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Future Air Quality in Danish Cities

Impact Study of the New EU Vehicle Emission Standards

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Preface

Background

The EU Commission has in co-operation with the European Auto- and Oil industry carried out the Auto-Oil Programme. The aim of the programme was to identify cost effective methods to comply to future EU air quality standards in cities in 2010. Based on the study, EU directives have been proposed and partly approved to regulate vehicle emissions and fuel qualities.

Objectives

The aim of the present project is to evaluate the impact on the future air quality in selected Danish cities of the new EU directives and proposals on vehicle emissions and fuel qualities. Furthermore, the objective is to compare the estimated future air quality with air quality limit values for protection of human health approved or proposed by EU as well as air quality guidelines by WHO and the Danish EPA.

Steering Committee

The project has been carried out by: Steen Solvang Jensen, Ruwim Berkowicz, Morten Winther, Finn Palmgren and Zahari Zlatev from the National Environmental Research Institute. The report has been writing by Steen Solvang Jensen with contributions from Morten Winther (vehicle emissions, Chapter 3) and Finn Palmgren (assessment of particulate air pollution, Section 6.6).

A Steering committee has conducted the project: Chairman: Erik Iversen, the Danish EPA and members: Poul Bo Larsen, the Danish EPA, Gitte Ploug Lorenzen, the EPA of Municipality of Copenhagen, Ole Hertel, National Environmental Research Institute, Jesper Schramm, the Technical University of Denmark.

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Project Period

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Electronic Version of Report

An electronic version of this report is posted on the web site of the Danish EPA at www.mst.dk.

Information About Air Pollution

Additional information about air pollution in Denmark can be obtained at the web site of the National Environmental Research Institute under the Department of Atmospheric Environment at http://www.dmu.dk/atmosphericenvironment.

Summary in English

Future Air Quality in Danish cities

Background and Objectives

Background

The EU Commission has in co-operation with the European Auto- and Oil industry carried out the Auto-Oil Programme. The aim of the programme was to identify cost effective measures to comply to future EU air quality standards in cities in 2010 according to the new EU directive "Council 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". Based on the study, EU directives have been proposed and partly approved to regulate vehicle emissions and fuel qualities.

Objectives

The aim of the present project is to evaluate the impact on the future air quality in selected Danish cities of the new EU directives and proposals on vehicle emissions and fuel qualities. Furthermore, the objective is to compare the estimated future air quality with air quality limit values for protection of human health approved or proposed by EU as well as air quality guidelines by WHO and the Danish EPA.

Overall Approach, Applied Models and Main Assumptions

Overall Methodology

The assessment is carried out for the reference year 1995 and the scenario years: 2000, 2005, 2010, 2015 and 2020. Modelled substances include health related substances: NO_2 (NO_x), O_3, CO and benzene. Predictions for particles are based on expert judgement. Future air quality levels are predicted in a selected street named Jagtvej in the central part of Copenhagen that represent a near worst case. Jagtvej has an average daily traffic of about 24.000 vehicles, the street width is 25 meters with 3-5 storeyed buildings. Traffic loads and vehicle composition are assumed to be constant 1995-2020 in the street of Jagtvej which is in accordance with assessments of traffic development by local authorities. Air quality levels in the street is modelled by nested modelling taking into account emissions in the street, urban background levels and regional background levels. Interactions between the street air, the urban background air and the regional background air together with chemical transformations are modelled.

Additionally, calculations are carried out with less detailed input data for 103 other streets in the Copenhagen area with a wide range of traffic loads and street configurations to be able to generalise and relate the results to general traffic conditions in urban areas.

Danish Eulerian Model (DEM)

Regional background levels are predicted by the Danish Eulerian Model (DEM), a large-scale transport model based on 50 x 50 km^2 emission grids for all Europe and meteorology on a 150 x 150 km^2 grid. Development in European emissions is based on proposals for the new ECE protocols on regulation of trans-boundary air pollution to be met in 2010. Development in European emissions is determined by development in emission factors for each activity and development in the activities (industry, energy, transport etc.). National emission ceilings include all these sources. Expected increases in e.g. transport are therefore included.

Danish Urban Background Model (UBM) and Urban Emission Model (UBE)

The urban background levels are modelled by the Danish Urban Background Model (UBM) based on a 2 x 2 km^2 emission grid for the Greater Copenhagen urban area covering 151 km^2. Grid emissions are determined by a Urban Emission Model (UEM) that takes into account the traffic levels on the road network. Other sources are not considered as traffic is the dominating source in larger urban areas. Validation studies of the UBM model show a good agreement between modelled and measured levels when just considering traffic as source indicating that other sources play a minor role. Traffic is expected to increase by 17% on main roads in the urban road network during 1995-2010 corresponding to a general traffic increase of 10% in the road network. Development in traffic emission factors is based on the EU COPERT III emission model, proposed emission reductions and prediction of the development of the age profile of the Danish car fleet.

Danish Operational Street Pollution Model (OSPM)

Air pollution levels in the street of Jagtvej in Copenhagen are modelled by the Danish Operational Street Pollution Model (OSPM) as a contribution from the direct traffic emission in the street and a contribution from the modelled urban background. Vehicle emission factors are also based on COPERT III.

Predicted Future Air Quality

Vehicle Emission Reduction

Vehicle emission reductions during 1995-2010 are determined to about 70%, 75% and 85% for NO_x, CO and benzene, respectively. The impact on future air quality levels has been modelled and compared with limit values.

Importance of Regional and Urban Background Concentrations

The relation between air quality levels in the street of Jagtvej in Copenhagen has been related to concentration levels in the urban background of Copenhagen and the regional background outside Copenhagen, see Table 1. In 1995, urban background and regional background NO_2 levels are about 50% and 25% of the levels in the street, respectively. For CO and benzene, it is about 25% and 10%, respectively. Urban and regional NO_2 levels are relatively high compared to the street levels because NO_2 is mainly a secondary pollutant formed in reactions between NO and ozone. For ozone, concentration levels in the regional background, the urban background and at street level will narrow down from 1995 to 2010. For non-reactive species like CO and benzene, urban and regional levels are relatively low compared to the street levels.

Direct Vehicle Emissions - Decrease in Importance in Determining Street Levels

It is also seen that the regional and urban background will play a relatively larger role in determining street levels in 2010 compared to 1995, most profound for CO and benzene, and less for NO_2. In other words, the direct vehicle emission in the street will decrease in importance in determining air quality levels, although still dominating.

Table 1 *The Relation Between Air Quality at Street Level and in the Urban and Regional Background (Index)*

	NO_2		CO		Benzene		Ozone	
Type	1995 (Index)	2010 (Index)	1995 (Index)	2010 (Index)	1995 (Index)	2010 (Index)	1995 (Index)	2010 (Index)
Street (Jagtvej, Copenhagen)	100	100	100	100	100	100	100	100
Urban background (Copenhagen)	54	56	20	37	26	38	150	128
Regional (outside Copenhagen)	26	38	10	22	9	21	169	124

Predicted Future Trends in Air Quality

In Table 2, the predicted regional background, urban background and street air quality levels are shown for the different scenario years.

***Table 2** Development in Regional, Urban Background and Street Air Quality Levels (Index and Annual Means)*

Regional Background Levels outside Copenhagen					
Scenario	NO_x (Index)	NO_2 (Index)	CO (Index)	Benzene (Index)	O_3 (Index)
1995	100	100	100	100	100
2000	86	88	89	36	99
2005	73	76	79	31	99
2010	59	64	69	28	98
2015	59	64	69	28	98
2020	59	64	69	28	98
	NO_x (µg/m^3)	NO_2 (µg/m^3)	CO (mg/m^3)	Benzene (µg/m^3)	O_3 (µg/m^3)
1995_obs	16.9	13.6	0.19	1.59	50.4
2000	14.6	11.9	0.17	0.57	50.2
2005	12.3	10.3	0.15	0.50	49.9
2010	10.0	8.7	0.13	0.44	49.6
2015	10.0	8.7	0.13	0.44	49.6
2020	10.0	8.7	0.13	0.44	49.6
Urban Background Levels in Copenhagen					
Scenario	NO_x (Index)	NO_2 (Index)	CO (Index)	Benzene (Index)	O_3 (Index)
1995	100	100	100	100	100
2000	77	81	82	30	105
2005	58	64	70	23	110
2010	39	46	57	18	114
2015	34	40	53	17	116
2020	32	38	53	16	116
	NO_x (µg/m^3)	NO_2 (µg/m^3)	CO (mg/m^3)	Benzene (µg/m^3)	O_3 (µg/m^3)
1995_obs	38.6	28.2	0.39	4.4	44.7
2000	29.9	23.0	0.32	1.4	47.0
2005	22.3	17.9	0.27	1.0	49.1
2010	15.2	12.9	0.22	0.79	50.9
2015	13.1	11.4	0.21	0.74	51.7
2020	12.3	10.8	0.20	0.73	52.0
Street Concentrations at Jagtvej, Copenhagen					
	NO_x (Index)	NO_2 (Index)	CO (Index)	Benzene (Index)	Ozone (Index)
1995	100	100	100	100	100
2000	74	83	69	30	110
2005	46	63	50	16	123
2010	28	44	35	12	134
2015	21	37	31	11	139
2020	18	34	29	10	142
	NO_x (µg/m^3)	NO_2 (µg/m^3)	CO (mg/m^3)	Benzene (µg/m^3)	Ozone (µg/m^3)
1995_obs	164	52	2	17	30
2000	122	44	1.1	5.2	33
2005	75	33	0.8	2.9	37
2010	46	23	0.6	2.1	40
2015	34	20	0.5	1.9	41
2020	29	18	0.5	1.8	42
EU limit value (2010)	-	40	-	5	-
WHO guidelines	-	40	-	0.17	-
Danish EPA criteria	-	15-20	-	0.13-0.25	-

NO Becomes Limiting Factor in Forming NO_2

Catalyst cars were introduced in Denmark in 1990/91 and reduce NO_x emissions (NO and NO_2). NO_2 observed levels in Jagtvej were more or less constant during 1990-95 indicating that ozone was the limiting factor in forming NO_2 in reactions between NO and ozone. From 1995 to 1998, measurements show a downward trend in NO_2 levels, and this trend is also reproduced by the OSPM model.

During 1995-2010/2020, 98- and 99.8-percentiles of NO_2 are predicted to decrease about 50% and 35%, respectively. The predictions show that NO becomes the limiting factor in forming NO_2 in reactions with ozone in the future due to the steadily decreasing NO_x emissions (NO and NO_2). NO constitutes about 95% of NO_x vehicle emissions.

Ozone

Annual regional ozone levels are only predicted to decrease about 2% in Denmark during 1995-2010 despite European reductions of ozone precursors like NO_x and VOCs of about 40%. However, high ozone levels during spring and summer decreases more. At Danish meteorological conditions, the regional background ozone is dominated by long-range transport as the net production of ozone is small in Denmark. Ozone levels are modelled to increase about 14% during 1995-2010 in the urban background since less NO is available for ozone depletion due to NO_x vehicle emission reductions.

CO and Benzene

CO levels are predicted to decrease by a factor of 4 and benzene levels by a factor of 10 from 1995 to 2010. The predicted downward trends of CO and benzene are also supported by observed levels during 1995-1998.

Comparison with Air Quality Guidelines

Air Quality Guidelines

Modelled street levels in Jagtvej, Copenhagen were compared with EU air quality limit values, WHO guidelines and Danish EPA criteria. The Danish EPA air quality criteria were set up to minimize adverse health effects. The air quality criteria are not administrative limit values but should be regarded as desired long-term objectives (Larsen et al. 1997).

New EU limit values have to be met in 2010. A margin of tolerance has been defined to secure that limit values will be met in 2010. The margin of tolerance given as a percentage in the table refers to the year the directive entries into force. The margin of tolerance is equally stepped down each year to reach 0% in 2010. Member states have to take local action if the margin of tolerance is exceeded.

Ozone

At street levels, the proposed EU limit value for short-term exposure was not exceeded in 1995 nor will it be exceeded in 2010 despite an increase in ozone levels in the street due to a decrease in NO vehicle emissions leaving less NO for depletion of ozone in forming NO_2. However, the sum of NO_2 and O_3 decreases. The urban background is a better indicator for ozone exposure of the population than levels in the streets since ozone levels are influenced by NO emissions. The proposed EU limit value for short-term exposure was not exceeded in the urban background.

NO_2

The EU limit value for NO_2 for long-term exposure was exceeded in 1995 and the limit value for short-term exposure is tangent. However, the margin of tolerance of 50% in 1999 is not exceeded.

The predicted NO_2 levels in 2010 at Jagtvej are about half of the EU limit value in 2010. The Danish EPA criteria for short-term and long-term exposure is exceeded for all scenario years until 2015-2020.

CO

The EU limit value for CO will be between the 98- and 99.8-percentile. The EU limit value for CO was not exceeded in 1995, and the margin of tolerance of 50% will not be exceeded in the expected year of entry into force of the directive (2000). In 2010 the predicted CO levels will be 10-20% of the EU limit value for 2010. The EU limit value and WHO guidelines are identically for CO. The Danish EPA has not suggested criteria for CO.

Benzene

The EU limit value for benzene was exceeded in 1995. The margin of tolerance of 100% will not be exceeded based on modelled levels in 2000, the expected year of entry into force of the proposed directive. The predicted levels in 2010 will be about half of the EU limit value. WHO guidelines and Danish EPA criteria are exceeded for all scenario years.

103 Streets in Copenhagen

Crude calculations of annual levels of NO_2 and benzene for 103 streets in Copenhagen showed that levels were below EU limit values for all streets.

The health impacts of NO_2, benzene and CO are likely to decrease in the future due to improved air quality for these pollutants.

Particulate Matter

Preliminary assessment

A separate assessment was carried out for particulate matter since Danish air quality models for particles are not yet available but under development. A preliminary assessment of the particle levels of TSP (Total Suspended Particulate Matter) and PM_{10} (particles less than 10 μm) in selected streets in Denmark was carried out and levels were related to the new EU limit values for PM_{10}. Measurements of ultrafine particles from vehicles in two Danish streets (particles less than 0.2 μm) were also presented.

TSP/PM_{10}

Measurements show that TSP is approx. 35% higher than PM_{10}, that is, PM_{10} constitutes on average about 74% of TSP. This relation was used to give an indicative estimation of PM_{10} levels at selected streets in Denmark where TSP is measured. Estimated PM_{10} levels in 1998-99 were below the new limit value for 2005 but exceed the limit value for 2010.

Possible Future Development

Denmark has a national objective to reduce particle vehicle emission by 50% in urban areas 1988-2010, and further reductions after 2010. The increase in penetration of catalyst converters reduce particle emissions for petrol powered vehicles due to unleaded petrol. Catalysts become mandatory in 1990. New stringent particulate emission standards for especially diesel powered vehicles will reduce particle emissions. The conversion to diesel with a low content of sulphur will also reduce particulate emissions.

Previous assessments indicate that the total particulate emissions (as mass) from vehicle within the EU will decrease by about 70% 1995-2010 including expected increases in traffic. Based on a few number of European studies, WHO has estimated that the particulate emission from vehicles in urban areas contributes about 40-60% of PM_{10}.

Due to the above mentioned regulation of vehicle particulate emissions it is likely that the PM_{10} will decrease in the future but it is difficult to estimate how much based on existing knowledge and to estimate if the limit value for 2010 will be met. The above figures indicate that it might be a problem.

Uncertainties and Future Research Needs

COPERT III underestimates emissions

Validation of the Urban Background Model and the OSPM model by comparing modelled and measured concentration levels showed that the models underestimate observed concentrations when using the EU COPERT III emission factors indicating that COPERT III underestimates real world emissions on the road assuming that the air quality models are correct.

A test was carried out that compared the ratio between modelled and measured CO and NO_x in the street of Jagtvej using COPERT III emission factors for CO and NO_x. If the ratio between CO and NO_x emissions is correct then the same ratio will be found in the observed concentrations of CO and NO_x. It was seen that the slope of modelled air quality levels using COPERT III emission factors was very different from the measured ratio between CO and NO_x in the street air. This indicates that the ratio between COPERT III emission factors for CO and NO_x is questionable since it does not comply with the ratio found in the measured street air.

Nevertheless, COPERT III emission factors were applied throughout the study although predicted air quality levels to begin with become underestimated. To compensate, the following approach was applied. For prediction of future concentrations in the urban background or in the street, observed levels have been applied from 1995 as a baseline for calibration, and the modelled trend as an index has been used to estimate future levels to give realistic predicted air quality levels that can be compared to air quality limit values. For reactive species like NO_2 this approach may underestimate future NO_2 levels in the street because of the non-linear relation between NO_x emissions and NO_2 due to interaction with ozone.

A study should be carried out that examines how well COPERT III emission factors correspond to on the road emissions by linking emissions to air quality levels in streets using models and measurements.

Particulate Matter

Particle emissions by mass and probably also by numbers are expected to decrease in the future promising less health impacts due to particulate matter. However, the knowledge about the air pollution with particulate matter is still rather limited. By the new $PM_{10}/PM_{2.5}$ methods and measurements of ultrafine particles from traffic, possibilities have opened to obtain valuable data. Systematic measurements, including long time-series, by these methods at representative sites will improve the possibilities for health studies substantially. However, more knowledge is needed about the chemical/physical properties of the particle, e.g. chemical composition, surface properties and morphology. The characterisation of the particles is also important for quantification of the contribution from different sources and parameterisation of the properties of the particles to be included in air quality models. This is necessary for decisions on abatement measures to be taken to reduce the health impacts of particulate air pollution and to evaluate the effects of the measures taken.

Traffic loads

Traffic loads at Jagtvej in Copenhagen was assumed to be constant during the scenario years and traffic loads on the road network in the Copenhagen area was assumed to increase by 17% on main roads during 1995-2010 corresponding to a general traffic increase of 10% in the road network. If these assumptions are too optimistic, air quality levels will be higher than predicted. However, somewhat higher traffic loads will not compromise the downward trend in concentrations due to the profound emission reductions.

Scenarios 2015-2020 Predictions for 2015 and 2020 are indicative. They reflect the penetration of cars that comply to EURO IV for passenger cars and vans (2006-7) and EURO V for lorries and buses (2010). Obviously, these scenarios do not take into account possible future new EU national emission ceilings or vehicle emission regulation.

Other Sources than Traffic The regional and urban background concentrations gain in importance in relation to the direct vehicle emissions in urban streets in the future. However, traffic will still be the domination source in urban areas but more attention will have to be put on other sources in urban areas to predict concentration levels. In the present study, prediction of the regional background include all source but the Urban Background Model only includes traffic as source. However, it is likely that inclusion of other sources would not have changed predicted urban background levels significantly.

DEM Model Prediction of CO in the DEM model could be improved by applying better emission data what is available. A feature for predicting benzene levels could be develop.

CO Monitoring CO is a good indicator for petrol powered vehicles and can be used to estimate other pollutants like benzene. More CO monitoring in regional background is required to get a more complete picture of regional background concentrations, and to get reliable data for validation of the UBM model.

Summary in Danish

Den fremtidige luftkvalitet i byerne bliver bedre

Omfattende beregninger med en rækkeluftkvalitetsmodeller udviklet af Danmarks Miljøundersøgelser viser, at den regionale baggrundsforurening uden for byerne, bybaggrundsforureningen over byerne og luftkvaliteten i gadeniveau bliver bedre i fremtiden. Dette skyldes især EU's skærpede regulering af køretøjers emission. EU's nye grænseværdier fokvælstofdioxid (NO_2), kulilte (CO) og benzen gældende for 2010 forventes ikke at blive overskredet. Ozonniveauerne forventes at stige lidt, fordi begrænsningen i bilernes emission af kvælstofmonoxid (NO) betyder, at mindre ozon fjernes i reaktioner med NO i dannelsen af NO_2. Det er endnu ikke muligt at modellere partikler. Ud fra foreløbige vurderinger er der usikkerhed om, hvorvidt EU's grænseværdi for partikler kan overholdes i 2010. Grænseværdierne er opstillet for at beskytte befolkningens sundhed.

Baggrund og formål

EU har vedtaget et rammedirektiv for vurdering og styring af luftkvaliteten som med datterdirektiver fastsætter skærpede grænseværdier for 12 stoffer. Vi har tidligere haft grænseværdier for 5 af stofferne. I forbindelse med udarbejdelse af luftkvalitetsdirektiverne er der sideløbende iværksat det såkaldte Auto-Oil program, som undersøgte, hvordan luftkvalitetsmålene kunne opfyldes gennem regulering af bilernes emission og af brænstofskvaliteten. Dette arbejde er mundet ud i en række nye direktiver, som skærper kravene til nye køretøjers emission af skadelige stoffer og til brændstofskvaliteten fx svovlindholdet.

Formålet med projektet har derfor været at undersøge den fremtidige luftkvalitet i danske byer som følge af de strengere emissions- og brændstofskrav, og vurdere om de nye skærpede EU grænseværdier for luftkvalitet i 2010 kan forventes at blive overholdt.

Undersøgelsen

Den fremtidige luftkvalitet er beregnet i Jagtvej i København, som repræsenterer en gade med forholdsvis høje koncentrationer. Den er ret trafikeret med omkring 24.000 biler i døgnet, og gaden er ca. 25 meter bred og er omgivet af 2-5 etagers bygninger. Time for time beregninger for NO_x ($NO+NO_2$), NO_2, ozon, CO og benzen er gennemført for referenceåret 1995 og scenarieårene: 2000, 2005, 2010, 2015 og 2020. Udviklingen i partikler er baseret på ekspertvurderinger. Ozon udsendes ikke direkte men dannes i atmosfæren ud fra NO_x og kulbrinter under indvirkning af sollys. Ozon i Danmark skyldes overvejende langtransport, idet det primært dannes i syd- og centraleuropa.

Den fremtidige luftkvalitet i gaden er beregnet ved at kombinere en række luftkvalitetsmodeller. En model beregner den regionale luftkvalitet uden for København, som er bestemt af emissionsudviklingen i hele Europa. Emissionudviklingen reguleres gennem en række internationale konventioner, hvor Danmark har forpligtiget sig til at opfylde en række mål for reduktion af de nationale emissioner. En anden model beregner bybaggrundsforureningen over København ud fra den regionale forurening og trafikkens emission i Københavnområdet. Trafikken emission er bestemt med en byemissionsmodel. Det er forudsat at trafikken stiger med 10% fra 1995 til 2010 i København med 17% på de store veje, hvilket er i overensstemmelse med Københavns Kommunes egne vurderinger. Luftkvaliteten på Jagtvej er bestemt med en gadeluftkvalitetsmodel, som tager hensyn til trafikken i gaden, gadens udformning, bybaggrundsforureningen og meteologien. Det er forudsat at trafikken på Jagtvej er den samme i alle scenarieårene.

