic measurement points are shown by the black curve. Data from up to four rural stations in Brandenburg was added, for purposes of comparison with the data from urban areas.

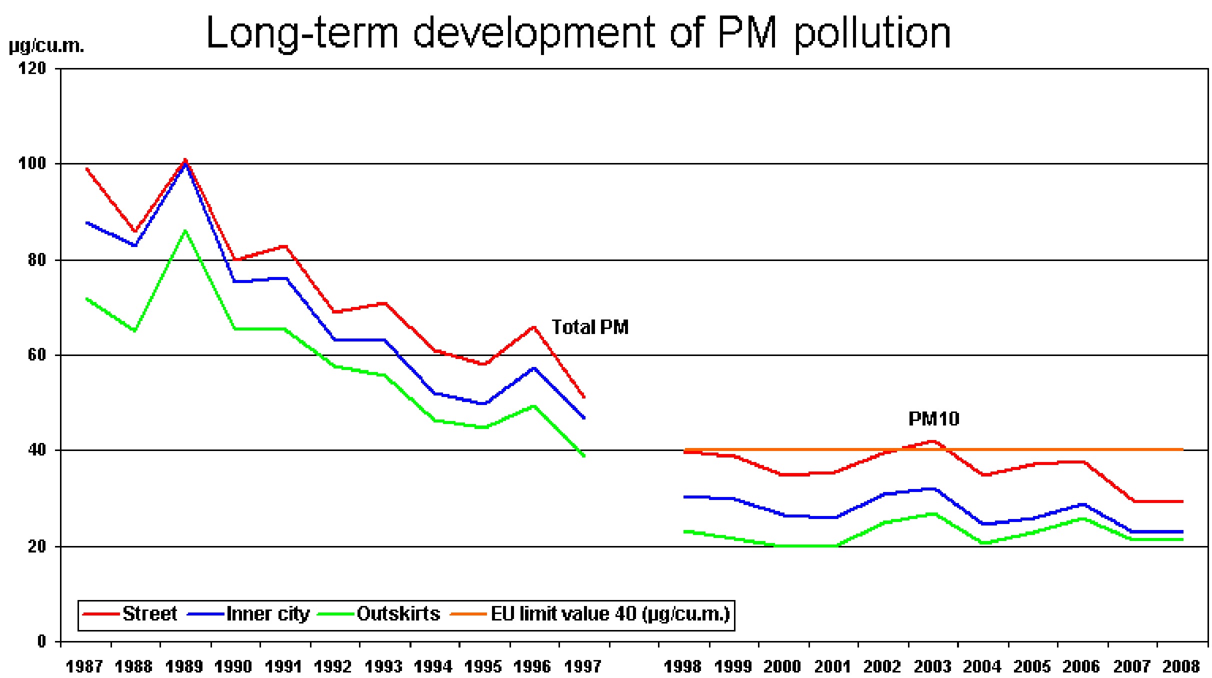

Fig. 8: Long-term trend of PM10 and soot concentrations in Berlin
(more information provided under Long-Term Development of Air Quality)

A comparison of the curves reveals the following noteworthy points:

- The PM10 concentrations in the rural areas of Brandenburg around Berlin in 2003 already came to approximately half the PM10 pollution level on major Berlin inner-city streets, and increased through 2007 to about two thirds of the level of the PM10 pollution on major Berlin streets.
- The drop in dust values which continued throughout the nineties has not continued during the past few years. By contrast, the soot pollution level on major streets declined continuously from 1998 to 2004, by almost 40 %, one cause being the improvements in exhaust gas technology in the vehicles, including those of the bus fleet of the Berlin Transport Company (BVG) (cf. Fig. 8, Berlin Environmental Atlas Map 03.11, 2005 Edition).
- The annual variation of PM10 levels is similar at all stations. In particular, the clear resurgence of PM10 levels in 2002 and 2003, and in 2005 and 2006 is a phenomenon that has appeared at the same time throughout the city, as well as at stations located on the outskirts of the city. Therefore, to find the cause, one should not concentrate primarily on Berlin's PM10 emissions; rather, the cause is attributable to unfavourable weather conditions and large scale transport of particulate matter. The values then rose again in subsequent years, following a slight drop in 2004.

Methodology

Use of the Model

The results of street measurements show that the concentration levels set forth in Directive 99/30/EG and the 22nd BImSchV, especially soot levels, are exceeded at a large number of primary roads. Since measurement-based investigations are, for cost reasons, not possible on all streets in the city, the pollution immission from all the primary roads networks in Berlin were ascertained using emission and dispersion calculations. Under this process, those streets are ascertained where the legal limit values are almost certain to be exceeded, or where they will be met.

