03.09 Traffic-related Air Pollution – Hydrocarbons (Edition 1998)

Overview

Basic Situation

Berlin has been confronted with a considerable **increase in motor traffic** since the reunification of Germany. The number of motor vehicles registered in Berlin has risen about 30 % since 1989 to a present total of 1,280,000. A further growth in motor vehicle traffic is projected for the future, especially for heavily polluting freight transport.

These changes are not yet concluded. Traffic increases result from the expansion of the Berlin/Brandenburg residential and economic area; from the rapid growth of international economic relations; and particularly from the strengthening of links between Berlin and Eastern Europe.

Motor vehicle traffic has become the **greatest cause of air pollution** in Berlin. The most significant pollutants emitted by motor vehicles in terms of quantity are **carbon monoxide, hydrocarbons, nitrogen oxide and carbon dioxide**. The pollutant quantities of diesel particulates, tire abrasion and benzol are much smaller, but they are important because of their effects.

Motor vehicle pollution is especially high in the inner city, where over 1 million people inhabit an area of 100 sq km. The future functions of the inner city will clearly increase traffic and air pollution in this area.

The map shows spatial distributions of hydrocarbon emissions. **Hydrocarbons (HC)** were selected since they, along with nitrogen oxide, play a significant role as ozone precursors. Other hydrocarbons, e.g. benzol, require particular attention because of their carcinogenic effects (Hydrocarbons and ozone-building processes are treated in Map 03.06 SenStadtUmTech 1996).

Map 03.10, Traffic-related Air Pollution - Benzol, Nitrogen Oxide and Diesel Particulates (SenStadtUmTech 1998), describes air pollution of these three substances in Berlin. Both maps are based on emission and dispersal simulation models which are comparably constructed in methodology and which are grounded upon the same statistical base.

Causes and Amounts of Traffic-related Hydrocarbon Emissions

Hydrocarbons are released through the exhaust when fuel is unburned or incompletely burned. Considerable amounts also reach the atmosphere due to fuel evaporation. Hydrocarbons evaporate from the fuel tank and other fuel feed elements, such as the fuel line, carburetor, filter, reserve canister, etc.. Hydrocarbons also vaporize when fuel station storage depots and motor vehicle tanks are filled.

Figure 1 shows the development of motor vehicle hydrocarbon emissions in Berlin since the beginning of the 80s. A projection for the year 2000 is included. The fundamental restructuring of calculation methodology means that only limited comparisons can be made to previous emission investigations based on much simpler methods. Motor vehicle evaporative emissions were included only after 1985.

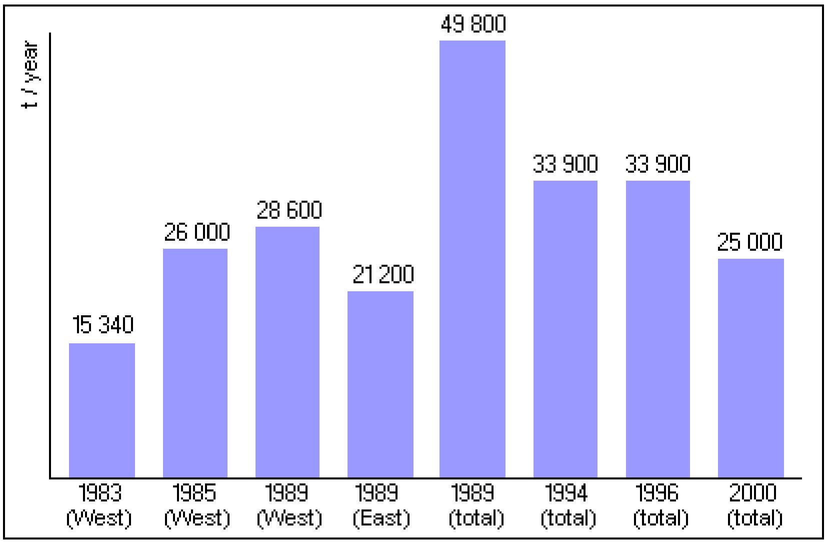

Fig. 1: Hydrocarbon Emissions of Berlin Motor Vehicle Traffic in Tons per Year

Emission data for 1989 show that hydrocarbon emissions in East Berlin were almost as high as in West Berlin, even though East Berlin has less than half the population, and far fewer motor vehicles. Causes of high hydrocarbon emissions in East Berlin were 1) motor vehicles with two-stroke engines (Trabbis, the East German peoples' auto) driven only in East Berlin until 1989, and 2) fuel quality. Hydrocarbon emissions decreased around 30 % from 1989 to 1996. This development is due to changes in the types of motor vehicles in East Berlin; general technical improvements in engines, including the wider use of catalytic converters for autos and improved fuel quality.