Hovedkonklusioner

Undersøgelsen viser, at den beregnede luftkvalitet på Jagtvej i København forbedres for NO_2, CO og benzen fra 1995 til 2010 og videre frem trods stigende trafik, således at EU's nye grænseværdier ikke overskrides i 2010. Ozonniveauerne i gaden vil stige, idet der er mindre NO emission i gaden til at omdanne ozon til NO_2. Summen af NO_2 og ozon vil dog falde. EU's forventede nye grænseværdi for ozon i 2010 vil dog ikke overskrides. Det samme gælder for 103 andre gader med forskellige trafikmængder i København, hvor beregningerne er gennemført med mindre detaljeret input data.

De beregnede niveauer er også sammenlignet med WHO's guidelines, og luftkvalitetskriterier foreslået af Miljøstyrelsen. Luftkvalitetskriterierne repræsenterer en minimering af mulige sundhedsskader med et meget højt sikkerhedsniveau. Kriterierne gælder ikke administrativ, men kan opfattes som ønskede langsigtede mål. (Larsen et al. 1997).

EU's forslåede grænseværdi for ozon vil ikke blive overskredet hverken i gadeniveau eller i bybaggrunden. For ozon er bybaggrunden en bedre indikator for befolkningens eksponering, idet ozonniveauerne i gadeniveau er stærkt påvirket af NO emissionen i gaden. WHO's strengere vejledende værdi og Miljøstyrelsens meget lave luftkvalitetskriterie vil være overskredet for ozon.

EU's og WHO's grænseværdier for NO_2 er ens, og er ikke overskredet i 2010, men Miljøstyrelsens luftkvalitetskriterie er overskredet frem til 2015-2020. De fremtidige NO_2 niveauer bliver begrænset af tilstedeværelsen af NO fra trafikken, hvor den tidligere har været begrænset af tilstedeværelsen af ozon.

EU og WHO har samme grænseværdi for CO, som ikke overskrides i referenceåret eller i scenarieårene. Miljøstyrelsen har ikke opstillet luftkvalitetskriterie for CO.

EU's foreslåede grænseværdi for benzen vil ikke være overskredet i 2010, men den strengere WHO grænseværdi og Miljøstyrelsens luftkvalitetskriterie er overskredet.

Den fremtidige grænseværdi for PM_{10} i 2005 overskrides ikke i 1998-99, men det kan ikke udelukkes at den skærpede grænseværdi i 2010 vil overskrides. PM_{10} er partikler under 10 mikrometer dvs. 10 tusindedele af en millimeter. Der er således brug for yderligere forskning i kilderne til partikler, bedre beskrivelse vha. målinger samt modeludvikling for at kunne bestemme fremtidige niveauer og for bedre at kunne vurdere effekten af forskellige tiltag.

Projektresultater

De beregnede årsmiddelkoncentrationer i den regionale baggrund, i bybaggrunden og i gadeniveau på Jagtvej i København er vist i tabellen, og sammenlignet med EU og WHO grænseværdier samt Miljøstyrelsens luftkvalitetskriterier.

Andet væsentligt

Undersøgensen viste også, at det er sandsynligt at de emissionsfaktorer (g/km) som ligger til grund for nationale emissionsopgørelser i EU herunder i Danmark underestimerer NO_x og CO. Luftkvalitetsberegninger med disse emissionsfaktorer viste en underestimering i forhold til målinger af koncentrationer af NO_x og CO i luften. Derfor er der i beregningerne af den fremtidige luftkvalitet kompenseret herfor. Disse forhold bør undersøges nærmere.

Andre kilder

Larsen, P.B., Larsen, J.C., Fenger, J., Jensen, S.S. (1997): Sundhedsmæssig vurdering af luftforurening fra vejtrafik, Miljøprojekt nr. 352, Miljøstyrelsen. 287 s.

Box:

Anvendte luftkvalitets- og emissionsmodeller

Den regionale luftkvalitet er beregnet med Danish Eulerian Model (DEM) på baggrund af 50x50 km^2 gitternet for hele Europa med emissioner samt meteorologisk data på et 150x150 km^2 gitternet. En supercomputer på UNI-C i København udfører beregningerne. Øvrige beregninger udføres på PC. Bybaggrundsforureningen er modelleret med Urban Background Model (UBM) på baggrund af emissionsdata fra trafikken på et 2x2 km^2 gitternet for Storkøbenhavn samt meteorologiske data fra København. Emissionen er beregnet med en videreudviklet udgave af Urban Emission Model (UEM), som oprindeligt blev opstillet af Vejdirektoratet. Luftkvaliteten i gaderummet er beregnet med Operational Street Pollution Model (OSPM) ud fra oplysninger om trafikkens emission i gaden, gadens udformning, bybaggrundsforureningen og meteorologi. Emissionsfaktorer er baseret på EU's COPERT III emissionsmodel med danske trafikforudsætninger. Beregningerne er kalibreret med målingerne i referenceåret 1995.

Udvikling i regional baggrundsforurening, bybaggrundsforurening og luftkvaliteten i gadeniveau for Jagtvej i København (Indeks og årsniveauer)

	Regional baggrund uden for København				
Scenarie	NO_x (Indeks)	NO_2 (Indeks)	CO (Indeks)	Benzen (Indeks)	Ozone (Indeks)
1995	100	100	100	100	100
2000	86	88	89	36	99
2005	73	76	79	31	99
2010	59	64	69	28	98
2015	59	64	69	28	98
2020	59	64	69	28	98
	NO_x (µg/m^3)	NO_2 (µg/m^3)	CO (mg/m^3)	Benzen (µg/m^3)	Ozon (µg/m^3)
1995_observeret	16.9	13.6	0.19	1.59	50.4
2000	14.6	11.9	0.17	0.57	50.2
2005	12.3	10.3	0.15	0.50	49.9
2010	10.0	8.7	0.13	0.44	49.6
2015	10.0	8.7	0.13	0.44	49.6
2020	10.0	8.7	0.13	0.44	49.6
	Bybaggrundskoncentrationen over København				
Scenarie	NO_x (Indeks)	NO_2 (Indeks)	CO (Indeks)	Benzen (Indeks)	Ozon (Indeks)
1995	100	100	100	100	100
2000	77	81	82	30	105
2005	58	64	70	23	110
2010	39	46	57	18	114
2015	34	40	53	17	116
2020	32	38	53	16	116
	NO_x (µg/m^3)	NO_2 (µg/m^3)	CO (mg/m^3)	Benzen (µg/m^3)	Ozon (µg/m^3)
1995_observeret	38.6	28.2	0.39	4.4	44.7
2000	29.9	23.0	0.32	1.4	47.0
2005	22.3	17.9	0.27	1.0	49.1
2010	15.2	12.9	0.22	0.79	50.9
2015	13.1	11.4	0.21	0.74	51.7
2020	12.3	10.8	0.20	0.73	52.0
	Gadekoncentrationer i Jagtvej, København				
Scenarie	NO_x (Indeks)	NO_2 (Indeks)	CO (Indeks)	Benzen (Indeks)	Ozon (Indeks)
1995	100	100	100	100	100
2000	74	83	69	30	110
2005	46	63	50	16	123
2010	28	44	35	12	134
2015	21	37	31	11	139
2020	18	34	29	10	142
	NO_x (µg/m^3)	NO_2 (µg/m^3)	CO (mg/m^3)	Benzen (µg/m^3)	Ozon (µg/m^3)
1995_observeret	164	52	2	17	29.8
2000	122	44	1.1	5.2	32.8
2005	75	33	0.8	2.9	36.6
2010	46	23	0.6	2.1	39.9
2015	34	20	0.5	1.9	41.4
2020	29	18	0.5	1.8	42.3
EU grænseværdi	-	40	-	5	-
WHO guidelines	-	40	-	0.17	-
Miljøstyrelsens luftkvalitetskriterie	-	15-20	-	0.13-0.25	-

1 Introduction

Background and Objectives

The EU Commission has in co-operation with the European Auto- and Oil industry carried out the Auto-Oil Programme. The aim of the programme was to identify cost effective measures to comply to future EU air quality standards in cities in 2010 according to the new EU directive ”Council 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”. Based on the study, EU directives have been proposed and partly approved to regulate vehicle emissions and fuel qualities. These directives include directive 98/69/EC on emissions from motor vehicles (EC 1998), directive 98/70/EC on the quality of petrol and diesel fuels (EC 1998a), and directive 99/96/EC relating to heavy trucks (EC 1999).

The aim of the present project is to evaluate the impact on the future air quality in selected Danish cities of the new EU directives and proposals on vehicle emissions and fuel qualities. Furthermore, the objective is to compare the estimated future air quality with air quality limit values for protection of human health approved or proposed by EU as well as air quality guidelines by WHO and the Danish EPA.

Overall Methodology

The assessment is carried out for the reference year 1995 and the scenario years: 2000, 2005, 2010, 2015 and 2020.

Modelled substances include health related substances: NO_2 (NO_x), O_3, CO and benzene. Predictions for particles are based on expert judgement.

Future air quality levels are predicted in a selected street in Copenhagen (Jagtvej) that represent a near worst case. Air quality levels in the street is modelled by nested modelling taking into account emissions in the street, urban background levels and regional background levels. Interactions between the street air, the urban background air and the regional background air together with chemical transformations are modelled.

Additionally, calculations are carried out with less detailed input data for 103 other streets in the Copenhagen area with a wide range of traffic loads and street configurations to be able to generalise and relate the results to general traffic conditions in urban areas.

Danish Eulerian Model (DEM)

Regional background levels are predicted by the Danish Eulerian Model (DEM), a large-scale transport model based on 50 x 50 km^2 emission grids for all Europe and meteorology on a 150 x 150 km^2 grid. Development in European emissions is based on proposals for the new ECE protocols on regulation of trans-boundary air pollution.

Danish Urban Background Model (UBM) and Urban Emission Model (UBE)

The urban background levels are modelled by the Danish Urban Background Model (UBM) based on a 2 x 2 km^2 emission grid for the urban area. Grid emissions are determined by a Urban Emission Model (UEM) that takes into account the traffic levels on the road network. The model was originally developed by the Danish Road Directorate but it has been improved as part of the present project. Development in traffic emission factors is based on the EU COPERT III emission model, proposed emission reductions and prediction of the development of the age profile of the Danish car fleet.

Danish Operational Street Pollution Model (OSPM)

Air pollution levels in the street are modelled by the Danish Operational Street Pollution Model (OSPM) as a contribution from the direct traffic emission in the street and a contribution from the urban background. Vehicle emission factors are also based on COPERT III.

Content of Report

Chapter 2 outlines the overall methodology for prediction of future air quality levels. The applied models are shortly described, and this chapter also includes a short description of the selected case areas and scenario studies.

Chapter 3 describes the assumptions for and the development in emission factors based on COPERT III.

Chapter 4 includes a validation study of the prediction of the regional background levels by the DEM model and results from scenario studies.

Chapter 5 comprises a validation study of the prediction of the urban background levels by the UBM and UEM models and results from scenario studies.

Chapter 6 includes a validation study of the prediction of the street levels by the OSPM model and results from scenario studies. The results are compared with EU air quality limit values as well as WHO air quality guidelines and the Danish EPA air quality criteria.

In chapter 7 the results of the present study is compared with the ongoing EU study “Urban Impact Assessment” of the Auto-Oil Programme in 11 European cities as well as national vehicle emission scenarios carried out by the EU Commission.

Appendices include detailed information about the assumed development in traffic and emissions used as input for the different models.

Unit Conversion

The following values are used for conversion between different units:

ppb to µg/m^3		µg/m^3 to ppb	
NO_x*	1.882	NO_x*	0.531
NO_2	1.882	NO_2	0.531
CO**	1.146	CO***	0.873
Benzene	3.257	Benzene	0.307
Ozone	1.963	Ozone	0.509

*As NO_2-units.**ppm to mg/m^3 .***mg/m^3 to ppm

2 Methodology

This chapter describes the overall approach and applied air quality models to estimate future air quality concentrations at street level.

Scenario Years

The assessment is carried out for the reference year 1995 and the scenario years: 2000, 2005, 2010, 2015 and 2020. All scenario years are run with meteorological parameters for the reference year 1995.

Species

Modelled substances include health related substances: NO_2 (NO_x), O_3, CO and benzene. Predictions for particles are based on expert judgement since high quality air quality models for prediction of particle concentrations are not available at present but under development.

Cases

Future air quality levels are predicted in a street named Jagtvej in the central part of Copenhagen. Jagtvej is selected because it represents a near worst case situation and because a monitor station is present in the street and in the urban background. Furthermore, detailed traffic data is available. Jagtvej has an average daily traffic of about 24.000 vehicles, the street width is 25 meters with 3-5 storeyed buildings.

Additionally, calculations are carried out with less detailed input data for 103 other streets in the Copenhagen area with a wide range of traffic loads and street configurations to be able to generalise and relate the results to general traffic conditions in urban areas.

Nested Modelling

Nested Modelling

Future air quality levels are predicted in Jagtvej, Copenhagen by nested modelling taking into account emissions in the street, urban background levels and regional air quality levels. Interactions between the street air, the urban background air and the regional background air together with chemical transformations are modelled, see Figure 2.1.

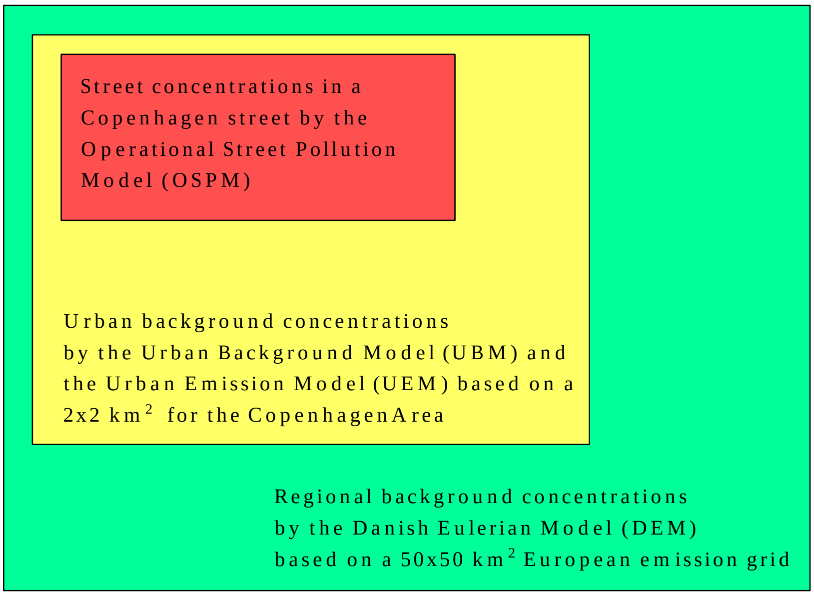


Figure 2.1 *Illustration of the overall nested modelling approach estimating regional, urban and street air quality levels*

In Figure 2.2 different components of the nesting modelling system is shown in greater details.

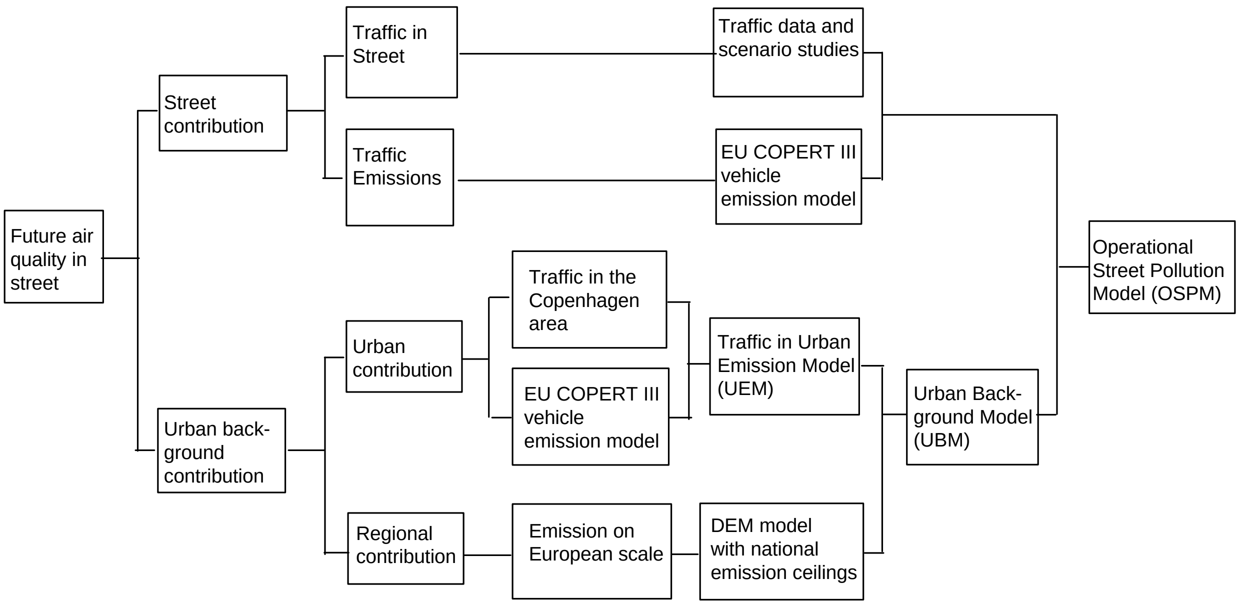


Figure 2.2 *Illustration of the different components of the nested modelling approach*

Regional Background levels

Regional Background Modelling

Regional background levels are predicted by the Danish Eulerian Model (DEM), a large-scale transport model based on 50x50 km^2 emission grids and 150x150 km^2 meteorological grids for all Europe (Zlatev 1995; Zlatev et al.1998). Development in European emissions is based on proposals for the new ECE protocols on regulation of trans-boundary air pollution, see Appendix 1. The model estimates hourly time-series of NO_x, NO_2, O_3 and CO. The model runs on a super computer at UNI•C in Copenhagen. An example of model results is given in Figure 2.3.

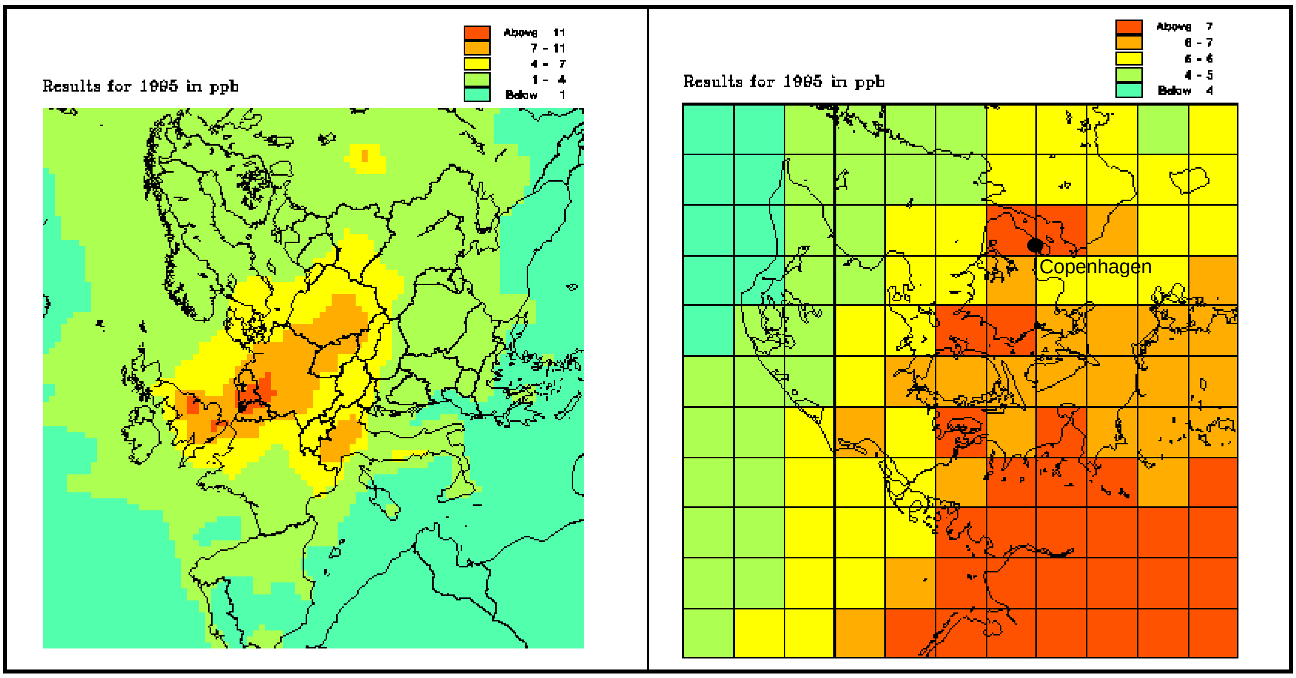


Figure 2.3 *Example of model results from the DEM model shown on a 50x50 km^2 grid. Annual regional background concentrations of NO_2 in 1995. Left: Europe. Right: close-up of Denmark.*

Urban Background Modelling

Urban Background Levels

The urban background levels in Copenhagen are modelled by the dispersion model Urban Background Model (Berkowicz 1999) based on a 2x2 km^2 emission grid for the urban area. Meteorological parameters are taken from an urban background top-roof mast at a nearby university building (HC Ørsted Institute). Grid emissions are given by the Urban Emission Model (Danish Road Directorate 1996).

Urban Emission Model (UBE)

The Urban Emission Model (UEM) estimates vehicle emissions on a 2 x 2 km^2 grid. The emission model takes into account the traffic levels on each road in each grid cell. The model covers an urban area of 151 km^2 around Jagtvej in Copenhagen. The model was originally developed by the Danish Road Directorate (Danish Road Directorate 1996) but it has been improved as part of the present project with more vehicle categories, more detailed diurnal variation in traffic loads and new emission factors based on COPERT III.

The model domain is illustrated in Figure 2.4.