To achieve this, these measurements are supplemented with model calculations in all traffic filled streets in which limits are potentially exceeded. However, even in a traffic filled canyon street, the background pollution produced by other sources in the city, and introduced by the long distance transportation of pollution, is an important factor. Therefore, to plan the improvement of air quality in Berlin, a system of models was developed that can calculate both the large scale influence of distant sources and the contribution of all emitters in the city, even in traffic filled canyon streets. For such an estimation of all primary roads ("**screening**"), the aptly designed modular programme system IMMIS■■■ is suitable.

IMMIS-Luft■■■ (air) is a screening programme system for the evaluation of pollution caused by road traffic. It was developed specifically for application in the context of traffic related assessments. With the aid of this programme - provided the necessary input data is known - a rapid calculation of the pollution immission is possible for both particular streets and for comprehensive street systems.

In this process, the pollution immission is calculated on both sides of the street for one point on each side, at an elevation of 1.5 m, and at a distance of 1.5 m from the edge of the building (cf. Figure 6). The mean of the calculated immission at these two points is considered the characteristic estimate of the immission pollution in this section.

Traffic-caused air pollution immission in canyon streets was modelled with the programme segment IMMIS^{cpb}. It enables the calculation of hourly values of pollutant immission produced by local traffic at any receptor in a canyon street with varying building heights and with spaces between buildings which allow the passage of wind, on the basis of easily accessible meteorological quanta. An additional required input quantum is the emission level for each section of the street. The emissions were calculated from the current traffic data using the programme segment IMMIS^{em}. The pollution produced by the city is derived from the sum of the additional pollution measured using the canyon street model, the local street traffic, and the urban background pollution calculated using the IMMIS^{net} programme.

Evaluation Based on an Index

The map drafted using this process shows the spatial distribution of traffic caused air pollution for NO_2 and PM10. A comprehensive assessment was conducted for both substances. The index developed weighs the calculated concentrations of both pollutants according to their readings from about 7,000 street sections of the primary roads network for 2005, and adds the quotients. For example, if the two components both reach 50 % of the limit, an index of 1.00 will result. All sections that show a reading in excess of 2.00 will require special attention in the future (cf. Effects on Human Health).

Data Display

The data display includes detailed information on selected street sections. (Click on the appropriate button/s with the right mouse key to mark one or more of the coloured count sections, and then confirm with the left mouse key. If you press the "Factual data display" button, the selected data will appear on the right side.) The following parameters are provided next to the key number of each section:

- name of the borough where the section is located;
- street name;
- average daily traffic volume (DTV) for automobiles, lorries and two-wheeled vehicles;
- number of BVG busses per day;
- emission data for 2005, in reference to the following substances:
    - benzene;
    - soot;
    - carbon dioxide
    - nitrogen oxides;
    - particles (total); and
    - particles (exhaust);
- the calculated immission for 2005 in reference to the following substances:
    - the annual mean for NO_2;
    - the 24 hour value of PM10; and
    - the annual mean for PM10;
- the trend calculations of immission for 2015, each in reference to the following substances:
    - the annual mean for NO2;
    - the 24 hour value of PM10; and
    - the annual mean for PM10.

Map Description

Index of the Atmospheric Pollution from PM10 and NO_2 in 2005

Measurements of the concentrations are only representative for a limited area around the measurement point, and particularly for the particulate PM10, strongly dependent on meteorological conditions.

These dependences will become clear on the basis of the following representations in Figure 9 to 11.

The trend of PM10 daily mean values in 2002, 2005 and 2007 at the measurement stations of BLUME measurement network

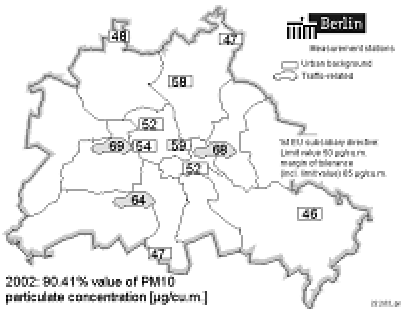

Fig. 9: 90.41% value of particulate concentration PM10 [µg/cu.m.] in 2002 at the measurement stations of the BLUME measurement network.