Table 1 gives information for 1993 according to vehicle types. This information is: the total travelled distances of motor traffic in millions of vehicle kilometers per year (km/a) within the urban area of Berlin; fuel consumption in tons (t); and exhaust and abrasion emissions from motor traffic in tons per year (t/a). Motorized two-wheel vehicles and evaporative emissions are not included here since they cannot be assigned to types of streets.

Tab. 1: Total Travelled Distances in Millions of Vehicle km/a; Fuel Consumption in Tons, t; and Exhaust and Abrasion Emissions in Tons per Year, t/a. These Figures are Presented according to Vehicle Types in Urban Area of Berlin in 1993. Excluded are Motorized Two-wheel Vehicles and Evaporative Emissions (Liwicki, Garben 1993).					
	Total	**Cars**	**Heavy utility vehicles**	**Light utility vehicles**	**Scheduled busses**
Primary Road Network					
Total travelled distances	10,088.4	8,814.0	514.2	674.6	85.6
Fuel consumption	898,968.4	645,519.5	154,291.9	66,150.9	33,006.1
Hydrocarbons	17,211.5	14,724.8	1,449.5	802.2	235.0
Benzol	863.4	811.6	13.0	36.7	2.1
Carbon dioxide	2,710,593.3	1,923,532.3	481,891.3	202,184.1	102,985.6
Carbon monoxide	94,690.9	86,908.1	2,189.7	4,751.0	842.1
Nitrogen oxides	16,139.5	7,619.7	5,938.0	953.5	1,628.0
Exhaust particles	937.9	260.4	446.1	139.5	91.9
Tire abrasion	1,100.3	564.1	394.9	75.5	65.8
Elementary carbon (exhaust + tire abrasion)	733.5	249.1	329.8	95.2	59.4
Sulfur dioxide	1,150.5	409.6	493.7	141.6	105.6
Secondary Road Network					
Total travelled distances	2,063.4	1,848.4	65.7	141.5	7.8
Fuel consumption	239,077.7	193,112.7	22,694.0	19,793.0	3,478.0
Hydrocarbons	8,250.2	7,534.2	288.9	395.6	31.5
Benzol	416.1	395.5	2.6	17.7	0.3
Carbon dioxide	713,926.1	572,276.4	70,527.5	60,297.7	10,824.5
Carbon monoxide	49,507.6	46,637.0	385.9	2,380.2	104.5
Nitrogen oxides	2,885.6	1,617.2	864.6	229.8	174.0
Exhaust particules	197.6	68.8	76.0	41.4	11.4
Tire abrasion	190.6	118.3	50.4	15.9	6.0
Elementary carbon (exhaust + tire abrasion)	140.0	59.0	48.1	26.0	6.9
Sulfur dioxide	247.7	121.8	72.7	42.1	11.1
Total Urban Area					
Total travelled distances	12,151.8	10,662.4	579.9	816.1	93.4
Fuel consumption	1,138,046.1	838,632.2	176,985.9	85,943.9	36,484.1
Hydrocarbons	25,461.7	22,259.0	1,738.4	1,197.8	266.5
Benzol	1,279.5	1,207.1	15.6	54.4	2.4
Carbon dioxide	3,424,519.4	2,495,808.7	552,418.8	262,481.8	113,810.1
Carbon monoxide	144,198.5	133,545.1	2,575.6	7,131.2	946.6
Nitrogen oxides	19,024.8	9,236.9	6,802.6	1,183.3	1,802.0
Exhaust particules	1,135.5	329.2	522.1	180.9	103.3
Tire abrasion	1,290.9	682.4	445.3	91.4	71.8
Elementary carbon (exhaust + tire abrasion)	873.5	308.1	377.9	121.2	66.3
Sulfur dioxide	1,398.2	531.4	566.4	183.7	116.7

Tab. 1: Total Travelled Distances in Millions of Vehicle km/a; Fuel Consumption in Tons, t; and Exhaust and Abrasion Emissions in Tons per Year, t/a. These Figures are Presented according to Vehicle Types in the Urban Area of Berlin in 1993. Excluded are Motorized Two-wheel Vehicles and Evaporative Emissions (Liwicki, Garben 1993).

The **trends** above indicate a worsening of the situation for some pollutants and no significant reductions for other pollutants (see Map 03.10 SenStadtUmTech 1998). This is particulary so for nitrogen oxides and (diesel) particulates. (Diesel) particulates have the greatest current need for action. Hydrocarbon emissions, however, are expected to decline significantly even without regulatory intervention because 1) more vehicles are being equipped with 3-way catalytic converters and 2) fuel quality is improving. Technical improvements for passenger cars have had significant effects. The situation for diesel particulates is different. Trucks and buses make up 5 % of total travelled distances and are responsible for 10 % of total emissions - but they are responsible for 90 % of carcinogenic diesel particulate emissions.

Two-wheel vehicles are not listed. They are responsible for 1.4 % of hydrocarbon and benzol emissions and this percentage corresponds to their amount of total distance travelled. Motorcycles are driven mainly in the summer. The high contribution of motorcycle emissions to ozone precursors cannot be derived from their share of total annual motor vehicle emissions.