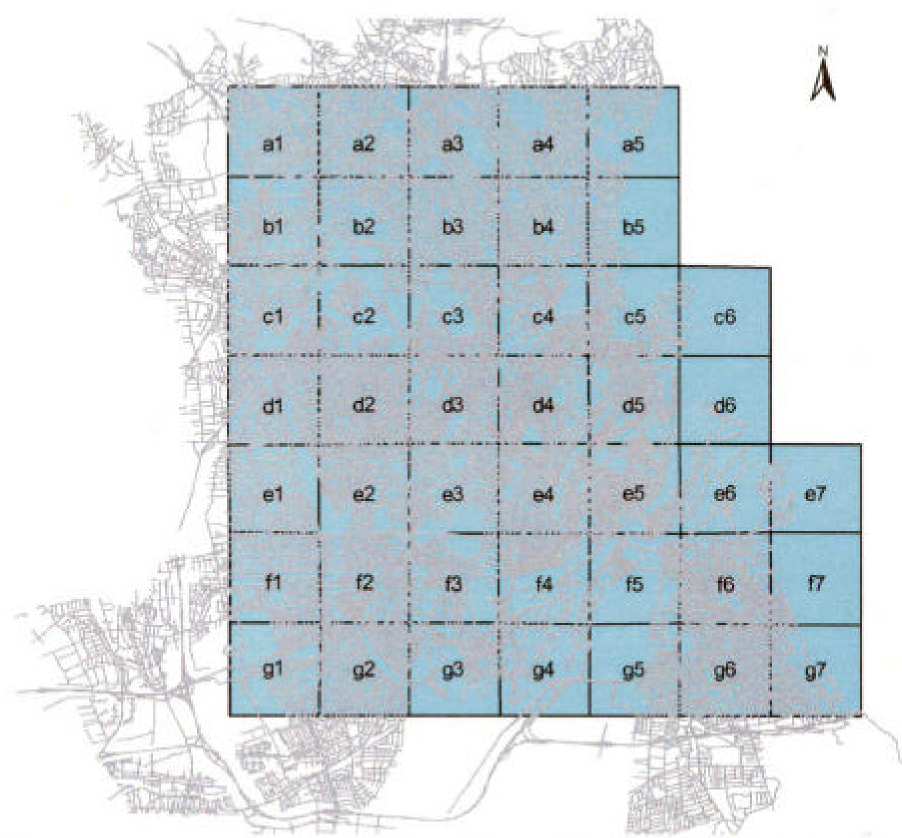


Figure 2.4 *Model domain of the Urban Background Model (UBM) and the Urban Emission Model (UEM). Identification No. for each 2x2 km^2 grid cell are also shown. Jagtvej in Copenhagen is located in cell d4.*

Species and Time Resolution

The following species are included: CO, NO_x, NMVOC, particulates, and also CO_2. The diurnal variation in emissions on an hourly basis is estimated for working days, Saturdays and Sundays further sub-divided in July and remaining months. CO and NO_x emissions are used in the Urban Background Model to produce a time-series of these pollutants.

Road Types

Road types includes residential streets (30 km/h), traffic roads (50 km/h), arterial roads (60 km/h) and motorways (110 km/h).

Vehicle categories

The following vehicle types are included:

- Conventional gasoline passenger cars
- Closed loop catalyst gasoline passenger cars
- Conventional gasoline light duty vehicles (vans)
- Closed loop catalyst gasoline light duty vehicles (vans)
- Diesel passenger cars
- Diesel light duty vehicles (vans)
- Lorries (3.5-7.5 tonnes)
- Lorries (7.5-16 tonnes)
- Lorries (16-32 tonnes)
- Lorries (> 32 tonnes)
- Urban buses.

Emissions

Development in traffic emission factors is based on the EU COPERT III emission model (see chapter 3).

Street Pollution Modelling

Danish Operational Street Pollution Model (OSPM)

Air pollution levels in the street are modelled by the Danish Operational Street Pollution Model (OSPM) as a contribution from the direct traffic emission in the street and a contribution from the urban background. (Berkowicz et al. 1997; Jensen 1997, 1998). The urban background is determined by the UBM model.

The OSPM model calculates hourly concentration levels of: CO, NO_2, NO_x (NO + NO_2), O_3 and benzene.

The model describes the physical and chemical process in the street. The model takes into account the street configuration (street orientation, width, building height etc.) and simple photo-chemistry between NO, NO_2 and O_3.

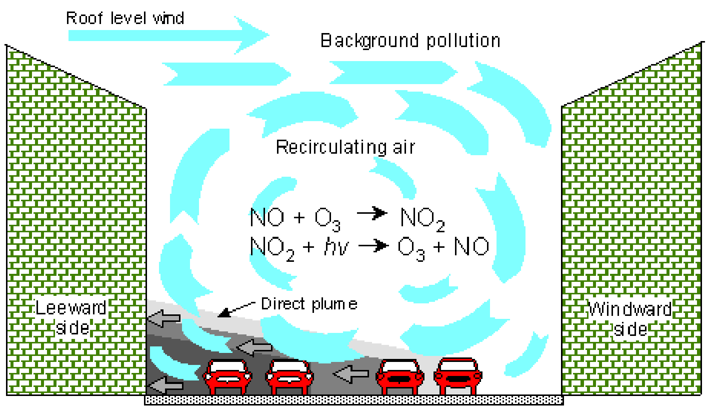


Figure 2.5 *The OSPM model describes the recirculation of air in a street canyon and simple photo-chemistry*

Traffic data and Emissions

The diurnal variation in hourly traffic loads has to be given for working days, Saturdays and Sundays and further sub-divided in July and remaining months. Emission factors are also based on COPERT III.

3 Vehicle Emission Factors

To provide the present study with emission data a simplified model has been made to forecast the emission factors for vehicles in the years 2000, 2005, 2010, 2015 and 2020 using 1995 as a reference year. The model covers the hot, cold and evaporative (running loss) emission types respectively for the emission species: CO, NO_x, VOC (NMVOC and CH_4), particulates, CO_2 and N_2O. CO and NO_x emission factors are used for air quality modelling of urban background and street levels.

The following vehicle types are included in the model:
- Conventional gasoline passenger cars
- Closed loop catalyst gasoline passenger cars
- Conventional gasoline light duty vehicles (vans)
- Closed loop catalyst gasoline light duty vehicles (vans)
- Diesel passenger cars
- Diesel light duty vehicles (vans)
- Lorries (3.5-7.5 tonnes)
- Lorries (7.5-16 tonnes)
- Lorries (16-32 tonnes)
- Lorries (> 32 tonnes)
- Urban buses.

3.1 Background Data for Vehicle Emissions

The travel speed dependent hot emission factors from the European road traffic emission model COPERT III are used as background emission data for all of today's and future vehicle types (Ntziachristos, 1999). An overview of the different emission legislation levels for present and future vehicle layers are given in Table 3.1 and Table 3.2. A vehicle layer consists of the vehicles with comparable data for emissions and fuel consumption. In the present study the emission factors are picked out from COPERT III at a travel speed of 50 km/h. This choice of travel speed facilitates the subsequent use of data in models for air quality, where the single set of emission factors are scaled to represent the emission factors at travel speeds found in the selected case study streets.

An exception to the use of original emission data from COPERT III is made for conventional gasoline light duty vehicles. In this situation no classification is made in COPERT III to take into account vehicle age and technology levels. Instead the emission factors for these vehicles are represented by the emission factors from conventional gasoline light duty vehicles corresponding to first registration years, and emissions are multiplied with a factor of 1.5.

COPERT III does not give emission factors for benzene. Benzene emission factors have been established by so-called invert calculations by the OSPM model assuming that the OSPM gives a perfect description of the dispersion whereby emission factors for light and heavy vehicles can be estimated. In the reduction of benzene emission factors in the different scenario years, it is taken into account that the benzene content in petrol has decreased from 3% to 1% between 1995 and 2000.

Deterioration of Emission Factors

The emissions from catalyst equipped vehicles increase with increasing mileage due to wear of the catalytic converter. Emissions continue to increase until a certain cut-off mileage is reached. At this time the emissions stabilise at a constant level due to On Board Diagnostics (OBD) in future catalyst cars and the implementation of the Danish inspection and maintenance programme. This is true when the emissions from the entire fleet is considered on average. For the individual vehicles the emission curves may be serrated. The deterioration factors and cut-off mileage from COPERT III are used in the present project to simulate the influence on emissions and fuel consumption due to catalyst ageing, OBD and the Danish inspection and maintenance programme.

Cold Start Emission Factors

In general the cold start emission factors are calculated as the hot emission factors times the hot/cold emission ratio, the latter ratio, see Appendix 1, is given in COPERT III. For catalyst gasoline vehicles the ratios exist for three engine sizes of passenger cars and one ratio for vans. The ratios are equivalent for gasoline fuelled conventional passenger cars and vans, and for diesel passenger cars and vans, respectively. Even though, the hot/cold ratios are constant for each of the individual vehicle classes, the cold start emission factors will decrease in the future. This is due to the gradually decrease in the emissions from the hot engines as stricter emission standards come into force. Additionally, the average length of each trip driven with a cold engine will gradually become shorter in the future due to stricter emission legislation for cold starts. The cold driven part of the trip length for trips starting with cold engines are expressed by the so-called beta-factors.

Table 3.1 *Vehicle Layers for Passenger Cars According to EU Emission Legislation*

Category	Engine size	Emission level	First registration year
Gasoline	All sizes	PRE ECE	- 1970
		ECE 15/00-01	1970-1978
		ECE 15/02	1979-1980
		ECE 15/03	1981-1985
		ECE 15/04	1986-1990
		91/441/EEC	1991-1996
		94/12/EEC	1997-2000
		EURO III	2001-2005
		EURO IV	2006-
Diesel	All sizes	Conventional	- 1990
		91/441/EEC	1991-1996
		94/12/EEC	1997-2000
		EURO III	2001-2005
		EURO IV	2006-
LPG		Conventional	- 1990
		91/441/EEC	1991-1996
		94/12/EEC	1997-2000
		EURO III	2001-2005
		EURO IV	2006-

***Table 3.2** Vehicle Layers for Vans, Lorries and Buses According to EU emission Legislation*

Category	Fuel type/size	Emission level	First registration year
Vans	Gasoline	Conventional	-1994
		93/59/EEC	1995-1998
		96/69/EEC	1999-2001
		EURO III	2002-2006
		EURO IV	2007-
	Diesel	Conventional	-1994
		93/59/EEC	1995-1998
		96/69/EEC	1999-2001
		EURO III	2002-2006
		EURO IV	2007-
Lorries	Gasoline > 3,5 t.	Conventional	
	Diesel 3,5-7,5 t.	Conventional	-1993
		EURO I	1994-1996
		EURO II	1997-2001
		EURO III	2002-2006
		EURO IV	2007-2009
		EURO V	2010
	Diesel 7,5-16 t.	Conventional	-1993
		EURO I	1994-1996
		EURO II	1997-2001
		EURO III	2002-2006
		EURO IV	2007-2009
		EURO V	2010
	Diesel 16-32 t.	Conventional	-1993
		EURO I	1994-1996
		EURO II	1997-2001
		EURO III	2002-2006
		EURO IV	2007-2009
		EURO V	2010
	Diesel > 32 t.	Conventional	-1993
		EURO I	1994-1996
		EURO II	1997-2001
		EURO III	2002-2006
		EURO IV	2007-2009
		EURO V	2010
Buses		Conventional	-1993
		EURO I	1994-1996
		EURO II	1997-2001
		EURO III	2002-2006
		EURO IV	2007-2009
		EURO V	2010

3.2 Calculated Emission Factors for the Scenario Years

The core in the simulation of emission factors for future years is the hot emission factors from COPERT III for the different vehicle types. The hot emission factors are further processed taking into account lower emissions for future new registered vehicles, and for each layer the number of vehicles and their corresponding annual mileage. Catalyst vehicle emissions are also simulated taking into account the decline in catalyst efficiency (deterioration factors). The lowering of emissions for vehicles in compliance with future EU emission legislation levels compared to EURO I levels are given in Table 3.3 and Table 3.4 for passenger cars and vans, and lorries and buses, respectively.

No forecast of the vehicle stock and annual mileage in layers for the future scenario years could be made available for the present study. The absence of fleet and mileage projections is partly compensated for by the use of the baseline year (1997) distributions of vehicle stock and annual mileage per first registration year (see Appendix 2). The use of 1997 distributions assume constant percentage shares for all future scenario years of the number of one-year old, two-years old etc. vehicles and correspondent mileage.

For all scenario years the emission factors for this study's vehicle categories are subsequently calculated taking into account the implementation dates for new vehicle technologies and the number of km's driven by vehicles of a certain age; this approach keeps track on the number of vehicles in each layer and the degree of catalyst wear, which in turn affects the aggregated results.

The calculated hot and cold emission factors for the present study's vehicle categories are listed in Appendix 3 together with the weighted beta-factors (which represent the cold driven part of the trip length for trips starting with cold engines). Table 3.5 and Table 3.6 shows the development in the hot and cold emission factor levels and the beta-factors for the future scenario years with 1995 as base.

***Table 3.3** Future Emissions of Passenger Cars and Vans Compared to EURO I*

	Year	ECE	EU		CO	NO_x	VOC	Particulates
Gasoline cars	1991	R83-01	91/441	EURO I	100	100	100	100
	1997	R83-03	94/12	EURO II	68	36	21	100
	2001	-	-	EURO III	56	24	15	100
	2006	-	-	EURO IV	34	13	3	100
Diesel cars	1991	R83-01	91/441	EURO I	100	100	100	100
	1997	R83-03	94/12	EURO II	100	100	100	100
	2001	-	-	EURO III	100	77	85	72
	2006	-	-	EURO IV	100	53	69	45
Gasoline vans	1995	R83-01	91/441	EURO I	100	100	100	100
	1999	R83-03	94/12	EURO II	61	34	24	100
	2002	-	-	EURO III	52	21	14	100
	2007	-	-	EURO IV	28	10	6	100
Diesel vans	1995	R83-01	91/441	EURO I	100	100	100	100
	1999	R83-03	94/12	EURO II	100	100	100	100
	2002	-	-	EURO III	82	84	62	67
	2007	-	-	EURO IV	65	68	23	35

***Table 3.4** Future Emissions of Lorries and Buses Compared to EURO I*

	Year	ECE	EU		Lorries				Buses
					3,5-7,5 t.	7,5-16 t.	16-32 t.	> 32 t.	
CO	1991	R49-01	88/77	EURO 0	100	100	100	100	100
	1994	R49-02	91/542	EURO I	50	50	55	55	50
	1997	R49-02	91/542	EURO II	40	40	45	45	40
	2002	-	-	EURO III	28	28	32	32	28
	2007	-	-	EURO IV	20	20	23	23	20
	2010			EURO V	20	20	23	23	20
NO_x	1991	R49-01	88/77	EURO 0	100	100	100	100	100
	1994	R49-02	91/542	EURO I	70	70	55	55	70
	1997	R49-02	91/542	EURO II	50	50	40	40	50
	2002	-	-	EURO III	35	35	28	28	35
	2007	-	-	EURO IV	25	25	20	20	25
	2010			EURO V	14	14	11	11	14
VOC	1991	R49-01	88/77	EURO 0	100	100	100	100	100
	1994	R49-02	91/542	EURO I	75	75	50	50	75
	1997	R49-02	91/542	EURO II	70	70	45	45	70
	2002	-	-	EURO III	49	49	32	32	49
	2007	-	-	EURO IV	34	34	22	22	34
	2010			EURO V	34	34	22	22	34
Particles	1991	R49-01	88/77	EURO 0	100	100	100	100	100
	1994	R49-02	91/542	EURO I	65	65	65	65	65
	1997	R49-02	91/542	EURO II	40	40	25	25	40
	2002	-	-	EURO III	28	28	18	18	28
	2007	-	-	EURO IV	5.3	5.3	3.3	3.3	3.5
	2010			EURO V	5.3	5.3	3.3	3.3	3.5

Table 3.5 *Levels of Hot and Cold Emission Factors and Beta-factors (Index) for Passenger Cars and Vans*

			Levels of hot and cold emission factors					Levels of beta factors		
Category	Type	Year	CO	NO_x	VOC*	NMVOC	Particles	CO	NO_x	VOC
Pass. cars	Conventional	1995	100	100	100	-	100	100	100	100
		2000	80	100	93	-	92	100	100	100
		2005	85	100	95	-	94	100	100	100
		2010	88	100	97	-	97	100	100	100
		2015	67	101	88	-	88	100	100	100
		2020	-	-	-	-	-	-	-	-
	Catalyst	1995	100	100	100	-	100	100	100	100
		2000	111	102	78	-	84	83	83	74
		2005	105	89	64	-	69	76	63	59
		2010	78	49	27	-	29	49	42	38
		2015	61	31	13	-	15	35	27	26
		2020	51	23	7	-	8	23	21	21
	Diesel	1995	100	100	100	100	100	100	100	100
		2000	81	105	81	69	80	88	88	82
		2005	66	98	61	39	60	78	65	62
		2010	63	81	52	27	50	50	43	39
		2015	62	69	46	21	45	35	28	27
		2020	61	61	43	17	42	23	21	21
Vans	Conventional	1995	100	100	100	-	100	100	100	100
		2000	91	100	98	-	98	100	100	100
		2005	81	101	94	-	94	100	100	100
		2010	78	101	93	-	93	100	100	100
		2015	78	101	93	-	93	100	100	100
		2020	-	-	-	-	-	-	-	-
	Catalyst	1995	100	100	100	-	100	100	100	100
		2000	112	170	120	-	133	90	90	84
		2005	95	113	75	-	84	76	62	58
		2010	83	68	48	-	54	53	43	40
		2015	66	37	27	-	30	36	29	28
		2020	54	19	15	-	16	24	21	21
	Diesel	1995	100	100	100	100	100	100	100	100
		2000	72	94	100	68	101	95	95	92
		2005	50	85	87	42	89	82	72	69
		2010	34	74	62	22	64	57	47	45
		2015	25	65	42	12	43	36	30	29
		2020	23	61	29	9	30	24	21	21

* Exhaust

Table 3.6 *Levels of Hot and Cold Emission Factors and Beta-factors (Index) for Lorries and Buses*

			Levels of hot and cold emission factors					Levels of beta factors		
Category	Type	Year	CO	NO_x	VOC*	NMVOC	Particles	CO	NO_x	VOC
Lorries	3,5-7,5 t.	1995	100	100	100	100	100	-	-	-
		2000	77	82	89	78	89	-	-	-
		2005	55	61	73	55	73	-	-	-
		2010	37	42	56	32	56	-	-	-
		2015	27	27	44	17	44	-	-	-
		2020	25	20	40	9	40	-	-	-
	7,5-16 t.	1995	100	100	100	100	100	-	-	-
		2000	77	82	89	78	89	-	-	-
		2005	55	61	73	55	73	-	-	-
		2010	37	42	56	32	56	-	-	-
		2015	27	27	44	17	44	-	-	-
		2020	25	20	40	9	40	-	-	-
	16-32 t.	1995	100	100	100	100	100	-	-	-
		2000	79	77	78	72	78	-	-	-
		2005	58	55	58	47	58	-	-	-
		2010	40	36	40	24	40	-	-	-
		2015	31	22	30	11	30	-	-	-
		2020	27	17	27	6	27	-	-	-
	> 32 t.	1995	100	100	100	100	100	-	-	-
		2000	79	77	78	72	78	-	-	-
		2005	58	55	58	47	58	-	-	-
		2010	40	36	40	24	40	-	-	-
		2015	31	22	30	11	30	-	-	-
		2020	27	17	27	6	27	-	-	-
Buses	Diesel	1995	100	100	100	100	100	-	-	-
		2000	77	82	89	78	89	-	-	-
		2005	55	61	73	55	73	-	-	-
		2010	32	38	54	37	54	-	-	-
		2015	25	24	41	35	41	-	-	-
		2020	22	18	36	38	36	-	-	-

* Exhaust

4 Regional Air Quality Levels

Introduction

This chapter describes the future regional background levels as predicted by the Danish Eulerian Model (DEM). For the present study, the model predicts hourly air quality levels of NO_x, NO_2, O_3 and CO on a 50 x 50 km^2 grid. The model is not able to predict benzene levels. The levels represent average levels in the grid due to long-range transport of air pollution and the influence of local emission sources are not taking into account. The development in European emissions is based on EMEP data and ECE proposed developments in future national emission ceilings. The output of the DEM model is applied as input to the Urban Background Model (UBM) for prediction of urban background levels.

4.1 Scenario Emission data

EMEP/IIASA

The development in European emissions is based on EMEP data for 1990 and proposed national reductions in 2010 for all European countries under ECE. The national reductions are taking from an analysis by the International Institute for Applied Systems Analysis (IIASA) in Austria that carries out the preparatory work that leads to ECE protocols (IIASA 1999). In Autumn 1999, the ECE has proposed national emission ceilings for 2010 in a new multi-effect, multi-pollutant protocol on nitrogen oxides and related substances addressing photochemical pollution, acidification and eutrophication. This protocol is also referred to as the draft Protocol to Abate Acidification, Eutrophication and Ground-level Ozone which was approved in Gothenburg (Sweden) on 29 November - 3 December 1999 (ECE 1999).

New ECE protocol

The difference between the emissions by EMEP and IIASA applied in the project and the emission ceilings in the new ECE protocol for the reference year 1990 and the scenario year 2010 is given in Table 4.1. NO_x and VOCs are the main substances that form ozone in the atmosphere. The difference in reference data for 1990 is due to slightly difference emission data for some countries but also due to inclusion of emission from sea areas (ships) in the EMEP/IIASA data. There are also minor differences in the pro cent reduction assumed for the different countries. It is seen that the difference in emissions between the two scenarios is less than about 10 per cent. Therefore, all scenario studies have been carried out with the EMEP/IIASA data that was available to the project at an earlier stage than the new draft ECE protocol.

The national emissions in 1990 and the proposed emission ceilings in 2010 are given in Appendix 1 for all countries for EMEP/IIASA and for the new ECE protocol including the percentage reduction for each country.

For the reference year 1995 and the scenario years 2000 and 2005 it is assumed that the known reductions between 1990 and 2010 can be transferred to scenario years by linear interpolation. For the scenario years 2015 and 2020 the emissions for 2010 have been assumed since no data is available for these scenario years.

Table 4.1 *The Difference Between the European Emissions (EMEP/IIASA) Applied in the Project and the New ECE Protocol Emissions (thousands of tonnes per year)*

	1990			2010			Difference in %		
EMEP/IIASA:	NO_x	VOC	NH_3	NO_x	VOC	NH_3	NO_x	VOC	NH_3
EU	13208	14162	3501	6879	7160	3074	-48	-49	-12
Non-EU	10024	7994	4221	8277	6636	3923	-17	-17	-7
Total	23232	22156	7722	15156	13796	6997	-36	-38	-11
ECE:									
EU	13080	15349	3681	6671	6600	3129	-49	-57	-15
Non-EU	10320	9320	3989	7327	6990	3151	-29	-25	-21
Total	23400	24669	7670	13998	13590	6280	-40	-45	-18
Difference in %									
EU	1	-8	-5	3	8	-2			
Non-EU	-3	-14	6	13	-5	24			
Total	-1	-10	1	8	2	11			

4.2 Validation of DEM-Predictions for 1995

The predictions by the DEM model in 1995 have been validated against measurements at two regional background stations in the rural areas of the Greater Copenhagen Area: Frederiksborg and Lille Valby. A regional remote background stations in Jutland is also shown (Ulborg). Comparisons between modelled and measured values have been carried out for annual means, and seasonal and diurnal variation.