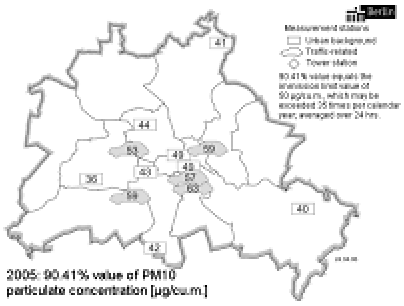

Fig. 10: 90.41% value of particulate concentration PM10 [µg/cu.m.] in 2005 at the measurement stations of the BLUME measurement network.

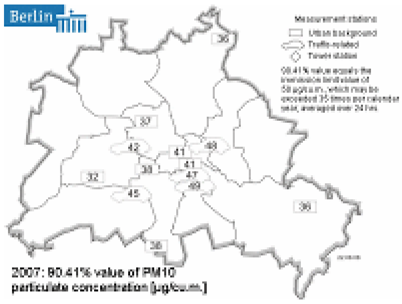

Fig. 11: 90.41% value of particulate concentration PM10 [µg/cu.m.] in 2007 at the measurement stations of the BLUME measurement network.

The daily mean value of particulate concentration PM10 of 50 µg/cu.m, corresponding to the value 90.41 %,may not be exceeded on more than 35 days a year.

Evaluations of the causes of particulate pollution show that approximately half of the particulate concentration in traffic near test points in central Berlin stem from sources outside the Berlin area. Depending on the process of meteorological conditions, this external influence can lead to a more or less strong transgression particularly of the second PM10 limit value. No more than 35 transgressions of a daily mean average value of 50 µg/cu.m of particulate PM10 are permitted.

While the short term limit value in some cases considerably exceeded in 2002 and 2005, according to measurements (e.g. 2005: 82 transgressions at the Frankfurter Allee measurement point), in 2007, favourable meteorological conditions, with a large number of west wind weather situations causing a high degree of air exchange, caused not only the mean annual value to be met at all measurement points for the first time, but the results also were below the second limit value.
However, this proven external influence on the particulate concentration does not provide any excuse to fail to make an effort locally to ensure a permanent reduction in PM10 pollution.

For a complete picture of the existing pollution and the distribution of pollutants in the municipal area beyond the information obtained from the BLUME measurement stations, elaborate model calculations were carried out in the context of the development of the Berlin Clean Air Maintenance and Action Plan for 2005-2010, as described above in detail in the chapter on Methodology, with reference to the canyon streets. These were based on weather conditions and traffic and emissions data from 2005.

The municipal background PM10 pollution for the exemplary year 2002 is shown in Figure 12; it shows a noticeable increase in values as one moves from the outskirts towards the city centre, i.e., the area within the urban rail (S-Bahn) Ring Line (the "big dog's head").
The concentration calculated for the inner city of between 25 and 30 µg/cu.m. is representative for the pollution in residential areas with low traffic and a considerable distance from industrial plants.