Figure 1 and Table 1 do not include evaporative emissions produced during refilling at fuel stations. Evaporative emissions amounted to about 3,630 tons in March 1994; about 15 % of hydrocarbon emissions resulting from motor traffic exhaust systems and fuel evaporation.

Effects

Motor vehicle hydrocarbons contribute significantly to the formation of ground-level ozone called "summer smog" in Berlin.

The hydrocarbon **benzol** is particularly hazardous to health (cf. Klippel, Jäcker-Küppers 1997). Benzol has been proven to cause bone marrow damage, leukaemia, and lymphome in human beings (cf. Kalker 1993).

The great majority of both total distance travelled and of pollutant emissions occur on the 1,600 km long **primary road network**. Approximately 250,000 residents live on these streets (cf. ACCON, IVU 1996). The **secondary road network** is more than twice as long, but has only about 20 % of total kilometers travelled and a correspondingly smaller amount of motor vehicle emissions. The pollutant load is strongly influenced by the type of surrounding building structures; some areas of the secondary road network have loads clearly above the general background level.

Legal Regulations and Limit Values

Great reductions in domestic heating and industry-related emissions were achieved both by regulations of the Federal Pollution Control Law (Bundesimmissionsschutz-Gesetz - BlmSchG), and from closures of outdated facilities in East Germany (cf. Map 03.01 and 03.03, SenStadtUmTech 1997a and 1997b). Motor vehicle traffic has not shown any similar development. A major cause of this unsatisfactory situation are the EC Guidelines stipulating waste gas requirements for motor vehicles. These EC Guidelines have not yet been oriented towards traffic development and its resulting pollution, nor towards environmental and health policy objectives.

Only in 1990 was a legal basis established by **Section 40 Para. 2 of the Federal Pollution Control Law** for the consideration of **traffic restrictions at high levels of traffic-related air pollution**. In 1991 the German Federal Environmental Agency (Bundesumweltministerium) proposed a regulation with concentration values for **nitrogen dioxide**, and the traffic-related carcinogenics **benzol** and **diesel particulates** "for the protection of health from deleterious environmental effects resulting from air pollution". The Upper House of the German Parliament (Bundesrat) passed the proposal for the **23rd Regulation** on 18 March 1994 after making numerous changes. The 23rd Regulation came into effect with other administrative regulations on 1 March 1997. The concentration values contained in the Regulation are not directed at reducing acute danger; they are directed towards controlling the dangers of **longterm exposure** to high yearly values. It is different with measures based on the "winter smog regulations" of Section 40 Para. 1 of the Federal Pollution Control Law and the **Ozone Regulations** of Sections 40a-e and 62a of the Federal Pollution Control Law. The objectives of these measures are to prevent acute dangers resulting from short-term air pollution peaks in large to very large areas (cf. Klippel, Jäcker-Küppers 1997). Both pollution situations allow for short-term traffic restrictions.

Table 2 gives an overview of limit values specified for 1) Ozone Regulation in Section 40a-e of the Federal Pollution Control Law; and for 2) nitrogen oxide, diesel particulates, and benzol in the 23rd Regulation.

Tab. 2: Limit and Concentration Values of the 23rd Regulation and Section 40a-e of the Federal Pollution Control Law (Ozone Regulation)		
Section 40a-e of the Federal Pollution Control Law of 19 July 1995 (Ozone Regulation) **Orientation values:**		
Public requested not to drive cars	180 µg/m³	as average for 1 hour on the same day (1-hour value)
Traffic forbidden on public streets	240 µg/m³	1-hour value [1)]
Traffic-related concentration values set by the 23rd Regulation of 1 March 1997		
Sulfur dioxide	160 µg/m³	98 % value of all half-hour values as of 1 July 1995
	160 µg/m³	98 % value of all half-hour values as of 1 July 1998
Benzol	15 µg/m³	arithmetical yearly average as of 1 July 1995
	10 µg/m³	arithmetical yearly average as of 1 July 1998
Diesel particulates	14 µg/m³	arithmetical yearly average as of 1 July 1995
	8 µg/m³	arithmetical yearly average as of 1 July 1998

1) Section 40a of the Federal Pollution Control Law (BImSchG) decrees that the given values be measured at a minimum of three monitoring stations that are 1) within German national boundaries, located more than 50 km but less than 250 km from each other; and that 2) at least two monitoring stations (for Berlin at least one) are located in that federal state or in an adjacent county. Traffic restrictions do not apply to motor vehicles with low pollutant emissions.

Tab. 2: Limit and Concentration Values of the 23rd Regulation and Section 40a-e of the Federal Pollution Control Law (Ozone Regulation)

The 21st Regulation (BImSchV) of 7 October 1992 order that a fuel vapor recovery system to limit hydrocarbon emissions be installed at every large fuel station. Table 3 gives the deadlines for this installation. Section 44 of the Federal Pollution Control Law defines Berlin as a study area and ranks Berlin in the "from 2,500 m³" category with shorter deadlines.