Annual Means

Copenhagen Regional Background

The differences in observed ozone levels in Denmark are minor since ozone formation is a large-scale phenomenon. The levels are slightly higher in Ulborg compared to Lille Valby and Frederiksborg since Ulborg is not influenced by ozone depletion due to local NO_x emissions. Levels are slightly lower at the forest station of Frederiksborg compared to the rural Lille Valby station probably due to a higher dry deposition of ozone on forest compared to agricultural land at Lille Valby (Jensen 1998).

Table 4.2 *Comparisons Between Modelled and Measured Annual Means at Regional Stations in 1995 (ppb)*

	O_3			NO_2				NO_x
Stations:	1993	1994	1995	1990	1993	1994	1995	1995
Lille Valby	25.9	28.2	25.7	-	8.0	6.6	7.2	-
Frederiksborg	22.1	24.5	-	6.6	-	-	-	-
Ulborg	29.7	(33.3)*	-	-	2.3	2.0	-	-
DEM 1995			29.5				5.5	6.8

*Years with limited observations are given in brackets.

Ozone The DEM model overestimates O_3 levels in the regional background areas of Copenhagen compared to measurements. However, the model gives average predictions on a 50 x 50 km^2 grid and it is not able to reflect the influence of local NO_x emissions. The modelled levels are in better agreement with the remote station of Ulborg that is not influenced by local NO_x emissions.

NO_2 The DEM model underestimates NO_2 levels for the regional Copenhagen area.

CO Few measurements are available for CO on Danish rural areas. Data from the Dutch monitoring programme shows that rural CO levels are about half of urban levels. The same ratio between urban and rural levels have been applied for the Danish rural background corresponding to 0.17 ppm in 1995 (Jensen 1998). The DEM model predicts about 0.5 ppm which is greatly overestimated. However, the DEM model has a crude estimation of CO emissions based on a ratio of VOC emissions. It is possible to obtain CO emission from EMEP for improving predictions but it has not been possible within the time frame of the present project. Therefore, the regional background annual level has been assumed to be 0.17 ppm in 1995. Measurements of CO at Frederiksværk in the background ofSealand during 1995 showed 0.33 ppm for a limited record during the year. This level seems to be overestimated since 0.34 ppm is measured in the urban background of Copenhagen. The monitor station of Frederiksværkis operated by the Greater Copenhagen Air Monitoring Unit.

Benzene Since the DEM model does not predict benzene the annual level of benzene is assumed to be the same ratio between CO and benzene as measured in the urban background of Copenhagen. The method for prediction of regional benzene is depending on urban background benzene described in greater details in Chapter 5.

Seasonal Variation

Ozone The predicted seasonal variation of ozone is compared to measurements at Frederiksborg and Lille Valby in Figure 4.1 and 4.2. There is a good agreement between modelled and measured levels during spring and summer but the model overestimates levels in February and in autumn.

The overestimation in February reflects that there are predicted relatively few low values during this month. It does not reflect that the highest values are predicted during February, see Figure 4.3. Therefore, the monthly mean becomes relatively high. Within the time frame of the present project it was not possible to modify the DEM model to obtain better predictions for February. The average overestimation in February will have little impact on the estimation of the highest NO_2 concentrations at street level in Copenhagen since the highest ozone levels are not predicted in February.

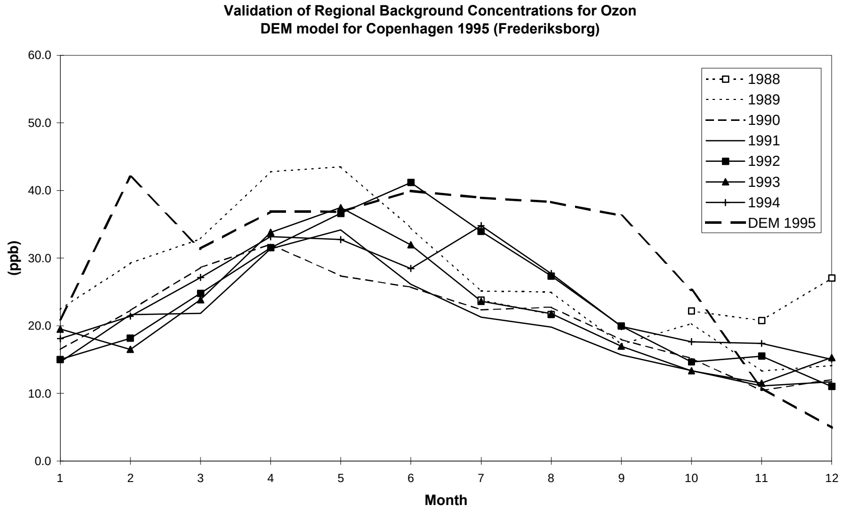


Figure 4.1 *Validation of seasonal variation of ozone at Frederiksborg*

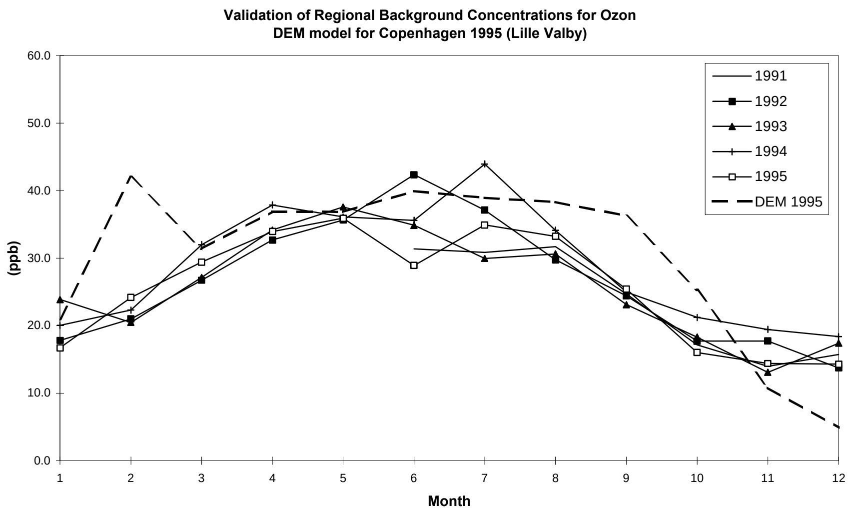


Figure 4.2 *Validation of seasonal variation of ozone at Lille Valby*

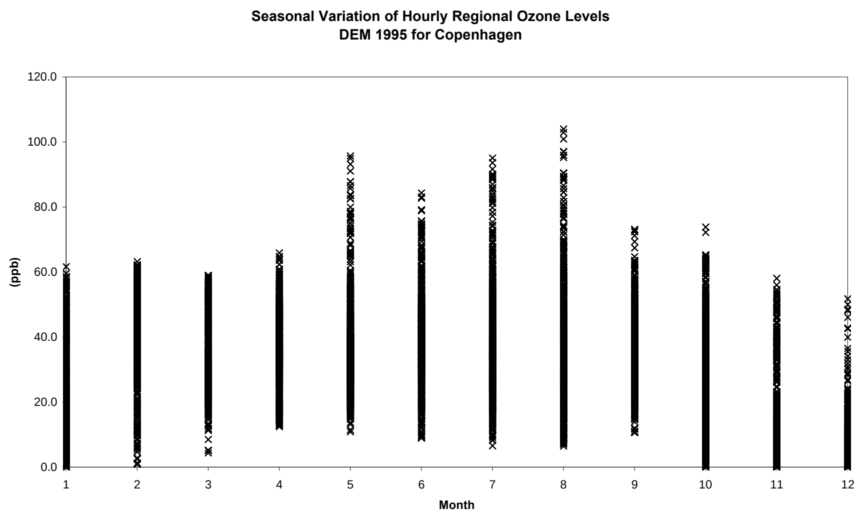


Figure 4.3 *DEM predicted seasonal variation of hourly regional ozone levels for the regional background of Copenhagen in 1995*

NO_2

The predicted seasonal variation of NO_2 is compared to measurements at Frederiksborg and Lille Valby in Figure 4.4 and 4.5. There is generally a fair agreement although predicted levels are underestimated during spring and summer months and overestimated during November and December. As expected, the seasonal variation of predicted NO_x shows similar results as NO_2 just with higher levels.

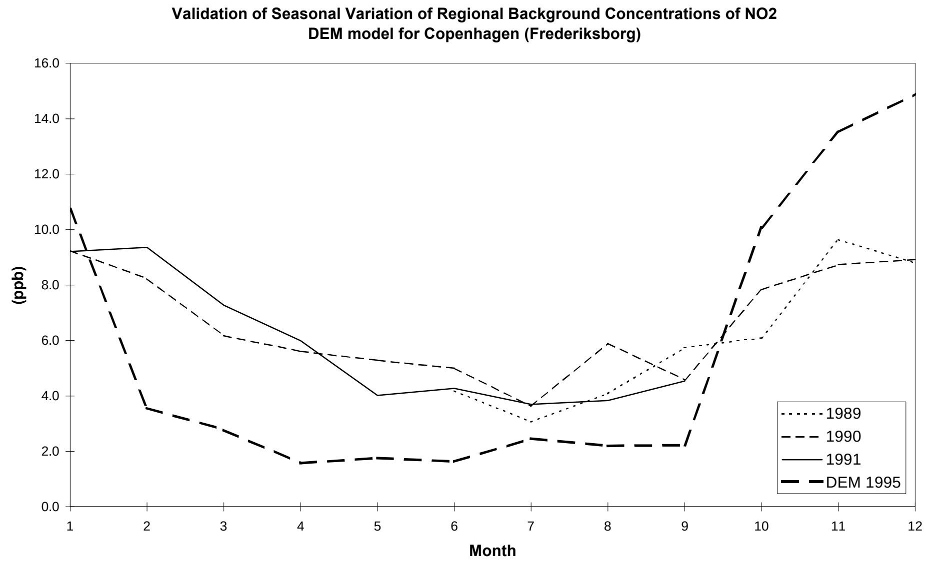


Figure 4.4 *Validation of seasonal variation of NO_2 at Frederiksborg.*

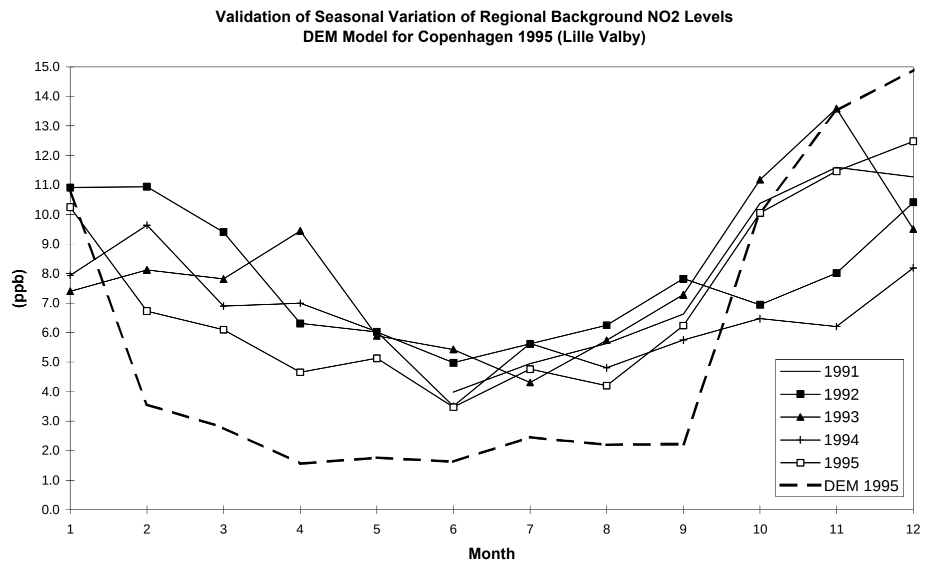


Figure 4.5 *Validation of seasonal variation of NO_2 regional background levels for Copenhagen at Lille Valby.*

CO The predicted seasonal variation of CO showed almost no variation which is unlikely. Therefore, it is assumed that the seasonal variation is similar to the seasonal variation in the urban background in Copenhagen where the only available measurements are carried out.

Benzene Since the DEM model does not predict benzene the seasonal variation of benzene is assumed to be similar to CO.

Diurnal Variation

Ozone The predicted diurnal variation of ozone is only compared to measurements at Frederiksborg in Figure 4.6 since the diurnal variation of ozone at Lille Valby is similar to Frederiksborg (Jensen 1998). There is generally a good agreement between modelled and measured levels although predicted levels show less relative difference between night and day time compared to measurements.

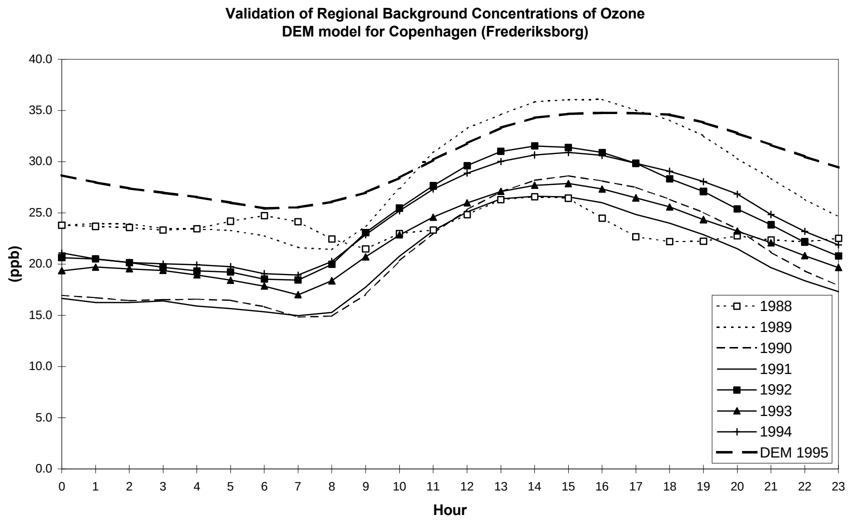


Figure 4.6 *Validation of diurnal variation of regional background concentrations of ozone for Copenhagen at Frederiksborg.*

NO_2 and NO_x The predicted diurnal variation of NO_2 is only compared to measurements at Lille Valby in Figure 4.7 since measurements are not available for Frederiksborg where only 24 hour samples are collected. NO_2 measurements at Lille Valby show a distinct diurnal variation with high levels in the morning and in the evening. The variation in measurements shows that Lille Valby is influenced by local traffic NO_x emissions from the nearby city of Roskilde and from the Copenhagen area. The predicted diurnal variation of NO_2 is smother since the DEM model is not able to take into account the influence of local emissions. As expected, the predicted diurnal variation of NO_x shows similar results although levels are slightly higher than NO_2.

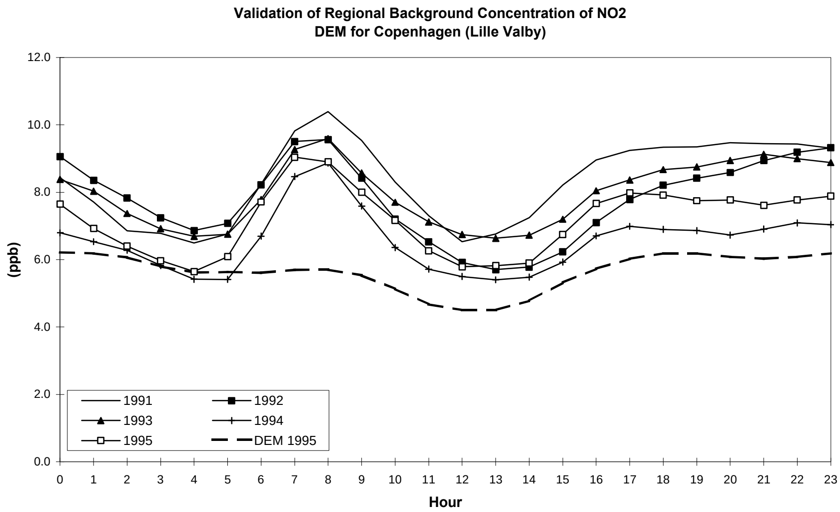


Figure 4.7 *Validation of diurnal variation of regional background concentrations of NO_2 for Copenhagen at Lille Valby.*

CO

The predicted diurnal variation of CO showed almost no variation which is unlikely. Therefore, it is assumed that the diurnal variation is similar to the diurnal variation in the urban background in Copenhagen where the only available measurements are carried out (Jensen 1999).

Benzene

Since the DEM model does not predict benzene the diurnal variation of benzene is assumed to be similar to CO.

4.3 Future Regional Air Quality

Copenhagen Regional Background

Table 4.3 sums up the DEM model runs for the different scenario years for the future regional background in the rural Copenhagen area.

The table gives the predicted development in annual levels in ppb/ppm, $\mu g/m^3/mg/m^3$ and as an index. The index is defined as the level in the scenario years divided by the level in 1995.

Future predicted levels are also given for the regional background station Ll. Valby about 40 km outside Copenhagen using observed levels from 1995 as a base.

Since the DEM model does not predict benzene levels, the development for benzene is assumed to be similar to CO. CO and benzene in 1995 are not DEM predictions but estimated based on measurement in the urban background of Copenhagen. Levels of CO and benzene in a scenario year are estimated based on the 1995 level and the index determined by DEM calculations.

Table 4.3 *DEM Predictions of Development in Future Regional Air Quality forthe Rural Copenhagen Area*

DEM Scenario	NO_x (ppb)	NO_2 (ppb)	Ozon (ppb)	CO (ppm)	BNZ (ppb)
1995	6.8	5.5	29.5	0.17	0.49
2000	5.8	4.8	29.4	0.15	0.17
2005	4.9	4.2	29.2	0.13	0.15
2010	4.0	3.5	29.0	0.12	0.14
2015	4.0	3.5	29.0	0.12	0.14
2020	4.0	3.5	29.0	0.12	0.14
DEM Scenario	NO_x (µg/m^3)	NO_2 (µg/m^3)	Ozon (µg/m^3)	CO (mg/m^3)	BNZ (µg/m^3)
1995	12.7	10.2	57.9	0.19	1.6
2000	10.9	9.0	57.6	0.17	0.57
2005	9.2	7.8	57.3	0.15	0.50
2010	7.5	6.6	56.9	0.13	0.44
2015	7.5	6.6	57.0	0.13	0.44
2020	7.5	6.6	56.9	0.13	0.44
DEM Scenario	NO_x (Index)	NO_2 (Index)	Ozon (Index)	CO (Index)	BNZ (Index)
1995	100	100	100	100	100
2000	86	88	99	89	36
2005	73	76	99	79	31
2010	59	64	98	69	28
2015	59	64	98	69	28
2020	59	64	98	69	28
Predicted for Ll.Valby	NO_x (µg/m^3)	NO_2 (µg/m^3)	Ozon (µg/m^3)	CO (mg/m^3)	BNZ (µg/m^3)
1995_obs	16.9	13.6	50.4	0.19	1.59
2000	14.6	11.9	50.2	0.17	0.57
2005	12.3	10.3	49.9	0.15	0.50
2010	10.0	8.7	49.6	0.13	0.44
2015	10.0	8.7	49.6	0.13	0.44
2020	10.0	8.7	49.6	0.13	0.44

From 1995 to 2010, NO_x and NO_2 levels are predicted to decrease about 40%. Ozone levels will only decrease by 2%, and CO and benzene by about 30% and 70%, respectively. Levels are the same from 2010-2020 since no information is available about future European emission ceilings beyond 2010.

5 Urban Background Levels

The Urban Background Model (UBM) is used to predict urban background air quality levels in Copenhagen. Apart from data about the regional background described in the previous chapter, the UBM model also requires inputs about urban emissions on a 2 x 2 km^2 grid. The Urban Emission Model (UBE) is used to estimate these emissions.

5.1 Urban Vehicle Emission Inventory

The urban emissions are depended on the development in traffic on the urban road network and in vehicle emission factors. The development in emission factors are described in chapter 3.

Development in Urban Traffic

For each grid cell, the Urban Emission Model requires traffic loads and vehicle composition on fire road types: local roads, traffic roads, arterial roads and motorways.

Traffic Loads

An analysis of the development in traffic loads in the city centre of Copenhagen shows that traffic loads have been constant during 1960-1994 with minor decreases and increases (Jensen 1997). The Municipality of Copenhagen has found similar results for 1970-1998 with a minor increasing trend since 1993 (Municipality of Copenhagen 1998). The geographic variation in traffic development has been uneven since traffic loads have increased by about 20% over the borders of the municipality and decreased 10% over the borders of the city centre. The regional roads within the municipality have had an increase of about 40% and other roads an decrease of about 15% (Municipality of Copenhagen 1997). The development in traffic loads has been characterised by stagnation in the city centre, increase on urban arterial roads and on the regional roads.

The Municipality of Copenhagen has carried out traffic forecast for 1992-2010 based on a traffic model for the Greater Copenhagen Area (HTM) and a traffic model (ØTM) developed for evaluating the impact of a new major development area in Copenhagen (Ørestad) (Municipality of Copenhagen 1997). Based on these traffic models the municipality assumes a 10 per cent traffic increase during 1992-2010 on the road network and the increase is expected to be on regional roads.

The regional roads have been identified (Municipality of Copenhagen 1999) and traffic increases on regional roads and other roads have been estimated based on the km travelled on these two road types assuming a traffic increase of 10 per cent on the entire road network during 1995-2010. Traffic increases for 2000 and 2005 have been estimated by interpolation, and traffic loads have been assumed to be constant after 2010. The increase on regional roads is 17 per cent from 1995-2010. The assumed development in traffic loads is given in Table 5.1.

Table 5.1 *Assumed Development in Traffic Loads on Different Road Types (Index)*

Scenario	Regional Roads	Other Roads
1995	100	100
2000	105	100
2005	112	100
2010, 2015, 2020	117	100

Traffic Composition

The Danish Road Directorate has carried out a forecast of the development in national km travelled broken down on different vehicle categories for 1997-2016 (Danish Road Directorate 1998). The analysis showed very small changes in traffic composition, therefore, the future vehicle composition on the urban road network is assumed to similar to 1995.

Penetration of Catalyst Vehicles

The number of catalyst vehicles has a major impact on emissions. The Danish Road Directorate was requested to supply data on the future penetration of catalyst vehicles based on km travelled which is given in Table 5.2

Table 5.2 *Development in Penetration of Catalyst Vehicles for Petrol-powered Passenger Cars and Vans in Per Cent*

Scenario	Without catalyst	With catalyst	Total
1995	56	44	100
2000	27	73	100
2005	9	91	100
2010	2	98	100
2015	1	99	100
2020	0	100	100

Cold Starts

The number of vehicles with cold engines has also a major impact on emissions. The assumed development in km travelled with cold engines based on data from COPERT III is given in Table 5.3

Table 5.3 *Development in Km Travelled with Cold Engines*

Scenario	Index	Percentage
1995	100	17
2000	83	14
2005	68	12
2010	44	8
2015	28	5
2020	22	4

Diurnal Traffic Variation

Diurnal traffic variations are assumed to be similar for all scenario years since no data is available to establish trends.