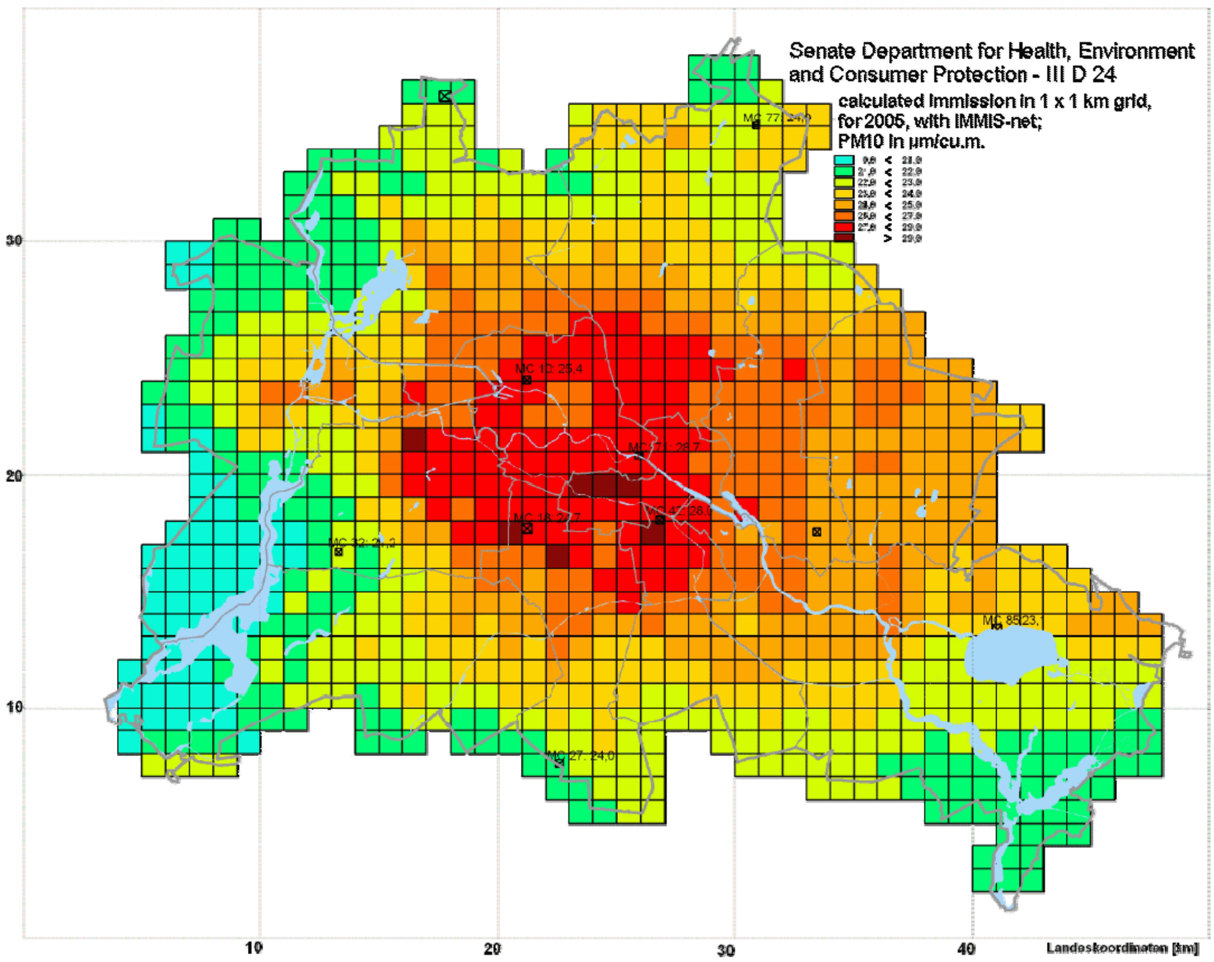

Fig. 12: PM10 pollution (annual mean) in the Berlin municipal background, calculated with IMMIS^{net} and measured by BLUME measurement stations for the base year 2005 (SenGesUmV undated)

The calculation of the PM10 and NO_2 immission shown on the Map was carried out on the primary road network using the IMMIS^{air} model, complemented by a detailed data display for each street section assessed. This results from the overlaying of the respective concentration in the municipal background and the calculated additional pollution from local traffic in the respective section of each major street.

All street sections shown in red show **transgressions of the PM10 limit values for 24 hours and/or the annual mean average value of NO_2** in terms of the year 2005 (cf. Table 2).

As of 2015, an EU-wide limit value of an annual mean of 2.5 µm (PM 2.5) is provided for very fine particulate matter smaller than 25 µg/cu.m. Those sections in which limit value transgressions were calculated were therefore classified as "**very high pollution levels**", and will furthermore require special attention in future with regard to minimising near-surface air pollution. These sections are distributed throughout the city; however, they are concentrated in a ring around the inner city, on the major radial roads leading to the south and the east, and on the important connecting roads within Berlin, such as the Bismarckstr./Kaiserdamm corridor in Charlottenburg, Tempelhofer Damm including its southward extension, Frankfurter Allee, and Adlergestell in Treptow-Köpenick. The total length of these street sections adds up to approx. 163 km of roadway, and thus accounts for 12 % of the primary road network; more than 63,000 people live along these streets (cf. Table 4).

Most persons affected live in the area of the so-called "big dog's head", and along the radial roads. The urban motorway, which stands out for very high values on the Map in fact affects only a few residents, since the distance to residential areas is relatively great, and the air is well mixed, due to the open situation of the motorway.

Moreover, the Map indicates that a quarter of all sections exceed the index value of 1.76 to 2.00. This 294 km long part of the primary road network may constitute a problem in future, at least in some areas, since at least one parameter generally shows a transgression of the respective limit value here.