Tab. 3: Deadlines Given by the 21st Regulation (BImSchV) for Installation of Fuel Vapor Recovery Systems	
Annual turnover in m³ fuel/year	**Installation by**
up to 1,000	no deadline
1,000 to 2,500	end of 1997
2,500 to 5,000	end of 1995
more than 5,000	end of 1995

Tab. 3: Deadlines Given by the 21st Regulation (BImSchV) for Installation of Fuel Vapor Recovery Systems

Statistical Base

Cadastre of Motor Traffic Emissions

The Berlin Department of Urban Development, Environmental Protection and Technology (SenStadtUmTech - Senatsverwaltung für Stadtentwicklung, Umweltschutz und Technologie) maintains a **cadastre of emissions** for the major groups of polluters, including the polluter group of motor vehicle traffic.

The 1993 Cadastre of Motor Vehicle Traffic Emissions gives the first unified picture of air pollutant emissions produced by motor vehicle traffic for the entire city of Berlin.

This cadastre uses a new method to calculate emissions. This method is also a suitable basis for dispersal calculations which can ascertain pollutant loads on roads. The far-reaching restructuring of calculation methodology allows only limited comparisons to be made with previous emission investigations based on much simpler methods.

Investigation of Motor Traffic Pollution

The basis is the first comprehensive **traffic count**, performed in **1993**. This count included the primary road network as well as scheduled bus routes. This count resulted in the availability of certain data for every road segment in the primary road network:

- average daily motor traffic (DTV) in motor vehicles/day,
- average daily truck traffic in trucks/day for heavy trucks,
- percentage of busses in regular traffic.

This data was supplemented with extensive analyses of vehicle types and total travelled distances of registered motor vehicles in Berlin. The data was also supplemented by emission factors that describe these cars and utility vehicles (cf. Map 07.01 SenStadtUm 1995).

Methodology of Emission Studies

Pollutant emissions produced by motor traffic include the exhausts and abrasions of moving traffic; the evaporative emissions of stopped traffic, and evaporative emissions at fuel stations. Figure 2 presents an overview of the emission study methodology. Fuel station emissions are listed under light industry.

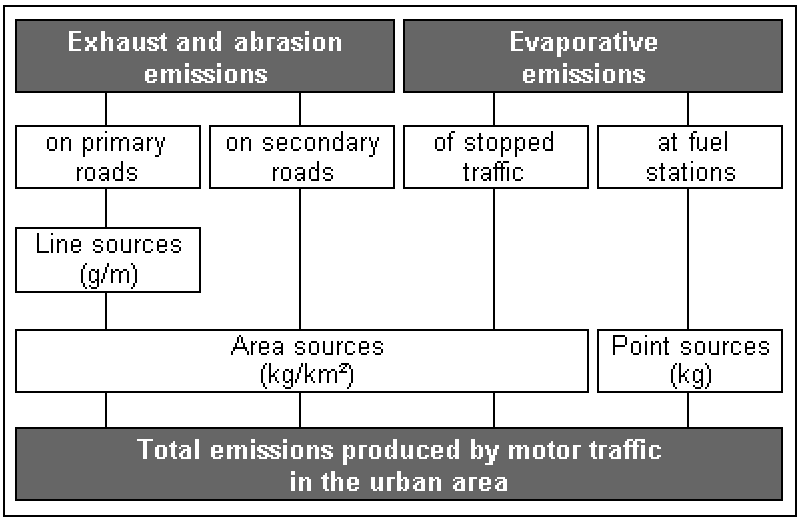

Fig. 2: Methodology of the 1993 Traffic Emission Cadastre

Emission models aided the calculation of pollutant and CO_2 emissions for line sources (primary roads), and area sources (secondary roads and evaporative emissions).

Exhaust and abrasion emissions appear as line sources on primary and secondary roads. These emissions are calculated as line sources only for the primary road network because only these streets had data available from previous counts for average daily traffic values (DTV) and hourly capacity. Emissions from line sources are classified as area values in the grid system. Emissions for the secondary road network, however, are directly deduced from the seperate grids from assumptions made about traffic volumes and amounts of trucks.

Hydrocarbon evaporative emissions occur from pressure differences between the fuel tank and the carburetor float chamber. They occur

- in non-moving motor vehicles resulting from daily temperature fluctuations (tank respiration emissions),
- in hot engines after long distances,

- in warm engines after short distances.

Evaporative hydrocarbon emissions and benzol fractions are also determined for the grids. Evaporative emissions resulting from refueling are also calculated. Evaporative emissions from moving traffic could be neglected because they are very low.