Development in Urban Emissions

The development in urban emissions is estimated using the Urban Emission Model based on the traffic input outlined above and emission factors given in chapter 3. In Table 5.4 the total emissions for all grids are given for the different scenario years. NO_x and CO emissions are estimated to decrease by a factor of 7 and benzene by a factor of 10 from 1995 to 2020. The sharp decrease in emissions is a result of stringent emission standards, decrease in cold starts times and penetration of catalyst vehicles which greatly counterbalance the assumed 10% increase in traffic.

Table 5.4 *Development in Urban Emissions Estimated by the UBE Model. Distribution on Working Days, Saturdays and Sundays, July and not July.*

	NO_x						CO						Benzene					
	Work. Non-July kg/24h	Sat. Non-July kg/24h	Sun. Non-July kg/24h	Work. July kg/24h	Sat. July kg/24h	Sun. July kg/24h	Work. Non-July kg/24h	Sat. Non-July kg/24h	Sun. Non-July kg/24h	Work. July kg/24h	Sat. July kg/24h	Sun. July kg/24h	Work. Non-July kg/24h	Sat. Non-July kg/24h	Sun. Non-July kg/24h	Work. July kg/24h	Sat. July kg/24h	Sun. July kg/24h
1995	11584	7482	6891	9480	5580	5266	41713	33402	31912	33576	24891	24384	1461	1181	1129	1175	880	863
2000	8467	5336	4888	6939	3980	3734	26272	20979	20033	21149	15634	15309	404	326	312	325	243	238
2005	5739	3548	3234	4706	2647	2469	19438	15533	14837	15643	11576	11339	260	209	200	209	156	152
2010	3209	1927	1740	2621	1438	1325	10982	8762	8365	8833	6529	6391	184	148	141	148	110	108
2015	2114	1287	1164	1728	961	885	7038	5599	5342	5662	4173	4082	157	126	120	127	94	92
2020	1669	1039	942	1359	755	716	5558	4409	4204	4472	3286	3212	151	121	116	122	90	88
	NO_x						CO						Benzene					
	Work. Non-July Index	Sat. Non-July Index	Sun. Non-July Index	Work. July Index	Sat. July Index	Sun. July Index	Work. Non-July Index	Sat. Non-July Index	Sun. Non-July Index	Work. July Index	Sat. July Index	Sun. July Index	Work. Non-July Index	Sat. Non-July Index	Sun. Non-July Index	Work. July Index	Sat. July Index	Sun. July Index
1995	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
2000	73	71	71	73	71	71	63	63	63	63	63	63	28	28	28	28	28	28
2005	50	47	47	50	47	47	47	47	46	47	47	47	18	18	18	18	18	18
2010	28	26	25	28	26	25	26	26	26	26	26	26	13	13	12	13	13	13
2015	18	17	17	18	17	17	17	17	17	17	17	17	11	11	11	11	11	11
2020	14	14	14	14	14	14	13	13	13	13	13	13	10	10	10	10	10	10

5.2 Validation of UBM Predictions for 1995

The Urban background Model (UBM) is used to predict urban background concentrations based on input from the regional background levels produced by the DEM model and urban emissions produced by the UBE model.

Benzene

A method has been set up to estimate benzene concentrations in the regional background as input for the UBM model since the DEM model does not predict benzene levels in the regional background. Benzene measurements have only been carried out at street level (Jagtvej in Copenhagen). An analysis of measurements shows that the ratio between benzene (ppb) and CO (ppm) was 4.0 before 1996 and 1.6 in 1999. Therefore, the benzene levels in the urban background are estimated based on the ratio of 4.0 for 1995 and 1.6 for scenario years 2000-2020 assuming that these ratios also are valid for the urban background. The ratio decreases due to a shift from 3 to 1 per cent of benzene in gasoline. To estimate the regional background levels of benzene the UBM model was run with the assumption that the UBM model gives a perfect prediction of measurements, whereby, the regional levels are measured urban background levels minus modelled urban background concentrations. In this way, the average ratio between the regional and urban background was established as Bnz_reg = Bnz_urban*0.36. That is, on average the regional background levels of benzene are 64% less that urban background levels of benzene. All in all, regional and urban background levels of benzene are ratios of urban background levels of CO.

Annual Means

In Table 5.5 the annual means predicted by the UBM model is compared with measurements at the Copenhagen urban background station.

Table 5.5 *Comparison Between Modelled and Measured Annual Means for the Urban Background in Copenhagen in 1995 (ppb)*

	NO_X obs	NO_X mod	NO_2 obs	NO_2 mod	O_3 obs	O_3 mod	CO obs	CO mod	"BNZ obs"	BNZ mod
1995	20.5	16.9	15.0	12.1	22.7	24.6	0.34	0.24	1.36	1.36

The UBM model underestimates NO_x, NO_2 and CO air quality levels, and overestimates ozone levels. Observed benzene levels are actually modelled and therefore equivalent to modelled benzene levels.

Seasonal Variation

Ozone

The predicted seasonal variation of ozone is compared to measurements in Figure 5.2. There is generally a good agreement between modelled and observed levels although levels are overestimated in February due to too high predictions by the DEM model. It is also seen that urban background levels of ozone are highly dependent on the regional levels. Urban background levels are slightly lower than regional levels because urban NO_x emission deplete urban ozone levels.

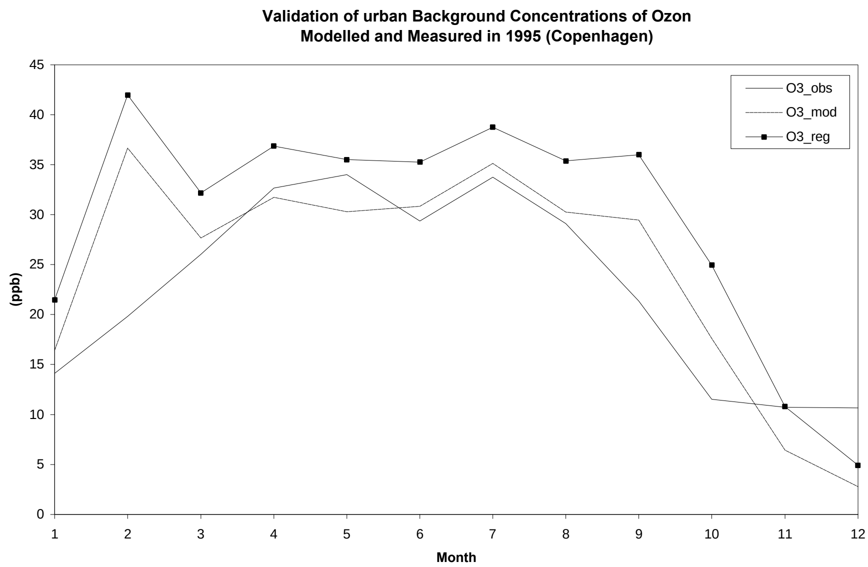


Figure 5.1 *Modelled and measured urban background levels of ozone in Copenhagen. Regional background levels are also shown.*

NO_x and NO_2

The predicted seasonal variation of NO_x and NO_2 is compared to measurements in Figure 5.2. There is generally a good agreement between modelled and observed levels although levels are generally underestimated.

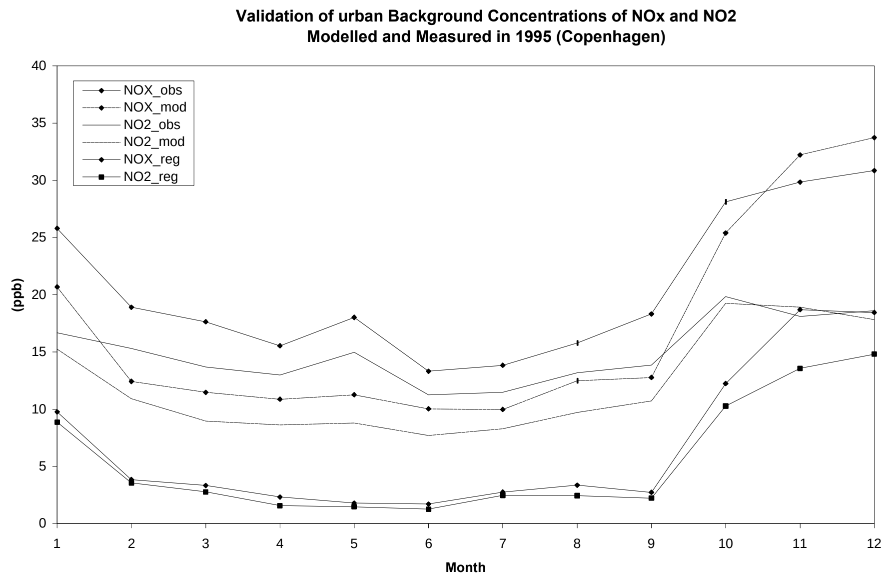


Figure 5.2 *Modelled and measured urban background levels of NO_x and NO_2 in Copenhagen. Regional background levels are also shown.*

CO and Benzene

The predicted seasonal variation of CO and benzene is compared to measurements in Figure 5.3. There is generally a good agreement between modelled and observed levels although CO levels are underestimated.

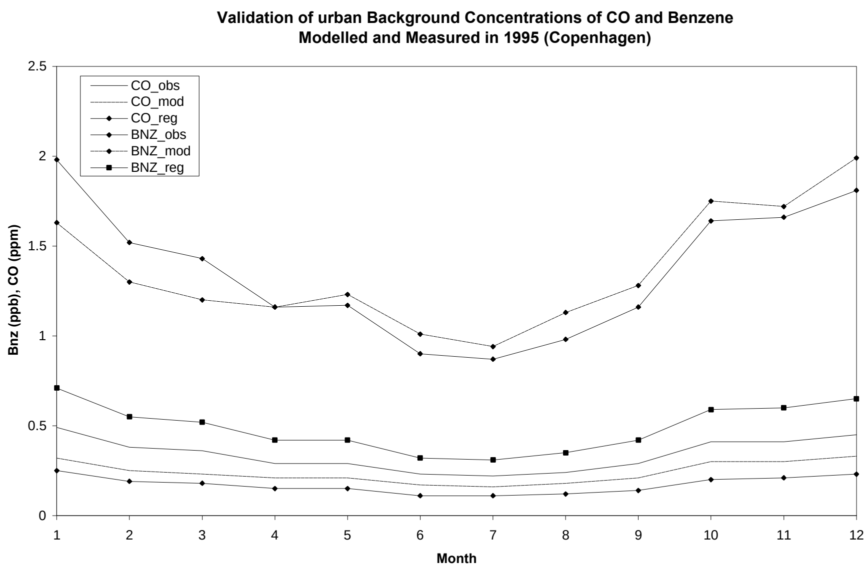


Figure 5.3 *Modelled and measured urban background levels of CO and benzene. Regional background levels are also shown.*

Diurnal Variation

Ozone

The predicted diurnal variation of ozone is compared to measurements at the Copenhagen urban background station in Figure 5.4. There is generally a good agreement between modelled and measured levels although predicted levels are overestimated during the evening and night.

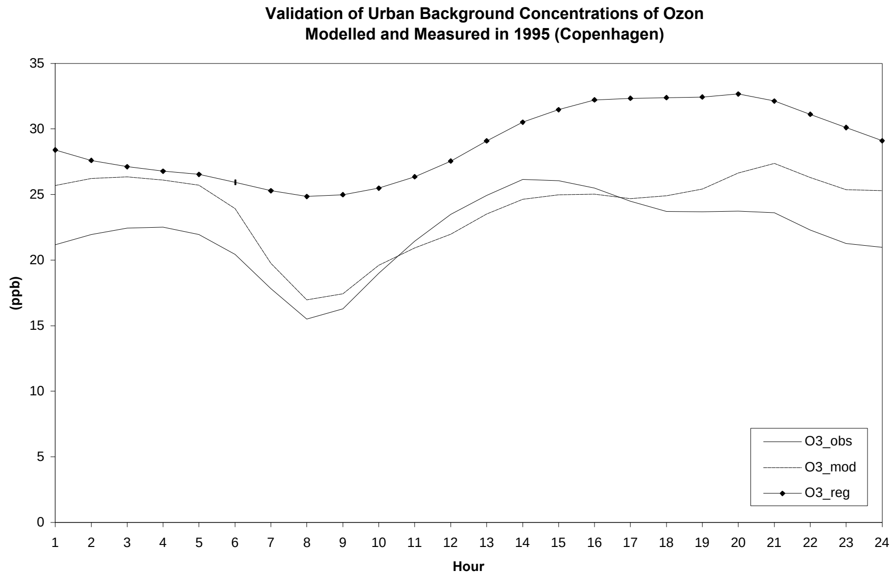


Figure 5.4 *Modelled and measured urban background levels of O_3. Regional background levels are also shown.*

NO_x and NO_2

The predicted diurnal variation of NO_x and NO_2 is compared to measurements at the Copenhagen urban background station in Figure 5.5. There is generally a good agreement between modelled and measured levels although predicted levels are generally underestimated.

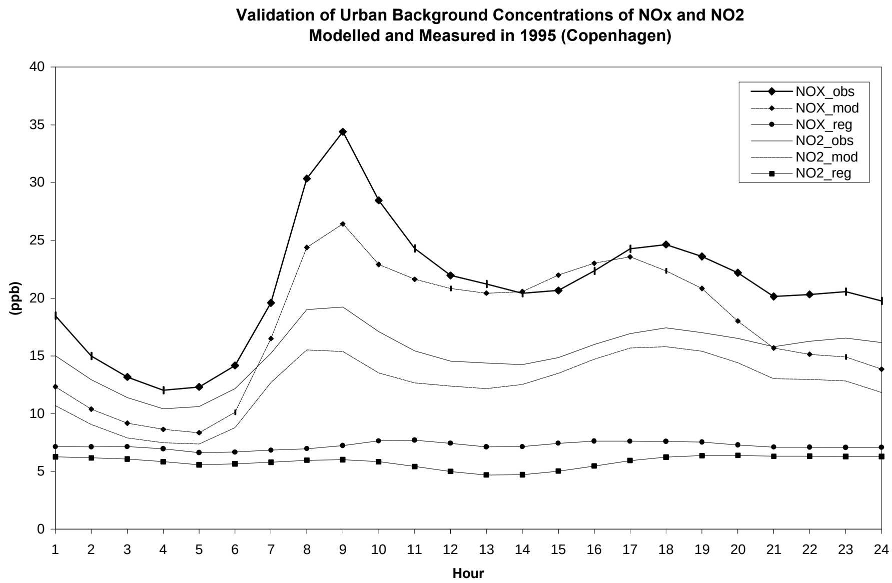


Figure 5.5 *Modelled and measured urban background levels of NO_x and NO_2. Regional background levels are also shown.*

CO and Benzene

The predicted diurnal variation of CO and benzene is compared to measurements at the Copenhagen urban background station in Figure 5.6. There is generally a good agreement between modelled and measured CO levels although predicted levels are generally underestimated. There is also a general good agreement between modelled and measured benzene levels although benzene levels are underestimated during night and overestimated during afternoon rush hours.

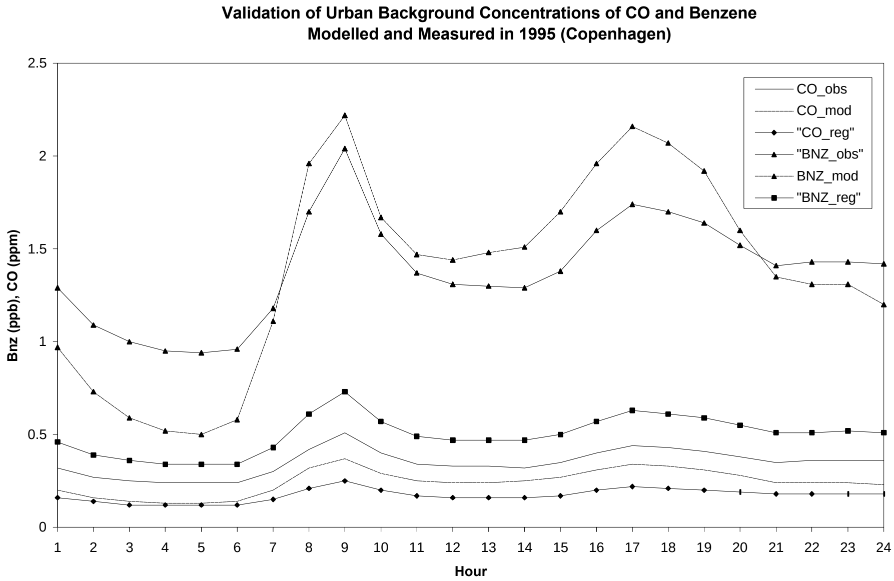


Figure 5.6 *Modelled and measured urban background levels of CO and benzene. Regional background levels are also shown.*

Underestimation by COPERT III

The general underestimation of NO_x and NO_2 (and therefore overestimation of ozone) may be due to too low vehicle emission factors for NO_x. The general underestimation of CO may also be due to underestimation of vehicle emissions for CO. Emission factors were based on COPERT III that may be too low for Danish conditions because a validation of the Urban Background Model was carried out with much better agreement between modelled and observed levels using emission factors based on Danish studies (Jensen 1992, 1995; Krawack 1991) and fitting of emission factors to obtain better agreement with measurements. The validation study is published in *Berkowicz* (1999). The main difference is the these emission factors have about a factor 2 higher CO values for passenger cars without catalysts and also about at factor 2 higher NO_x values for lorries. A possible underestimation of emission factors by COPERT III is further investigated in the next chapter.

5.3 Future Urban Background Air Quality

Copenhagen Urban Background

Table 5.1 sums up the UBM model runs for the difference scenario years for the future urban background air quality in Copenhagen. The table gives the predicted development in annual levels in ppb/ppm, µg/m^3/mg/m^3 and as an index. The index is defined as the levels in scenario years divided by the levels in 1995. Future predicted levels are also given for the urban background station in Copenhagen using observed levels from 1995 as a base and the index for the development.

Table 5.6 *UBM Predictions for Annual Levels of Future Urban Background Air Quality in Copenhagen*

UBM Scenario	NO_x-mod (ppb)	NO_2_mod (ppb)	O_3_mod (ppb)	CO_mod (ppm)	BNZ_mod (ppb)
1995	16.9	12.1	24.6	0.24	1.4
2000	13.1	9.8	25.9	0.20	0.41
2005	9.8	7.7	27.0	0.17	0.31
2010	6.7	5.5	28.1	0.14	0.24
2015	5.8	4.8	28.5	0.13	0.23
2020	5.4	4.6	28.6	0.13	0.22
UBM Scenario	**NO_x-mod ($\mu g/m^3$)**	**NO_2_mod ($\mu g/m^3$)**	**O_3_mod ($\mu g/m^3$)**	**CO_mod (mg/m^3)**	**BNZ_mod ($\mu g/m^3$)**
1995	31.9	22.7	48.3	0.27	4.4
2000	24.7	18.5	50.8	0.22	1.4
2005	18.4	14.5	53.1	0.19	1.0
2010	12.5	10.4	55.1	0.16	0.79
2015	10.8	9.2	55.9	0.15	0.74
2020	10.2	8.7	56.2	0.14	0.73
UBM Scenario	**NO_x-mod (Index)**	**NO_2_mod (Index)**	**O_3_mod (Index)**	**CO_mod (Index)**	**BNZ_mod (Index)**
1995	100	100	100	100	100
2000	77	81	105	82	30
2005	58	64	110	70	23
2010	39	46	114	57	18
2015	34	40	116	53	17
2020	32	38	116	53	16
Predicted for Copenhagen	**NO_x-mod ($\mu g/m^3$)**	**NO_2_mod ($\mu g/m^3$)**	**O_3_mod ($\mu g/m^3$)**	**CO_mod (mg/m^3)**	**BNZ_mod ($\mu g/m^3$)**
1995_obs	38.6	28.2	44.7	0.39	4.4
2000	29.9	23.0	47.0	0.32	1.4
2005	22.3	17.9	49.1	0.27	1.0
2010	15.2	12.9	50.9	0.22	0.79
2015	13.1	11.4	51.7	0.21	0.74
2020	12.3	10.8	52.0	0.20	0.73

6 Air Quality at Street Level

The OSPM model is used to predict air pollution levels in the street of Jagtvej in Copenhagen. The hourly time-series produced by the Urban Background Model is used as input to the OSPM model together with COPERT III based emission factors, and parameters on traffic in the street, street configuration and meteorology.

6.1 Validation of OSPM Predictions

Table 6.1 shows that the OSPM model underestimates the observed levels for NO_x, NO_2 and CO, especially for CO. Ozone levels are overestimated as a consequence of the underestimation of NO_x. Benzene levels are well predicted since benzene emission factors are determined by invert calculations with the OSPM.

Table 6.1 *Modelled and Measured Annual Means at Street Level in 1995 (ppb) (Jagtvej, Copenhagen)*

	Average					98-percentile				99.8-percentile			
	NO_x	NO_2	CO	Ozone	Benzene	NO_x	NO_2	CO	Benzene	NO_x	NO_2	CO	Benzene
1995_obs	87.0	27.8	1.4	29.8	5.4	281	55.0	4.0	14.1	465	96.8	6.5	23.8
1995_mod	64.1	20.4	0.6	37.9	5.3	197	49.1	1.8	14.0	299	74.9	2.6	24.0

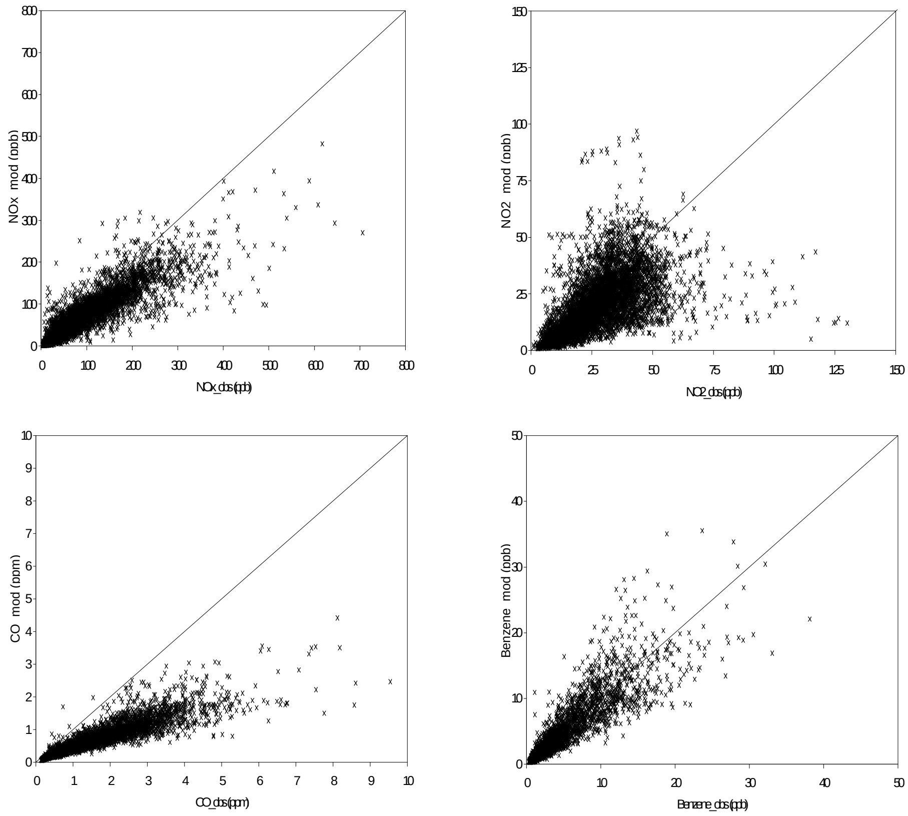


Figure 6.1 *Scatter plots of modelled and observed NO_x, NO_2, CO and benzene hourly concentrations in Jagtvej, Copenhagen. One to one lines are also drawn.*

Figure 6.1 shows a general good agreement between modelled and observed concentrations although predicted levels are systematically underestimated for NO_x, NO_2 and CO possible due to underestimation of emission factors.