Table 4: Section lengths of the air pollution index and affected residents in the primary road network of Berlin, 2005				
Index of air pollution by PM10 and NO2	Assessment, primary road network			
	km of street length	%	% Running total	Residents affected
<=1,50 slightly polluted	503,1	36,2%	36,2%	60.913
1,51 - 1,75 moderately polluted	427,8	30,8%	67,1%	115.480
1,76 - 2,00 increasingly polluted	294,2	21,2%	88,2%	108.114
> 2,00 very high polluted	163,3	11,8%	100,0%	63.747
Total	**1.388,3**	**100,0%**		**348.254**

Tab. 4: Section lengths of the air pollution index and affected residents in the primary road network of Berlin, 2005

The approach used to calculate the number of residents affected by limit value transgressions was also taken from the noise mapping procedure (see Maps 07.05 Strategic Noise Maps, 2008 Edition)). The number of residents in the flats facing the street front was counted. The number of citizens affected by limit value transgressions thus ascertained represents a rather conservative estimate, because the pollutants spread everywhere, so that increased concentrations can also occur outside highly polluted canyon streets.

Calculated trends through 2015 for the substances PM10 and nitrogen dioxide (NO_2)

With regard to permanent compliance with limit values for clean-air maintenance, the calculation of trend scenarios is of great importance. It permits the future development of large-scale and local air pollution to be assessed, and also enables an evaluation of whether additional measures beyond those already initiated are necessary to achieve a reduction in air pollution. The immission values for 2005, which are also the basis for the calculation of the air pollution indices, constitute the point of departure. The resulting trend scenario takes into account the reduction on the emissions side at the trend point in time 2015, for Europe and Germany, and also at the local level in Berlin. Thus, progress due to the implementation of European regulations for pollutant emissions by plants, power stations and motor vehicles is incorporated, as are agricultural emissions of particulate matter.
The exhaust emissions from motor vehicle traffic is likely to decrease, due to the gradual removal of older vehicles with high pollutant emissions; by 2015, this will amount to almost 40% for nitrogen oxides and more than 50% for particulates. However, the particulate produced by the abrasion of the road, tyres and brakes, as well as by the stirring up of street dust by the wind will increase insignificantly, due to increased driving activity.

In sum, the result for Berlin will be a drop in NO_x emissions by more than 21 % and in PM10 emissions by about 7 % by 2015,in comparison with 2005 levels.

In order to comply with the 24 hr limit value for particulates everywhere, a considerably greater reduction in concentrations will however be required. Nonetheless, such an improvement cannot be expected without additional reduction measures, either for the local nor for the imported portion of particulate pollution, so that even in 2015, it can be assumed that some 153 km of primary road network, with some 61,000 affected residents will show transgressions of the 24 hr value for PM10 (cf. Table 5). Such additional measures must be taken in Berlin, at the national and at the European levels, to reduce both shares further.

A similar result can be predicted for the development of nitrogen dioxide pollution. The measures of the trend scenario already initiated will cause the concentration on the major streets to drop considerably by 2015, which will also reduce the number of streets with limit value transgressions and the residents affected by about 86 %. However, additional measures, mainly in Berlin, will be required to relieve the remaining almost 16 km of streets and the 4,300 (check) people affected who live on them.

Table 5: Street section lengths of the primary road network and residents affected by limit value transgression, calculation for 2005 and trend calculation for 2015				
Substances observed: PM10 and NO_2	Calculation of limit value transgression, 2005		Trend calculation, limit value transgression for 2015	
	km street length	Affected residents	km street length	Affected residents
NO_2 [Annual mean in µg/cu.m.]	114	42.116	16	4.262
PM10 [24-hour limit in µg/ cu.m.	336	133.446	153	60.800
PM10 [Annual mean in µg/ cu.m.]	9	2.300	7	1.129

Tab. 5: Section lengths and residents affected by limit value transgressions in the primary road network, calculation for 2005 and trend calculation for 2015

In sum it can be stated that:

- on the measures side in Berlin, the emission of pollutants of industrial plants has been reduced considerably under the limit values stipulated since 2007;
- the measures already realised or initiated will cause the particulate pollution levels in municipal residential areas to decline by 7-10 %, and the nitrogen dioxide levels by 22 %, by 2010;
- this reduction will suffice to enable the limit values defined as annual means for particulates to be complied with, even in years with unfavourable weather conditions, to more than cut in half the total length of street sections with transgressions of the 24 hr. limit value for particulates by 2015, and to reduce the annual limit value for nitrogen dioxide by almost 90 %.

The Berlin Clean Air Maintenance and Action Plan for 2005-2010 adopted by the Berlin Senate in August 2005 describes in detail the additional possible measures and their effects on air quality.

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