Emission Models for Primary Road Networks (Line Sources) and Secondary Road Networks (Area Sources)

The emission simulation model EMISS helped calculate pollutant and CO_2 emissions (cf. Map 08.03 CO_2 Emissions, SenStadtUmTech, in preparation), and fuel consumption for traffic on primary road networks.

Figure 3 shows the individual model parameters, including total travelled distance factors, stop-and-go formulas, cold start factors, etc., and the results. The methodological background is described in detail in Liwicki, Garben 1993.

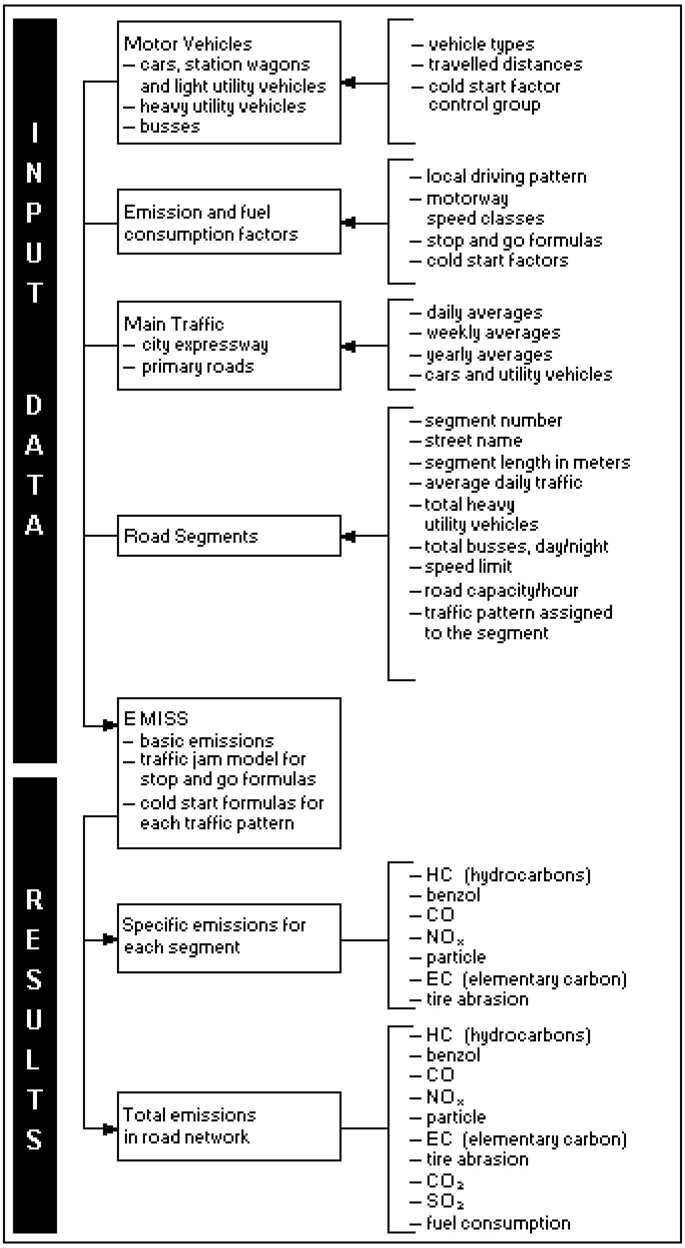

Fig. 3: EMISS - Emission Model for Primary Roads (Line Sources) (Liwicki, Garben 1993)

Emissions for motorized two-wheel vehicles could not be ascertained because traffic counts do not exist. Two-wheel vehicle contribution to total emissions are calculated on the basis of total travelled distances in Germany, and on available emission factors.

Road segments in areas of varying topography are classified according to longitudinal inclines; but this is not necessary for Berlin.

Emission Model for Secondary Road Network (Area Sources)