6.2 Possible Underestimation of COPERT III emissions

Underestimation by COPERT III

As discussed in the previous chapter, COPERT III emission factors may underestimate real world emissions on the road since better results were obtained with the Urban Background Model using emission factors that were about a factor 2 higher for CO for passenger cars without catalysts and about at factor 2 higher for NO_x for lorries.

In Figure 6.2, the possibility of underestimation is further investigated by comparison of COPERT III emission factors (new emissions) and the formerly used emission factors (old emissions) as input for OSPM calculations.

The figure shows the ratio between CO and NO_x for modelled and measured values in Jagtvej, Copenhagen for working days, Saturdays and Sundays. If the ratio between vehicle emissions of CO and NO_x is correct then the slope of the regression lines of modelled air quality levels will be identically to the measured concentrations in the street air.

It is seen that the slope of modelled air quality levels using COPERT III emission factors is very different from the measured ratio between CO and NO_x in the street air. Much better results are obtained with the old emission factors.

This indicates that the ratio between COPERT III emission factors for CO and NO_x is incorrect since it does not comply with the ratio found in the measured street air.

The emission factors in the OSPM model are adjusted according to travel speed during working days based on emission factors at 50 km/h. The same method has been applied for both new and old emission factors. For Saturdays, the travel speed is assumed to be 50 km/h, and the old emissions give almost a perfect fit in this situation between modelled and measured ratios of CO and NO_x indicating that the ratio between CO and NO_x is correct for the old emission factors and questionable for COPERT III, see Figure 6.2.

Nevertheless, COPERT III emission factors have been applied throughout the study although predicted air quality levels become underestimated. For prediction of future concentrations in the urban background or in the street, observed levels have been applied from 1995 as a baseline for calibration, and the modelled trend as an index has been used to estimate future levels to give realistic predicted air quality levels that can be compared to air quality limit values.

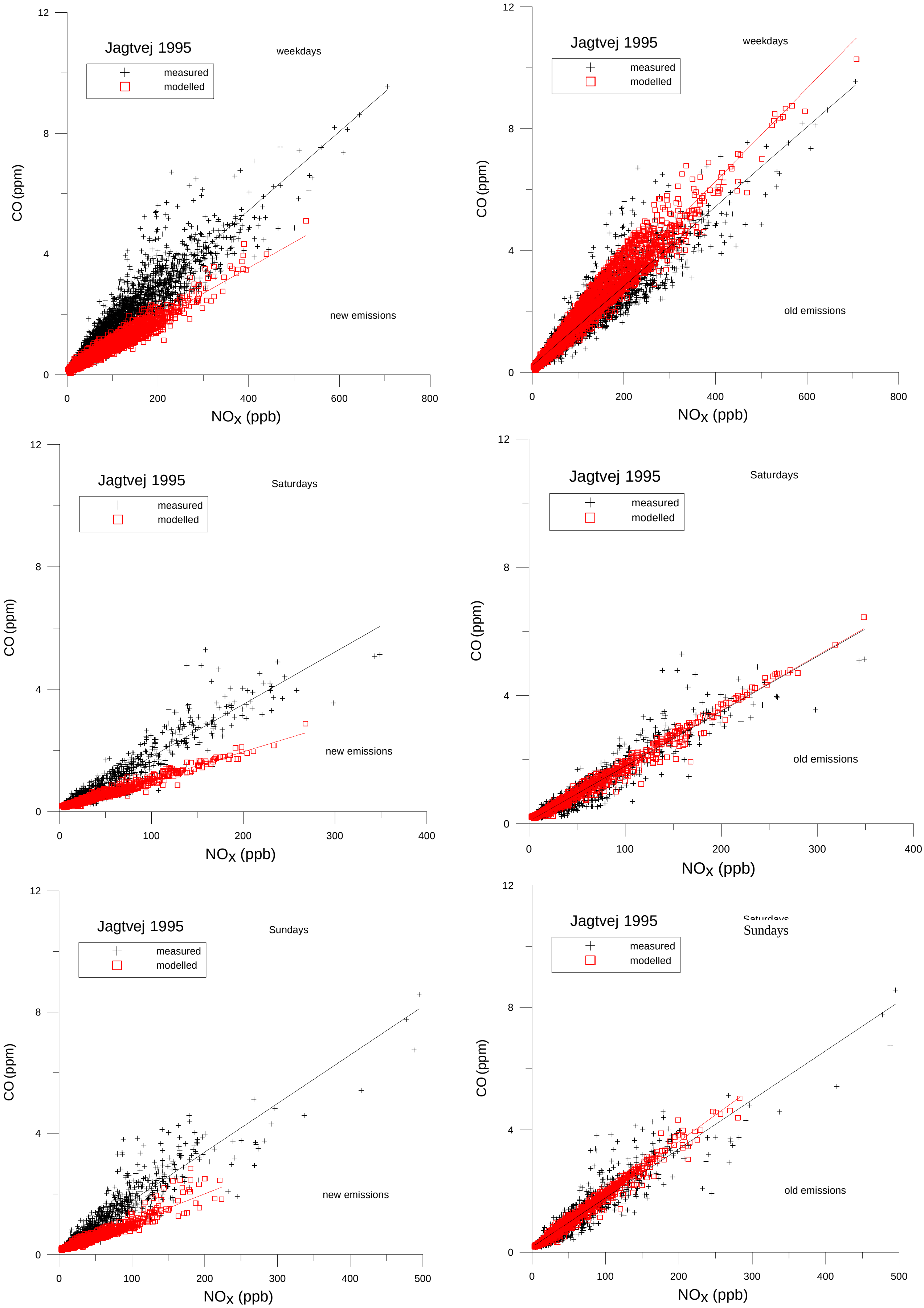


***Figure 6.2** Comparison of the ratio between modelled CO and NO_x levels in the street with COPERT III emission factors (new emissions) and formerly applied emission factors (old emissions).*

6.3 Future Air Quality at Street Level

Table 6.2 sums up the OSPM model runs for the difference scenario years for the future air quality at street level in Copenhagen.

***Table 6.2** OSPM Predictions for Future Air Quality at Street Level in Copenhagen (Jagtvej)*

	Average					98-percentile				99.8-percentile			
OSPM	NO_x (ppb)	NO_2 (ppb)	CO (ppm)	Bnz (ppb)	O_3 (ppb)	NO_x (ppb)	NO_2 (ppb)	CO (ppm)	Bnz (ppb)	NO_x (ppb)	NO_2 (ppb)	CO (ppm)	Bnz (ppb)
1995_obs	87.0	27.8	1.4	5.4	15.2	281	55.0	4.0	14.1	465	96.8	6.5	23.8
1995	64.1	20.4	0.6	5.3	19.3	197	49.1	1.8	14.0	299	74.9	2.6	24.0
2000	47.6	17.0	0.4	1.6	21.2	147	42.3	1.2	4.2	221	66.4	1.9	7.2
2005	29.4	12.8	0.3	0.9	23.8	92	34.2	0.8	2.2	137	64.0	1.4	3.9
2010	17.9	9.1	0.2	0.6	25.9	58	26.4	0.6	1.6	85	48.9	1.0	2.8
2015	13.4	7.6	0.2	0.6	26.9	44	23.7	0.5	1.5	64	48.7	0.9	2.5
2020	11.2	6.9	0.2	0.6	27.4	38	22.9	0.4	1.3	59	48.7	0.8	2.3
OSPM	NO_x (µg/m^3)	NO_2 (µg/m^3)	CO (mg/m^3)	Bnz (µg/m^3)	O_3 (µg/m^3)	NO_x (µg/m^3)	NO_2 (µg/m^3)	CO (mg/m^3)	Bnz (µg/m^3)	NO_x (µg/m^3)	NO_2 (µg/m^3)	CO (mg/m^3)	Bnz (µg/m^3)
1995_obs	164	52	1.6	17.5	29.8	529	104	4.6	45.9	875	182	7.4	78
1995	121	38	0.7	17.1	37.9	370	92	2.0	45.7	562	141	3.0	78
2000	90	32	0.5	5.1	41.6	277	80	1.4	13.6	416	125	2.2	23
2005	55	24	0.4	2.8	46.6	174	64	0.9	7.1	259	120	1.6	13
2010	34	17	0.3	2.1	50.8	109	50	0.7	5.2	159	92	1.2	9
2015	25	14	0.2	1.9	52.8	83	45	0.6	4.7	120	92	1.0	8
2020	21	13	0.2	1.8	53.8	72	43	0.5	4.4	111	92	0.9	7
OSPM	NO_x (Index)	NO_2 (Index)	CO (Index)	Bnz (Index)	O_3 (Index)	NO_x (Index)	NO_2 (Index)	CO (Index)	Bnz (Index)	NO_x (Index)	NO_2 (Index)	CO (Index)	Bnz (Index)
1995	100	100	100	100	100	100	100	100	100	100	100	100	100
2000	74	83	69	30	110	75	86	67	30	74	89	71	30
2005	46	63	50	16	123	47	70	47	16	46	85	52	16
2010	28	44	35	12	134	29	54	33	11	28	65	38	12
2015	21	37	31	11	139	22	48	27	10	21	65	33	10
2020	18	34	29	10	142	20	47	25	10	20	65	30	10
Predicted for Jagtvej	NO_x (µg/m^3)	NO_2 (µg/m^3)	CO (mg/m^3)	Bnz (µg/m^3)	O_3 (µg/m^3)	NO_x (µg/m^3)	NO_2 (µg/m^3)	CO (mg/m^3)	Bnz (µg/m^3)	NO_x (µg/m^3)	NO_2 (µg/m^3)	CO (mg/m^3)	Bnz (µg/m^3)
1995_obs	164	52	2	17	30	529	104	5	46	875	182	7	78
2000	122	44	1.1	5.2	33	397	89	3	14	648	161	5	23
2005	75	33	0.8	2.9	37	248	72	2	7	403	156	4	13
2010	46	23	0.6	2.1	40	156	56	2	5	248	119	3	9
2015	34	20	0.5	1.9	41	118	50	1	5	187	118	2	8
2020	29	18	0.5	1.8	42	103	48	1	4	172	118	2	7

The table gives the predicted development in annual levels, and 98- and 99.8-percentiles in ppb/ppm, µg/m^3/mg/m^3 and as an index with the reference year equals 100. Future predicted levels are also given for Jagtvej in Copenhagen using observed levels from 1995 as a base and the development represented by the index. The calibration is required to give realistic future air quality predictions that can be compared to limit values because too low air quality levels are predicted using COPERT III emission factors without calibration.

NO Becomes Limiting Factor in Forming NO_2

Catalyst cars were introduced in Denmark in 1990/91 and reduce NO_x emissions (NO and NO_2).

NO_2 observed levels in Jagtvej were more or less constant during 1990-95 indicating that ozone was the limiting factor in forming NO_2 in reactions between NO and ozone.

From 1995 to 1998, measurements show a downward trend in NO_2 levels, and this trend is also reproduced by the OSPM model.

During 1995-2010/2020, 98- and 99.8-percentiles of NO_2 are predicted to decrease about 50% and 35%, respectively.

The predictions show that NO becomes the limiting factor in forming NO_2 in reactions with ozone in the future due to the steadily decreasing NO_x emissions (NO and NO_2, NO constitutes about 95% of NO_x vehicle emissions).

Ozone

Ozone levels increase because less NO emitted from vehicles in the street is available for ozone depletion.

CO and Benzene

CO levels are predicted to decrease by a factor of 4 and benzene levels by a factor of 10 from 1995 to 2010. The predicted downward trends of CO and benzene are also support by observed levels during 1995-1998.

6.4 Comparison With Air Quality Guidelines

Air Quality Guidelines

A summary of present EU air quality limit values, WHO guidelines and Danish EPA criteria for the modelled pollutants is presented in Table 6.3.

The Danish EPA air quality criteria were set up to minimize of adverse health effects. The air quality criteria are not administrative limit values but should be regarded as desired long-term objectives (Larsen et al. 1997).

New EU limit values have to be met in 2010. A margin of tolerance has been defined to secure that limit values will be met in 2010. The margin of tolerance given as a percentage in the table refers to the year the directive entries into force. The margin of tolerance is equally stepped down each year to reach 0% in 2010. Member states have to take local action if the margin of tolerance is exceeded.

Table 6.3 *EU Air Quality Limit Values, WHO Guidelines and Danish EPA Criteria for Protection of Human Health*

	Party	Short term exposure	Long term exposure	Date of compliance	Margin of tolerance	Status
NO_2	EU limit values	200 µg/m^3 (99.8-p)	40 µg/m^3 (annual)	1.1.2010	50%	Approved
	WHO guidelines	200 µg/m^3 (1 hour)	40 µg/m^3 (annual)	-	-	Guidelines
	Danish EPA criteria	50 µg/m^3 (98-p)	15-20 µg/m^3 (annual)	-	-	Suggested criteria
Ozone	EU limit values	120 µg/m^3 (8 hours)[1]	-	1.1.2010	-	Proposal
	EU information threshold value	180 µg/m^3 (1 hour)	-	-	-	Proposal
	EU alert threshold value	240 µg/m^3 (1 hours)	-	-	-	Proposal
	WHO guidelines	120 µg/m^3 (8 hours)	-	-	-	Guidelines
	Danish EPA criteria	10 µg/m^3 (8 hours)	-	-	-	Suggested criteria
CO	EU limit values	10 mg/m^3 (8 hours)	-	1.1.2010	50%	Proposal
	WHO guidelines	10 mg/m^3 (8 hours)	-	-	-	Guidelines
	Danish EPA criteria	-	-	-	-	Suggested criteria
Benzene	EU limit values	-	5 µg/m^3 (annual)	1.1.2010	100%	Proposal
	WHO guidelines	-	0.17 µg/m^3 (annual)	-	-	Guidelines
	Danish EPA criteria	-	0.13-0.25 µg/m^3 (annual)	-	-	Suggested criteria

[1] Not to be exceeded on more than 20 days per calendar year averaged over three years

NO_2

The EU limit value for NO_2 for long-term exposure was exceeded in 1995 and the limit value for short-term exposure is tangent. However, the margin of tolerance of 50% in 1999 is not exceeded.

The predicted NO_2 levels in 2010 at Jagtvej are about half of the EU limit value in 2010. The Danish EPA criteria for short-term and long-term exposure is exceeded for all scenario years until 2015-2020.

CO

The EU limit value for CO will be between the 98- and 99.8-percentile. The EU limit value for CO was not exceeded in 1995, and the margin of tolerance of 50% will not be exceeded in the expected year of entry into force of the directive (2000). In 2010 the predicted CO levels will be 10-20% of the EU limit value in 2010. The EU limit value and WHO guidelines are identically for CO. The Danish EPA has not suggested criteria for CO.

Benzene

The EU limit value for benzene was exceeded in 1995. The margin of tolerance of 100% will not be exceeded based on modelled levels in 2000, the expected year of entry into force of the proposed directive. The predicted levels in 2010 will be about half of the EU limit value. WHO guidelines and Danish EPA criteria are exceeded for all scenario years.

Ozone at Street Level

The average ozone levels in the street will increase due to a decrease in NO vehicle emissions in the street leaving less NO for depletion of ozone in forming NO_2, see Table 6.2. However, the sum of NO_2 and O_3 will decrease.

The highest levels calculated as a 8 hour running maximum will slightly decrease over the years because the highest ozone levels in the regional background are predicted to decrease. The proposed EU limit value for ozone is 120 $\mu g/m^3$ as a 8 hour running maximum not to be exceeded on more than 20 days per calendar year averaged over three years. This short-term limit value was not exceeded in 1995 nor is it predicted to be exceeded in 2010 and the following years despite an increase in average ozone levels in the street.

Ozone in Urban Background

In Table 6.4 exceedances of the ozone threshold of 120 $\mu g/m^3$ are given for the urban background. The urban background is a better indicator for ozone exposure of the population than levels in the streets since ozone levels are influenced by NO emissions.

Since the number of exceedances are less than 20, the EU limit value is not violated in the urban background. The number of exceedances of the threshold value of 120 $\mu g/m^3$ increases over the years. This is due to the general increase in ozone levels in the urban background that will cause more peak values to exceed the 120 $\mu g/m^3$ threshold. However, the model overestimates ozone levels as was seen in the previous Chapter 5, Table 5.5, and the presented exceedances in Table 6.4 are based on modelled ozone data that have not been adjusted to the observed level in 1995. Furthermore, since several modelled values are close to the threshold value 120 $\mu g/m^3$ and the model overestimates ozone levels, it is likely that there will be few exceedances of this threshold in future observed ozone levels in the urban background.

Table 6.4 *Exceedances of Proposed Threshold for EU Limit Value for Ozone Based on Modelled Ozone Data*

Year	Exceedances No.	Range of Values ug/m3
1995	15	120-171
2000	14	120-164
2005	13	120-155
2010	14	120-148
2015	14	120-149
2020	14	120-149

6.5 Future Air Quality in 103 Copenhagen Streets

OSPM Calculation for 103 Copenhagen Streets

Based on OSPM calculations for 103 different streets in the Copenhagen Area, an empirical relation between traffic density and street air quality for NO_2 and benzene was established in 2000 and 2010, see figure 6.3-5. The streets represent a wide range of traffic loads and street configurations however with a little less detailed information about traffic and street configuration data compared to data available for Jagtvej. Traffic density is here defined as average daily traffic divided by the width of the street. The modelled emission reductions and predicted urban background levels in 2000 and 2010 by the present study has been applied.

This relation can be applied for crude assessment of the air quality in a street just knowing the traffic density as defined. Since urban background data for Copenhagen was used, the street levels will be overestimated in other Danish cities where the urban background concentrations are lower. Since the relation was established for urban streets in built-up areas, air quality levels will be overestimated if applied for rural roads where dispersion characteristics are different.

It is seen that annual levels of NO_2 and benzene in 2000 are exceeding the limit value for 2010.

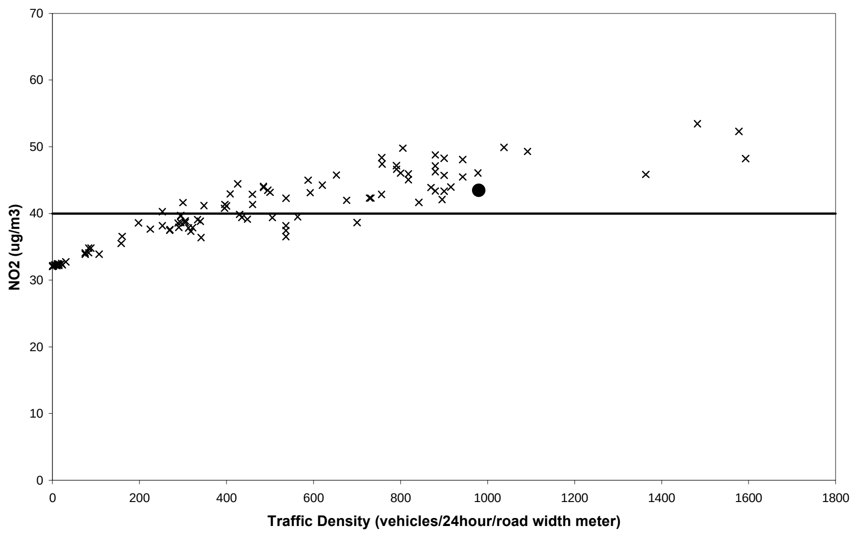


Figure 6.3 *Model calculations for annual mean of NO_2 in 2000 for 103 Copenhagen streets with the OSPM model. Jagtvej is marked with a bold dot. The new EU limit value for 2010 is also shown.*

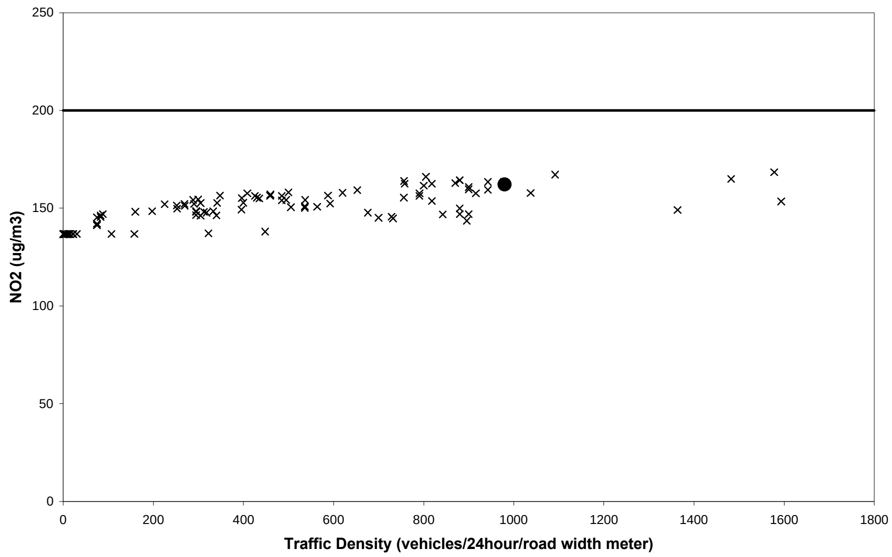
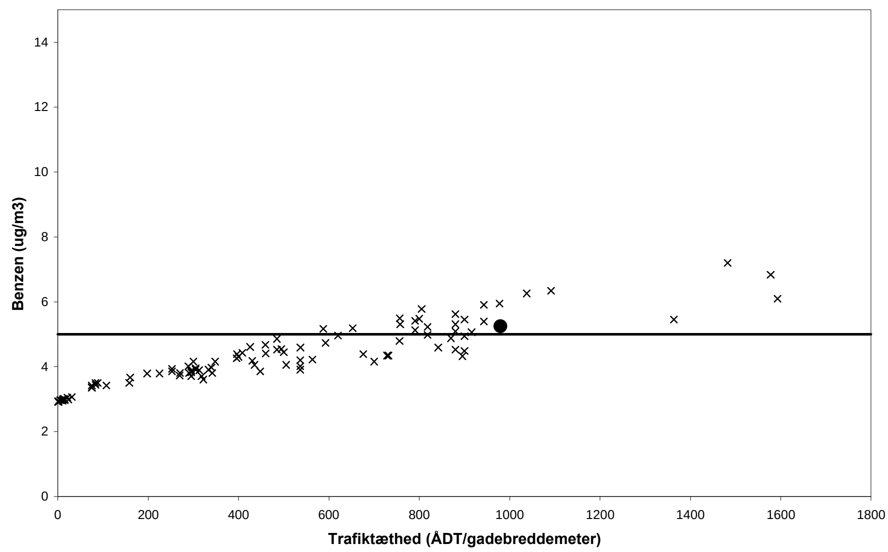


Figure 6.4 *Model calculations for 99.8-percentile of* NO_2 *in 2000 for 103 Copenhagen streets with the OSPM model. Jagtvej is marked with a bold dot. The new EU limit value for 2010 is also shown.*



Figur 6.5 *Model calculations for annual levels of benzene in 2000 for 103 Copenhagen streets with the OSPM model. Jagtvej is marked with a bold dot. The new EU limit value for 2010 is also shown*

Air Quality Levels in 2010

NO_2 and benzene in 2010

The predicted development in future air quality levels in 2010 for NO_2 and benzene for the 103 Copenhagen streets is given in Figure 6.6-8.

Similar to the scenario 2010, it is assumed that traffic loads are constant in the streets considered while an increase on main roads of 17% is assumed corresponding to a general traffic increase in the road network considered of 10% 1995-2010.

Air quality levels in 2010 are predicted to decrease for NO_2 and benzene, and none of the considered Copenhagen streets will violate the limit values of NO_2 and benzene for 2010.

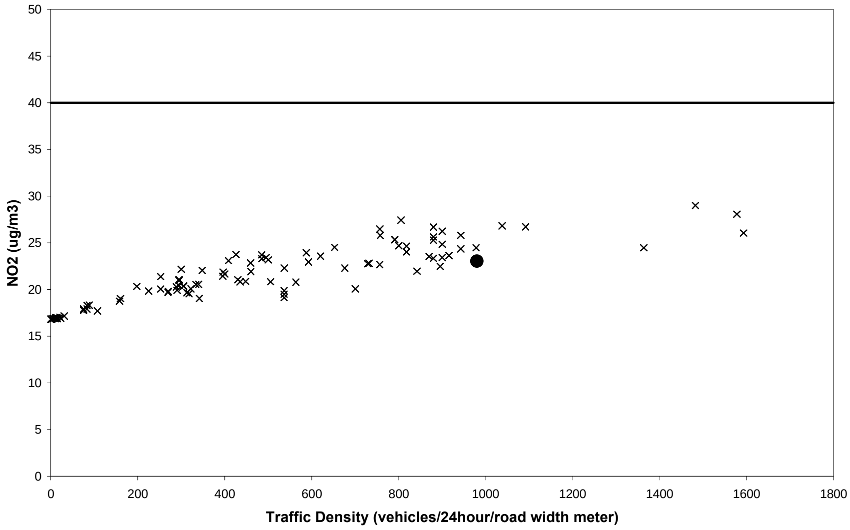


Figure 6.6 *Model calculations for annual levels of NO_2 in 2010 for 103 Copenhagen streets with the OSPM model. Jagtvej is marked with a bold dot. The new EU limit value for 2010 is also shown.*

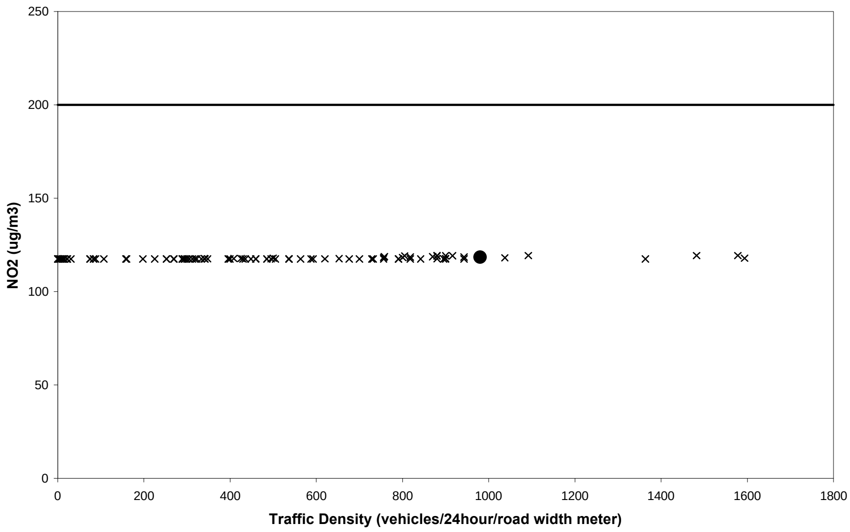


Figure 6.7 *Model calculations for 99.8-percentile of NO_2 in 2010 for 103 Copenhagen streets with the OSPM model. Jagtvej is marked with a bold dot. The new EU limit value for 2010 is also shown.*

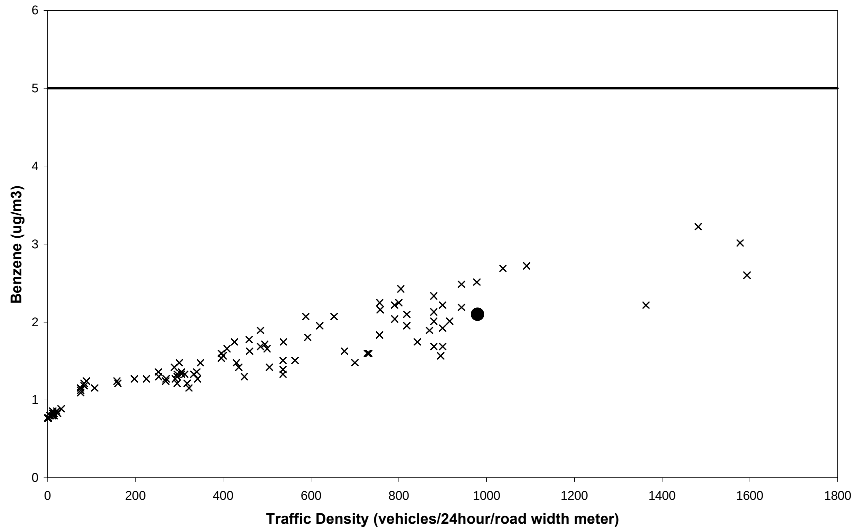


Figure 6.8 *Model calculations for annual levels of benzene in 2010 for 103 Copenhagen streets with the OSPM model. Jagtvej is marked with a bold dot. The new EU limit value for 2010 is also shown.*

6.6 Preliminary Assessment of Particulate Air Pollution at Street Level

Introduction

In this section, a preliminary assessment of the particle levels in selected streets in Denmark is carried out and levels are related to the new EU limit values for PM_{10}. The impacts of future particle emission reductions are also briefly discussed. The assessment is based on measurements since air quality models for particles are not fully developed.

Health Effects

It is recognised that particles in urban air are responsible for serious health effects, i.e. long-term effects like cancer, and cadio-vascular decease and acute effects like allergy or irritation of eyes, nose and throat (Larsen et al. 1997). Particles are often characterised by the mass determined as PM_{10} or $PM_{2.5}$, particulate matter less than 10 µm and 2.5 µm, respectively.

New EU Limit Values

The regulation from the Danish Ministry of Environment no. 836 dated 10.12.1986 on air quality includes limit values for TSP (Total Suspended Particles), i.e. 300 µg/m^3 as 24 hour average and 150 µg/m^3 as annual average. A new EU directive ”Council 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” gives limit values for particulate matter (PM_{10}). The Member States have to comply with the 24 hour limit value 50 µg/m^3 - not to be exceeded more than 35 times per year and 7 times per year - before 2005 and 2010, respectively. For annual averages the limit values are 40 µg/m^3 and 20 µg/m^3 for 2005 and 2010, respectively.

WHO has not recommended a limit value for PM, because knowledge is missing and no lower observed effect level has been identified. Consequently, the EU Commission has also realised that our knowledge about adverse health effect and the sources and chemical/physical characteristics of particles is too limited; therefore it has been decided to revise the limit values for particles within a few years when more information is available. The directive also includes obligations for the Member States to collect data on smaller particles $PM_{2.5}$. However, investigations have shown that the correlation between particle concentration and health effect increases with decreasing particle diameter. It is therefore important to determine the concentration given as number of particles in many size intervals.

Characteristics of Particles

The particle size distribution is an important factor that needs to be addressed whenever the PM pollution is concerned. A major contribution to particulate pollution in urban areas is believed to be from traffic, especially diesel powered vehicles. Particles emitted from car engines, petrol as well as diesel engines, are formed at high temperatures in the engine, in the exhaust pipe or immediately after emission to the atmosphere. These particles are in the so-called nucleation mode and the diameter of the particles is < 0.2 µm, ultrafine particles. Other particle modes are accumulation mode (fine particles), > 0.2 µm - 2 µm, which typically are formed by chemical reactions of (e.g. SO_2 and NO_x to form sulphate and nitrate), coagulation, condensation of gases on particles or other relatively slow processes. The last mode is the coarse particles > 2 µm, which typically are formed mechanically by traffic turbulence, wind erosion etc. These larger particles may also cause health effect. The size distribution and the main characteristics of urban particles are shown schematically in Figure 6..

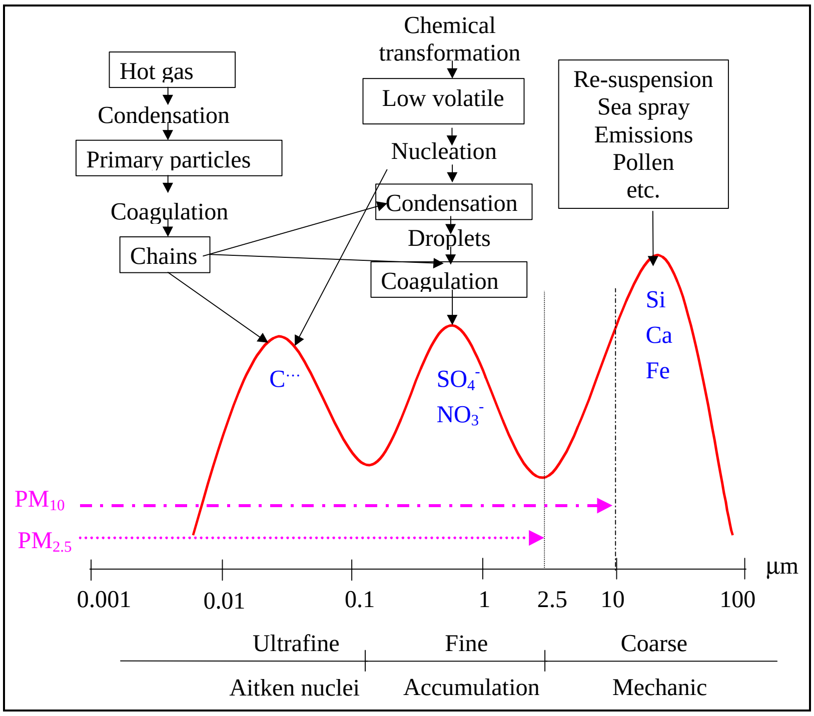


Figure 6.9 *Schematics of the size distribution of urban particles. The vertical scale is arbitrary. The shape of the distribution will change for a specific vertical axis; if the vertical axis is mass, then the ultrafine part of the distribution will be insignificant and if the vertical axis is number, then the coarse part of the distribution will be small.*

Trends and Levels of TSP and PM Pollution in Denmark

TSP

The total suspended particulate matter (TSP) is determined in the National Air Quality Monitoring Programme (LMP) (Kemp and Palmgren, 1999) by weighing of the aerosol filters. The samplers collect particles up to an aerodynamical diameter of around 25 µm, but this cut-off varies from about

10 to 50 µm depending on the wind speed (Kemp 1993). The particles are a mixture from the different source types, but the coarse particles (> 2.5 µm) of windblown dust of local origin are expected to dominate. The fine particle fraction includes contributions of long range transported soil dust and particles from combustion processes, e.g. sulphate and nitrate particles.

TSP was measured in 1998 as 24 hour average values at street stations in the major Danish cities: Copenhagen, Odense and Aalborg and at the regional background station of Lille Valby about 40 km outside Copenhagen. The measurements at Lille Valby started in the beginning of 1995. Statistics from 1998 are shown in Table 6.5 (Kemp and Palmgren, 1999). The old limit values were not exceeded.

Table 6.5. *Annual Values, 95-percentiles and Maximum Values for TSP in 1998. The Numbers are Calculated for 24-hour Average Values*

		TSP (µg/m^3)		
Station	Type	Annual	95-perc.	Max. value
Copenhagen/Jagtvej	Street	46	89	346
Odense/Albanigade	Street	46	95	243
Odense/albanigade	Street	39	76	125
Aalborg/Vesterbro	Street	51	102	166
Lille Valby	Rural	22	47	91
Old Limit value		150	300	-

Trends

The trends of TSP are shown in Figure 6.10. The general trend has been a decrease of about 30-50% during 1988-1998 for the street stations. A major part of the mass of the particles (coarse particles in Figure 6.) is windblown dust and may be considered to be either of "natural" origin, constructions or re-suspended particles from the roads. The particles from combustion processes are in the fine particle fraction, and it is expected to decrease in the future due to emission reductions.

The observed trend in TSP may be a result of i.e. better cleaning of emissions from power plants, obligatory three way catalysts (TWC) on petrol cars, restrictions on the diesel exhaust, and more green agricultural fields during winter (less soil dust).

TSP has been measured at the rural station Lille Valby for almost 4 years. The levels are between on third to half of the levels at the urban street stations.

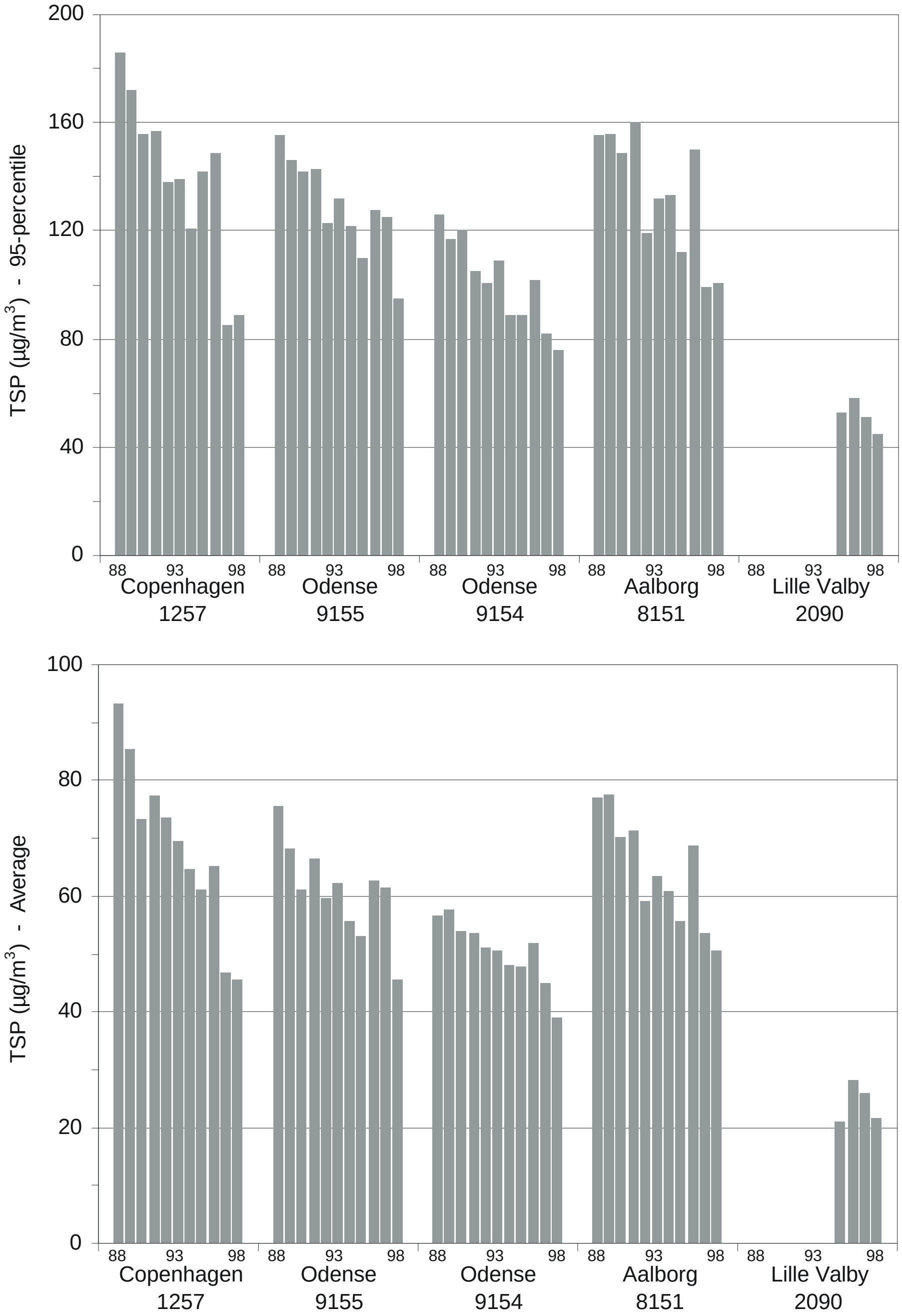


Figure 6.10 *Average values and 95-percentiles for TSP in Denmark from 1988 to 1998*

PM_{10}

Continuous measurement of PM_{10} was started in July 1998. Sampling in 24 hour intervals is performed using an OPSIS SM200 sampler at Jagtvej, Copenhagen. The particles are collected on membrane filters (Millipore type AA). The PM_{10} is determined both on-line with the build-in β-gauge and gravimetric, using the same procedure, as for TSP. TSP is approx. 35% higher than PM_{10}, that is, PM_{10} constitutes about 74% of TSP.

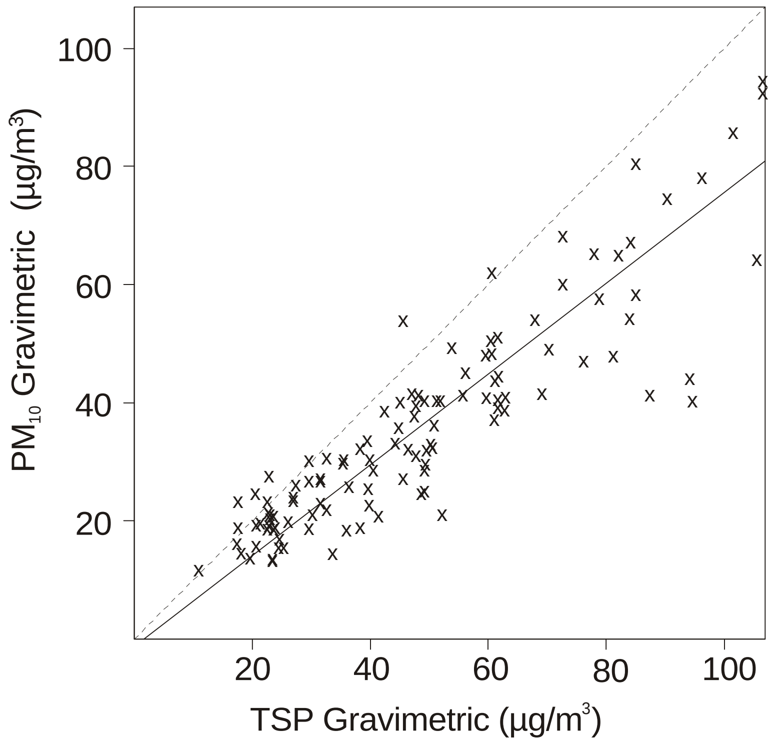


Figure 6.11 *The relationship between TSP and PM_{10} at Jagtvej in Copenhagen, 1998*

In Table 6.6, the PM_{10} level in selected streets in Denmark have been estimated based on the above relation between TSP and PM_{10}.

Tabel 6.6 *Estimated Annual PM_{10} Levels in Selected Streets in Danmark*[1]

Street	TSP 1998 (µg/m³)	TSP 1-3 quarter 1999 (µg/m³)	PM_{10} (estimate) 1998 (µg/m³)	PM_{10} (estimate) 1-3 quarter 1999 (µg/m³)
Jagtvej, Copenhagen	46	51	34	37
Albanigade, Odense	46	52	34	38
Vesterbro, Aalborg	51	53	38	39
Limit value 2005			40	
Limit value 2005			20	

[1] PM_{10} equals 74% of TSP

It is seen that the estimated PM_{10} levels in 1998-99 are below the new limit value for 2005 but exceed the limit value for 2010.

Denmark has a national objective to reduce particle vehicle emission by 50% in urban areas 1988-2010, and further reductions after 2010. The increase in penetration of catalyst converters reduce particle emissions for petrol powered vehicles due to unleaded petrol. Catalysts become mandatory in 1990. New stringent particulate emission standards for especially diesel powered vehicle will reduce particle emissions. The conversion to diesel with a low content of sulphur will also reduce particulate emissions.

Previous assessments indicate that the total particulate emissions (as mass) from vehicle within the EU will decrease by about 70% 1995-2010 including expected increases in traffic (Iversen 1999). Based on a few number of European studies, WHO has estimated that the particulate emission from vehicles in urban areas contributes about 40-60% of PM_{10} (WHO 1999).

Due to the above mentioned vehicle particulate emissions regulation it is likely that the PM_{10} will decrease in the future but it is difficult to predict how much based on existing knowledge and to predict if the limit value of 2010 will be met. The above figures indicate that it might be a problem.

Fine and Ultrafine Particles

The fine and especially the ultrafine particles emitted directly from the diesel and petrol fuelled vehicles contribute only a little to the particle mass TSP and PM_{10}.

It is therefore necessary to use other measurement techniques to measure these particles. In addition, we have some indication that the number of ultrafine particles, which can penetrate into the deepest parts of the lungs, is important to assess the health risk of particulate air pollution. A precise determination of the emission of particles from the actual car fleet is necessary for analysis of the problem in urban areas, investigations of the health impacts, and recommendations of abatement measures to be taken to reduce the pollution.

Particle Size Distribution

In order to characterise the particle pollution emitted directly from car engines, a method to measure the ultrafine particle mode has been developed. The method uses a Differential Mobility Analyser, DMA. This method is based on particle size fraction separation by the particles' mobility, determined by movement of charged particles in electrical fields. The DMA measures with a high time resolution which is necessary for identification of traffic air pollution in order to separate this source from other types of air pollution.