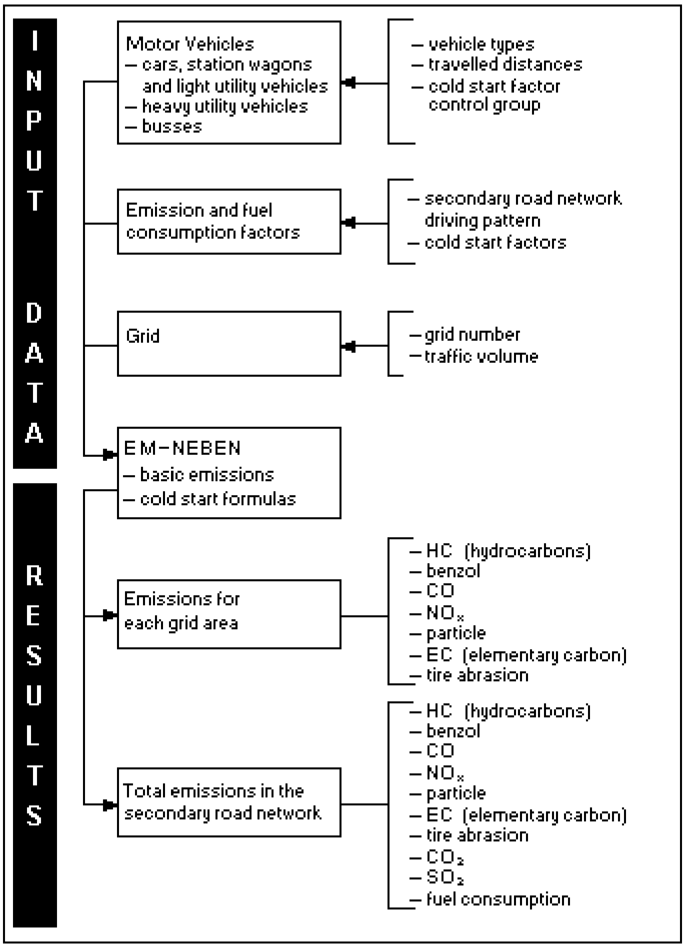

Fig. 4: EM-NEBEN - Emission Model for Secondary Road Network (Area Sources) (Liwicki, Garben 1993)

Emissions in the secondary road network are not calculated for each specific road segment. Emissions are calculated for a grid area of 1 km^2. Travelled distances within the grid surface area are estimated based on the following data:

- predominant use of the area, subdivided into:
  - residential living in outer areas of the city,
  - small business and industrial areas,
  - inner city and suburban areas,
- number of inhabitants and positions of employment, differentiated according to:
  - commercial and service industry,
  - manufacturing industry,
- and motor traffic source-goal-matrices derived from the above.

It can be assumed that significant traffic jams do not occur in the secondary road network. "Stop and go" supplements are not added to the calculations. Daily, weekly and annual matrices for the secondary road network were then not necessary.

Further input variables needed for determining total emissions for each pollutant component in each grid area correspond to the input variables used for calculating total emissions in the primary road network.

Refueling Emissions

Refueling emissions are determined based on permit-registered fuel stations and their fuel turnovers.

1.4 g of HC per liter of carburetor fuel are emitted at fuel stations with no fuel vapor recovery systems. The fuel vapor recovery system returns 80 % of emitted amounts.

HC emissions from the preliminary chain are not given: these emissions include the transfer of fuel from 1) tanker trucks, tanker ships and railroad tank cars to the fuel depot; from 2) the fuel depot to the tanker; and from 3) the tanker to the fuel station.

Methodology

Hydrocarbon emissions are depicted both in a color grid, and in absolute numbers; the two loads depicted are **hydrocarbon emission per sq. km** in the entire road network, and evaporative emissions at fuel stations. Color representations are based on rounded-off figures.

The Berlin primary road network has almost 3,000 numbered sections. Pollutant loads were depicted as lines for each separate segment.

Grids and lines were assigned the same color scheme.

Map Description

The Berlin primary road network has a length of 1,163 km. The daily travelled distance on this network totals 30,000,000 vehicle kilometers. This figure is almost 100 times the earth's circumference. The secondary road network is about 4,000 km long, and the daily travelled distance is only about 5,600,000 vehicle kilometers. Figure 5 depicts the percentual distribution of exhaust and abrasion emissions of various pollutants according to the Berlin primary and secondary road networks. It is conspicuous that an extremely high percentage of hydrocarbon and benzol emissions occur on the secondary road network. These emissions are strongly influenced by cold start factors; and about half of the initial kilometers travelled after a start occur on secondary roads.

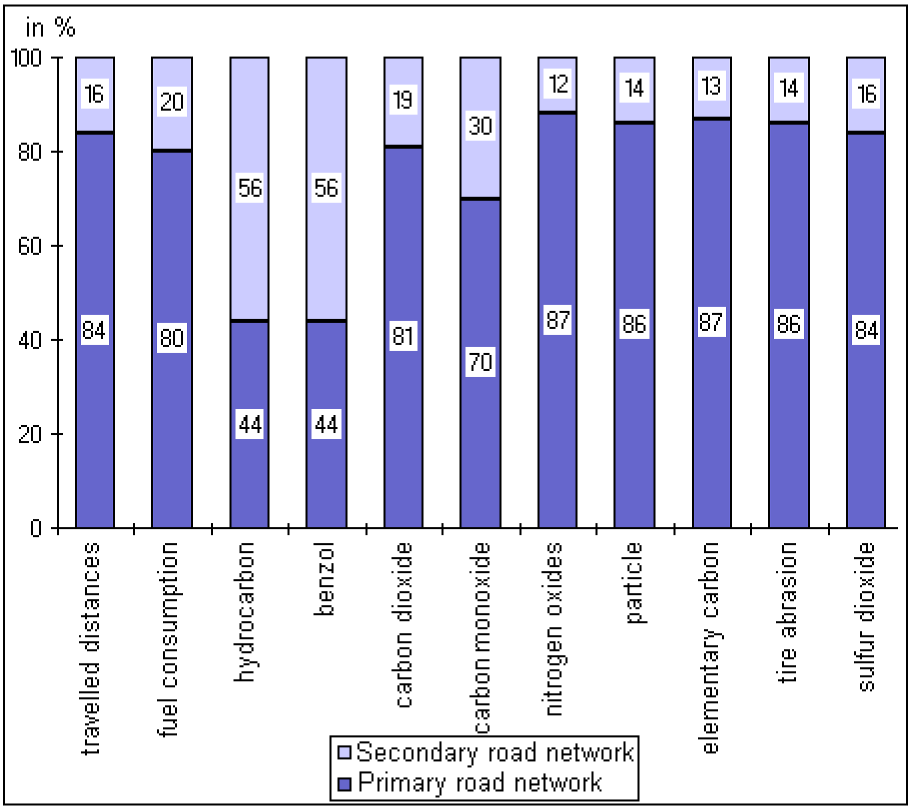

Fig. 5: Percentual Distribution of Emissions and Distance Travelled in Berlin (Liwicki; Garben 1993)

Hydrocarbon Emissions in Primary Road Network

Map 03.09.1 shows that the primary long outbound arterial roads stand out with particularly high **exhaust gas emissions** at 1) the city expressway ring (Stadtautobahnring), 2) along the east-west axis on roads such as Bismarckstrasse to Kaiserdamm in Charlottenburg, and Karl-Marx-Allee to Frankfurter Allee in Mitte and Friedrichshain and 3) other primary arterial roads. Emission loads over 50 kg/m and 50 t/km have been measured at these roads. The significant impact of these main emission segments are clearly to be seen in a comparison with the highest grid value (150 $t/km^2 \cdot a$) in Map 03.09.2, Exhaust Gas Emissions on the Entire Road Network. These primary roads have about 6 % of area on a 1 sq km grid; their emission values are about 30 %.

Emission level evaluations show clear correlation to traffic volume, insofar as the characteristics of individual roads are taken into consideration. Most of the 70 km-long expressway falls into the highest emission categories. The AVUS segment starting at the Funkturm (broadcast tower) triangle, however, has a traffic volume of over 70,000 vehicles a day, and shows a relatively lower pollutant load of 13 kg/m · a. This is due to a relatively undisturbed traffic flow.

Exhaust Gas Emissions in Entire Road Network

Distance travelled on the primary road network is about five times greater than distance travelled on the secondary road network. This 5:1 ratio is not reflected in the amounts of hydrocarbon emissions on the two road networks. This disproportion can be seen in Map 03.09.2 - Exhaust Gas Emissions in Entire Road Network. All grid areas within the inner ring of the City Rail Circle Line (S-Bahn-Ring) have over 50 $t/km^2 \cdot a$. The influence of individual long avenues is no longer so clear. 1993 pollutant loads in areas of West Berlin were greater than in East Berlin, but this difference should have evened out by now. East Berlin motor vehicle registrations and distances travelled have increased, and are now near western levels. Other local centers outside the inner city with over 50 $t/km^2 \cdot a$ have emerged in the boroughs of Spandau, Reinickendorf, Marzahn, Treptow and Neukölln.

Volatile hydrocarbon requires that fuel tank **evaporation** be considered separately from the direct emissions produced by moving vehicles. The fuel tank respiration of non-moving motor vehicles are differentiated from evaporative effects resulting from use; i.e. hot and warm motors. Map 03.09.3 gives parked motor vehicle vapor emissions and Map 03.09.4 gives evaporative emissions based on hot and warm engines.

Evaporative Emissions from Tank Respiration

Even vehicles parked and not driven for a day can produce hydrocarbon emissions through tank respiration. Tank respiration results from pressure differences between the fuel tank and the carburetor float chamber. Pressure differences are caused by temperature fluctuations. It has been calculated that tank respiration produced 1,830 tons of hydrocarbon emissions in Berlin in 1993. This is a good 5 % of total emissions. These tank respiration emissions could have been prevented and used for fuel if vehicles had been equipped with activated carbon filters.

The distribution of emission levels in the various grids reflects both population density and the ratio of vehicles to residents. Residential areas in outlying areas, some borough centers, and the densely built inner city stand out.

Evaporative Emissions from Vehicles after Use / Hot Engines and Warm Engines

Hot and warm engine evaporative emissions are produced when engine and exhaust systems heat the fuel contained in fuel-feed lines after the engine is shut off. Hot and warm engine evaporative emissions reach levels of 6,600 tons; much greater than tank respiration emissions. Hot and warm engine evaporative emissions are a decisive influence on the distribution of total motor vehicle evaporative emissions (Map 03.09.5 - Total Evaporative Emissions of Motor Vehicle Traffic). Cars, station wagons and light utility vehicles with conventional internal combustion engines (Otto engines) produce these evaporative emissions when their engines are switched off - this occurs about 3,270,000 times a day in Berlin. The grids with the highest levels of over 50 $t/km^2 \cdot a$ are within the inner city. The inner city is the most frequent destination for traffic - for work, recreation, and shopping. But some local centers, such as Schlossstrasse in Steglitz, have registered loads of around 30 $t/km^2 \cdot a$. These local centers are well above the average Berlin load of 7 $t/km^2 \cdot a$.

Total Emissions of Motor Traffic

Map 03.09.6 - Total Emissions of Motor Traffic portrays all emission producers. These producers were previously depicted only singly. A comparison with Map 03.09.2 - Traffic Emissions 1989 (cf. Map 03.08 SenStadtUm 1994) enables a few conclusions to be drawn about changes in the number of motor vehicles and in total emission loads. A total emission load of 51,900 tons was ascertained in 1989. The highest motor traffic emissions were determined in the eastern inner city. This is mainly due to the high emissions produced by vehicles with two-stroke engines. Total emissions then fell to 25,500 tons, after 1) a decrease in the number of vehicles with two-stroke engines, such as Trabants and Wartburgs, and after 2) a 57 % increase in the number of motor vehicles equipped with regulated catalytic converters (reference year 1993). Exhaust gas emissions are the dominate source, with 60 % of total emissions. Relatively high loads are registered in the area between the city expressways in the North and West, Steglitzer Kreisel in the South, and the Karl-Marx-Allee / Frankfurter Allee thoroughfare in the East. No particular focuses of loads were determined. The highest loads of 160 to 212 $t/km^2 \cdot a$ were found along the long Kaiserdamm - Bismarckstrasse avenues, as well as south of them. It is conspicuous that twice as many hydrocarbon emissions can be produced in residential areas with little traffic but many parked vehicles: stopped traffic can produce twice as much hydrocarbon emissions as moving traffic.

Evaporative Emissions at Fuel Stations

Map 03.09.7 shows fuel station refilling emissions for the inner city in 1993. Only motor vehicle refueling is considered here; refilling of the petrol depot at the fuel station is not considered. The most significant amount of refueling emissions, about 96 %, results from fuel stations which do not have fuel vapor recovery systems.

Tab. 4: Amount of Fuel Turnover and Annual Refueling Hydrocarbon Emissions at Berlin Fuel Stations in 1993

Fuel stations	Annual fuel turnover (m^3 fuel/year)	Emission faktor (g HC/l)	Total emissions (t HC/year)
without fuel vapor recovery system	932,379	1.40	1,305
with fuel vapor recovery system	173,715	0.28	49
total	1,106,094		1,354

Tab. 4: Amount of Fuel Turnover and Annual Refueling Hydrocarbon Emissions at Berlin Fuel Stations in 1993

Total refueling and transfer emissions at Berlin fuel stations include those resulting from the transfer of fuel from tankers, ship tankers, and railroad tank cars into fuel station depots. Total refueling and transfer emissions in 1993 amounted to about 3,630 tons of hydrocarbons; approximately 10 % of total hydrocarbon emissions. About 96 %, the most significant proportion by far, resulted from fuel stations which did not have fuel vapor recovery systems. All fuel stations selling more than 1,000 m^3 of fuel per year were required to be equipped with fuel vapor recovery systems before the end of 1997. This requirement has been mostly fulfilled, as noted in Table 3. The fuel vapor recovery systems and the declining number of fuel stations, taken together, should reduce loads to a little less than 20 % of the 1993 total.

The distribution of fuel stations is naturally closely coupled to developed areas. Some of these areas have emissions at levels similar to total motor traffic evaporation resulting from tank respiration and switched-off warm and hot engines. The number of grids registering high emission loads decreases noticeably as the edges of the city are approached.

Exhaust Gas Emissions of Benzol on Primary Road Network

Map 03.09.8 shows carcinogenic benzol emissions on the primary road network. For calculation purposes, different amounts of benzol in HC exhaust emissions were assigned based on engine type. The benzol percentage for vehicles with regulated catalytic converters in a "warm" condition was set at 8.1 %. A mean of 5.3 % was assigned for total vehicles.

Benzol emissions are proportional to hydrocarbon emissions due to their close relationship (see Map 03.09.1). A total of 793 tons of benzol were emitted on the Berlin primary road network; this is about 50 %

of total traffic-related benzol emissions. Knowledge about benzol emission distribution on the primary road network is necessary to ascertain the pollution concentration for each area, locate heavily polluted areas, and to conduct comparisons with the yearly average concentration value, as stipulated by the 23rd Regulation of the Federal Pollution Control Law (cf. Map 03.10).

Benzol - Total Emissions of Motor Vehicle Traffic

Map 03.09.9 shows that almost the entire inner city has emission levels of over three tons per square kilometer per year in each grid. Benzol loads are considerably lower towards the city edges; this is similar to total hydrocarbon loads. Only a few borough centers have levels close to those in the inner ring of the City Rail Circle Line (S-Bahn-Ring).

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