Measurements have been carried in busy streets in Copenhagen (Jagtvej) and Odense (Albanigade) comprising long time-series of particle spectra in connection with the normal monitoring of air pollutants, i.e. NO_x/NO_2, CO, benzene, O_3 and SO_2. In this way it was possible to determine the contribution from local traffic in the street by subtraction of the urban background concentration from the concentration measured in the street, and by inverse model calculation by the street pollution model OSPM (Berkowicz et al. 1997). The method has been used on stable pollutants like NO_x, CO and benzene (Palmgren et al. 1999). Preliminary investigations have shown that the ultrafine particles do not change size significantly during the residence time in the street, i.e. less than a few minutes (Vignati et al., 1999). The DMA method gives the size distribution in the range 0.01 – 0.7 μm. However, the distribution is not determined simultaneously, but by sweeping over the size range during a few minutes. The DMA was also applied for laboratory studies of the emissions from vehicles.

Examples of results are shown in Figure 6.. It is seen that particles from diesel powered vehicles are a little smaller than particles from petrol powered vehicles. Analysis shows that diesel vehicles on average emit about 25 times as many particles as petrol vehicles. The contribution from diesel and petrol vehicles was almost the same at Jagtvej because of few diesel vehicles. The contribution of ultrafine particle from diesel vehicles at Albanigade in Odense, which is a more typical city street, was much higher than from petrol vehicles (Palmgren and Wåhlin, 1999).

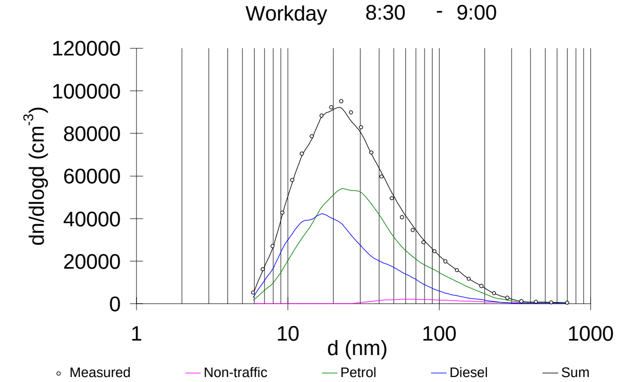
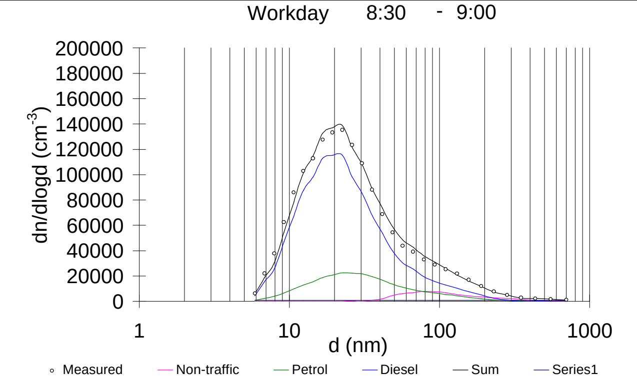


Figure 6.12 *The particle number spectrum at Jagtvej in Copenhagen during rush hour.*



The particle number spectrum at Albanigade in Odense during rush hour.

The number distribution can be translated to volume distribution (or mass distribution assuming mass density 1), see Figure 6.13. It is seen that the relatively few larger particles (Figure 6.12) contributes significantly to the mass. Traffic contributes about ¾ of the mass of ultrafine particles ($PM_{0.2}$). In this case, it is also seen that the petrol powered vehicle mass contribution is comparable with the non-traffic contribution for ultrafine particles.

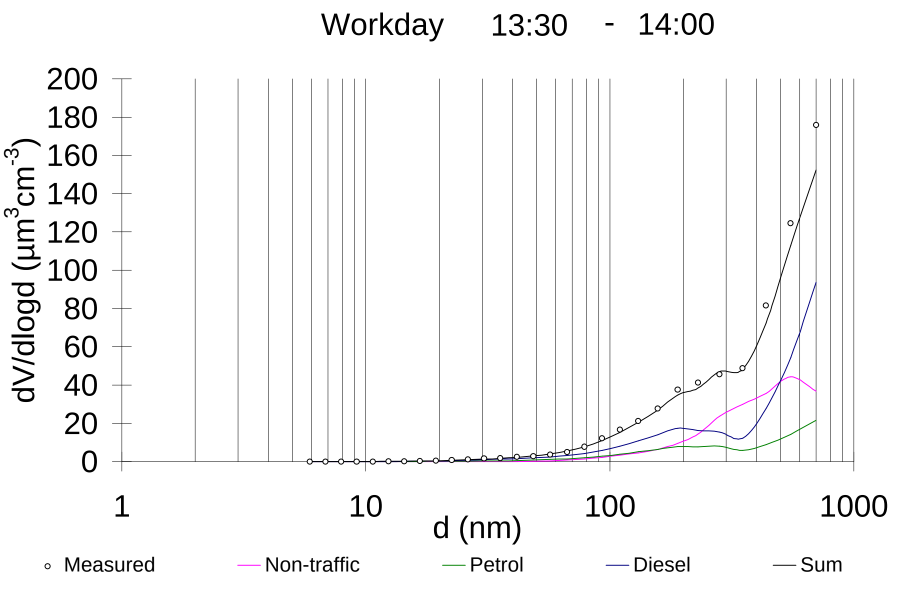


Figure 6.13 *The particle number translated to volume at Albanigade in Odense.*

Further investigations needed

The knowledge about the air pollution with particulate matter is still rather limited. By the new PM_{10}/$PM_{2.5}$ methods and the application of DMA for measurement of ultrafine particles from traffic, possibilities have opened to obtain valuable data. Systematic measurements, including long time-series, by these methods at representative sites will improve the possibilities for health studies substantially. However, more knowledge is needed about the chemical/physical properties of the particle, e.g. chemical composition, surface properties and morphology; for this purpose it is necessary to include other analytical techniques, e.g. SEM and micro probe analysis. The characterisation of the particles is also important for quantification of the contribution from different sources and parameterisation of the properties of the particles to be included in air quality models. This is necessary for decisions on abatement measures to be taken to reduce the health impacts of particulate air pollution and to evaluate the effects of the measures taken.

7 Comparison with EU Predictions

In this chapter, a comparison between the results of the present study and work carried out by the EU Commission is undertaken for emissions and air quality.

7.1 Comparison with EU Emission Predictions

AOPII Emissions Base Case

The EU Commission has carried out an impact assessment of the Auto-oil II programme on the total vehicle emissions. The task has been undertaken by Senco - Sustainable Environment Consultants - based on the TREMOVE model (AOPII Emissions Base Case). For further details see *Senco* (1999). The emission factors of the present study are derived for the different vehicle categories (g/km) based on COPERT 3 and Danish traffic characteristics. To be able to compare these emission factors with the results of the EU Commission, Danish national emissions were calculated by Risoe National Laboratory, Denmark and NERI (Fenhann 2000). The comparison is shown in Table 7.1.

Table 7.1 *Comparison of Total Vehicle Emission Predictions*

Substance	Party	1995	2000	2005	2010
CO	Denmark (Risoe/NERI)	100	69	35	21
	EU Commission (Senco)	100	73	47	29
NO_x	Denmark (Risoe/NERI)	100	74	47	29
	EU Commission (Senco)	100	75	51	31
NMVOC	Denmark (Risoe/NERI)	100	71	33	12
	EU Commission (Senco)	100	61	32	18

The comparison shows that the predicted total emissions are more or less similar. The observed differences may be due to differences in approach and assumptions about emission factors and traffic development.

7.2 Comparison with EU Air Quality Predictions

Comparison of the results of the present study with EU predictions and another Danish study has been carried out. The comparison includes urban background and street predictions.

EU and Danish Studies

Urban Impact Assessment Study, AOPII

The EU Commission has undertaken the Urban Impact Assessment study including ten larger European cities to estimate the impact of the Auto-oil II proposals for vehicle emission reductions on urban air quality 1995-2010 (EU Commission 1999). The urban background air quality has been modelled by different urban scale models: CALGRID, Urban Airshed Model

(UAM) v. IV, and the European Urban Airshed Model (EUAM). The regional background is the boundary conditions for the urban models. Data on the regional background has been derived from work carried out by IIASA with the RAINS model as part of the ongoing EU strategy to reduce transboundary air pollution.

As part of the project, street canyon modelling has been carried out in two of the cities: Milan and Berlin using the MICROCALGRID and the Danish OSPM model. The results for OSPM calculations are given in *Berkowicz* (1999a). Copenhagen is not included in the case studies.

Impact Assessment at Seven Streets in Copenhagen

A minor Danish study has carried out an impact assessment of the future air quality related to the new EU limit values in 2010 for seven streets in Copenhagen with reference year 1997 . This study did not model future vehicle emissions nor did it model the urban background. Crude assumptions were applied for future vehicle emission factors and the urban background (Berkowicz & Palmgren 1999).

Air Quality in the Urban Background

In Table 7.2, findings of the present study are compared with results from the urban background predictions in ten European cities based on preliminary results from the Urban Impact Assessment Study.

Table 7.2 Urban Background Predictions for NO_2 and Benzene in Ten European Cities (EU Commission 1999)

	Annual NO_2		Max 1 hour NO_2		Annual Benzene	
City:	1995	2010	1995	2010	1995	2010
Athens, Greece	88	66	252	205	17	5.2
Berlin, Germany	34	27	127	107	10	2.0
Cologne, Germany	46	36	158	132	2	1.0
Dublin, Ireland	30	22	118	94	2	1.0
Helsinki, Finland	31	27	119	108	2	1.0
London, England	60	39	192	141	6	2.0
Lyon, France	93	46	262	158	22	5.4
Madrid, Spain	45	30	155	116	6	2.0
Milan, Italy	67	38	208	137	19	5.3
Utrecht, Netherlands	78	47	232	160	11	3.0
Copenhagen, Denmark	28	13	-	-	4.4	0.79

Comparison with Ten European Cities

For the ten European cities, the results are preliminary based on *EU Commission* (1999). For each city, the modelled concentrations reflect the highest modelled levels in a grid cell of all the grid cells considered. It is seen that the annual NO_2 urban background levels in Copenhagen are the lowest compared to the other European cities. There is a tendency to high NO_2 levels in Southern Europe cities compared to Northern European cities due to high ozone levels in Southern Europe. Modelled annual benzene levels in the urban background are also relatively low in Copenhagen in 1995 and the lowest in 2010.

Comparison with Milan, Berlin and Danish Study

The urban background was also modelled as part of the project on street canyon modelling in Milan and Berlin (Berkowicz 1999a), and as part of a Danish study (Berkowicz & Palmgren 1999). Results of the present study are compared with these studies in Table 7.3.

Table 7.3 *Comparison of Annual Levels of Urban Background Predictions*

Levels µg/m^3	NO_x 1995	NO_x 2010	NO_2 1995	NO_2 2010	O_3 1995	O_3 2010	CO 1995	CO 2010	Bnz 1995	Bnz 2010
Copenhagen	39	15	28	13	45	51	0.39	0.22	4.4	0.79
Copenhagen, 7 streets[2]	N/A	15	N/A	12	N/A	N/A	N/A	0.15	N/A	1.0
Berlin[1]	39	17	23	13	36	46	0.33	0.2	2.1	0.5
Milan[1]	235	104	86	27	24	31	1.5	0.4	7.4	2.8
Index (2010/1995)	**NO_x 1995**	**NO_x 2010**	**NO_2 1995**	**NO_2 2010**	**O_3 1995**	**O_3 2010**	**CO 1995**	**CO 2010**	**Bnz 1995**	**Bnz 2010**
Copenhagen	100	39	100	46	100	114	100	57	100	18
Copenhagen, 7 streets[2]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Berlin[1]	100	44	100	56	100	126	100	60	100	24
Milan[1]	100	44	100	66	100	133	100	26	100	37

[1] based on Berkowicz (1999a), [2] based on Berkowicz & Palmgren (1999)

Berlin and Milan

It is seen that the results of the present study are similar to findings for Berlin and that much higher levels are modelled for Milan except for ozone due to depletion of ozone by the high NO_x levels in Milan. All pollutions decreases except ozone from 1995 to 2010.

Danish Study

It is surprising that predicted urban background levels in 2010 for the Danish study are very close to the predictions of the present study because crude assumptions were applied in *Berkowicz & Palmgren* (1999). The study assumed that urban background levels decreased 70% for NO_x, CO and benzene, and that regional background levels of NO_2 and ozone decreased by 50%. The NO_x emissions from trucks were assumed to decrease by 50% and 90% of passenger cars were assumed to have catalyst converters in 2010. The present study modelled a reduction in the urban background of NO_x, CO and benzene of 61%, 43% and 82%, respectively (see Table 5.6). The regional NO_2 background was modelled to decrease by 36%, and for ozone by only 2% (see Table 4.3). NO_x emissions from trucks were modelled to decrease by 61-67% (see Table 3.6). A combination of under- and overestimations that neutralizes each other explains why *Berkowicz & Palmgren* (1999) estimate similar results as the present study. Underestimation of the regional and urban background levels of NO_x and overestimation of NO_x emission explains the similar NO_x levels. NO_2 levels are similar although regional NO_2 and also urban NO_x are assumed to be lower. The reason is the combination of overestimated NO_x emissions and overestimated ozone levels raising NO_2 levels in the urban background.

Air Quality at Street Level

In Table 7.4, findings of the different studies are shown at street level. The selected roads in Milan, Berlin and Copenhagen are different with respect to traffic loads, vehicle composition, fraction of catalyst cars, and street configurations, and therefore air quality levels will vary.

Table 7.4 *Comparison of Predicted Annual Levels at Street Level*

Levels µg/m³	NO_x 1995	NO_x 2010	NO_2 1995	NO_2 2010	CO 1995	CO 2010	Bnz 1995	Bnz 2010
Copenhagen	164	46	52	23	2	0.6	17	2.1
Copenhagen, 7 streets[2]	N/A	60-90	N/A	18-20	N/A	0.6-0.8	N/A	3-4
Berlin[1]	221	77	50	28	2.0	0.6	8.7	1.5
Milan[1]	455	165	63	45	4.9	1.1	22	4.1
Index (2010/1995)	**NO_x 1995**	**NO_x 2010**	**NO_2 1995**	**NO_2 2010**	**CO 1995**	**CO 2010**	**Bnz 1995**	**Bnz 2010**
Copenhagen	100	28	100	44	100	35	100	12
Copenhagen, 7 streets[2]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Berlin[1]	100	35	100	56	100	31	100	17
Milan[1]	100	36	100	54	100	22	100	18

[1] based on Berkowicz (1999a), [2] based on Berkowicz & Palmgren (1999)

Berlin and Milan

It is seen that the results of the present study are similar to findings for Berlin (except for NO_x)and that much higher levels are modelled for Milan.

Danish Study

Compared to the present study, the assessment of the 7 Copenhagen streets finds higher NO_x levels due to overestimation of NO_x emissions. NO_2 levels are similar for the same reasons given as for the urban background. Benzene levels are overestimated because the reduction of the content of benzene in petrol to 1% in 2010 is not fully taken into account in the assumptions.

All in all, the findings of the present study for Copenhagen are in accordance with the EU Urban Impact Assessment study for a comparable city like Berlin.

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Appendix 1: Emission Data for DEM Model

EMEP and IIASA data

The development in European emissions is based on EMEP data for 1990 and proposed national reductions in 2010 for all European countries under ECE. The national reductions are taking from an analysis by the International Institute for Applied Systems Analysis (IIASA) in Austria that carries out the preparatory work that leads to ECE protocols (IIASA 1999). Emission levels in 1990 and 2010 and reduction factors 1990-2010 are given in Table 1.

Table 1 *Emission Levels in 1990 and 2010 and Reductions 1990-2010 (thousand tonnes per year)*

	1990			2010			Reductions in % 1990-2010		
	NO_x	VOC	NH_3	NO_x	VOC	NH_3	NO_x	VOC	NH_3
Albania	24	32	31	36	42	34	50	32	9
Austria	196	367	85	106	213	74	-46	-42	-13
Belgium	343	339	104	185	176	103	-46	-48	-1
Bulgaria	376	187	144	316	181	128	-16	-3	-11
Denmark	282	178	122	133	84	115	-53	-53	-6
Finland	300	209	35	165	109	27	-45	-48	-23
France	1590	2393	700	731	1220	672	-54	-49	-4
German Democratic Rep.	691	948	212	304	341	159	-56	-64	-25
German Federal Rep.	1963	2233	557	864	804	418	-56	-64	-25
Greece	392	293	78	392	231	72	0	-21	-8
Hungary	238	205	164	214	160	187	-10	-22	14
Iceland	2	1	1	2	2	1	0	0	0
Ireland	115	102	126	71	51	125	-38	-50	-1
Italy	2047	2080	416	1126	1165	391	-45	-44	-6
Luxembourg	23	19	7	10	7	7	-55	-63	0
Netherlands	596	502	232	310	241	135	-48	-52	-42
Norway	227	299	23	184	197	21	-19	-34	-9
Poland	1279	797	508	921	797	544	-28	0	7
Portugal	221	202	93	188	137	87	-15	-32	-6
Romania	546	568	300	480	568	312	-12	0	4
Spain	1188	1051	353	867	694	353	-27	-34	0
Sweden	411	526	61	230	300	48	-44	-43	-21
Switzerland	165	283	72	79	147	66	-52	-48	-8
Turkey	497	175	415	497	175	415	0	0	0
United Kingdom	2850	2720	320	1197	1387	288	-58	-49	-10
Other areas	100	200	56	100	200	56	0	0	0
The Baltic Sea	80	0	0	80	0	0	0	0	0
The North Sea	639	0	0	639	0	0	0	0	0
Rem. Atlantic Waters	745	0	0	745	0	0	0	0	0
The Mediterranian	13	0	0	13	0	0	0	0	0
The Black Sea	0	0	0	0	0	0	0	0	0
Natural Ocean Emissions	0	0	0	0	0	0	0	0	0
Kola-Karelia	48	31	25	36	24	18	-24	-21	-30
Lening.-Novgorod-Pskov	110	108	55	84	85	39	-24	-21	-30
Kaliningrad	16	19	7	12	15	5	-24	-21	-30
Belarus	285	533	219	225	442	162	-21	-17	-26
Ukraine	1097	1369	729	834	999	649	-24	-27	-11
Moldovia	39	11	47	30	9	48	-24	-16	2
Rest of Russia	1685	2009	796	1281	1587	557	-24	-21	-30
Estonia	68	88	29	59	96	29	-13	9	0
Latvia	90	63	44	90	56	36	0	-11	-19
Lithuania	158	111	84	142	105	85	-10	-5	1
The Czeck Republic	742	435	105	401	300	106	-46	-31	1
Slovakia	225	149	62	135	145	48	-40	-3	-22
Slovenia	62	42	24	37	31	22	-40	-27	-9
Croatia	83	105	44	92	113	40	11	8	-8
Bosna and Herzogovina	80	101	31	60	95	23	-25	-6	-26
Yugoslavia	66	66	90	48	59	82	-28	-11	-9
Macedonia	39	7	17	29	7	16	-26	0	-6
Kazachstan	12	0	2	188	0	97	0	0	0
Georgia	188	0	97	188	0	97	0	0	0
EU	13208	14162	3501	6879	7160	3074	-48	-49	-12
Non-EU	10024	7994	4221	8277	6636	3923	-17	-17	-7
Total for Europe	23232	22156	7722	15156	13796	6997	-36	-38	-11

New ECE Protocol

The emission levels in 1990, emission ceilings for 2010 and the percentage emission reduction is based on the Draft Protocol to the 1979 Convention on Long-range Transboundary Air Pollution to Abate Acification, Eutrofication and Ground-level Ozone from 15 October 1999 (ECE 1999).

Table 2 *Emission Ceilings for Nitrogen Oxides (thousands of tonnes of NO_2 per year)*

Country:	Emission 1990	Emission ceilings 2010	Reductions 1990-2010 (%)
Armenia	46	46	0
Austria	194	107	-45
Belarus	285	255	-11
Belgium	339	181	-47
Bulgaria	361	266	-26
Croatia	87	87	0
Czech Republic	742	286	-61
Denmark	282	127	-55
Finland	300	170	-43
France	1882	860	-54
Germany	2693	1081	-60
Greece	343	344	0
Hungary	238	198	-17
Ireland	115	65	-43
Italy	1938	1000	-48
Latvia	93	84	-10
Liechtenstein	1	0.37	-41
Lithuania	158	110	-30
Luxembourg	23	11	-52
Netherlands	580	266	-54
Norway	218	156	-28
Poland	1280	879	-31
Portugal	348	260	-25
Republic of Moldova	100	90	-10
Romania	546	437	-20
Russian Federation /b	3600		
PEMA	360	265	-26
Slovakia	225	130	-42
Slovenia	62	45	-27
Spain /b	1113	847	-24
Sweden	338	148	-56
Switzerland	166	79	-52
Ukraine	1888	1222	-35
United Kingdom	2673	1181	-56
European Community	13161	6671	-49

b/ Figures apply to the European part within the EMEP area.

Table 3 *Emission ceilings for ammonia (thousands of tonnes of NH_3 per year)*

	Emission levels 1990	Emission ceilings for 2010	Reduction 1990-2010 (%)
Armenia	25	25	0%
Austria	81	66	-19%
Belarus	219	158	-28%
Belgium	107	74	-31%
Bulgaria	144	108	-25%
Croatia	37	30	-19%
Czech Republic	156	101	-35%
Denmark	122	69	-43%
Finland	35	31	-11%
France	814	780	-4%
Germany	764	550	-28%
Greece	80	73	-9%
Hungary	124	90	-27%
Ireland	126	116	-8%
Italy	466	419	-10%
Latvia	44	44	0%
Liechtenstein	0.15	0.15	0%
Lithuania	84	84	0%
Luxembourg	7	7	0%
Netherlands	226	128	-43%
Norway	23	23	0%
Poland	508	468	-8%
Portugal	98	108	10%
Republic of Moldova	49	42	-14%
Romania	300	210	-30%
Russian Federation a/	1191		
PEMA	61	49	-20%
Slovakia	62	39	-37%
Slovenia	24	20	-17%
Spain a/	351	353	1%
Sweden	61	57	-7%
Switzerland	72	63	-13%
Ukraine	729	592	-19%
United Kingdom	333	297	-11%
European Community	3671	3129	-15%

a/Figures apply to the European part within the EMEP area.

Table 4 *Emission ceilings for volatile organic compounds (thousands of tonnes of VOC per year)*

	Emission 1990	Emission ceilings for 2010	Reductions 1990-2010 (%)
Armenia	81	81	0%
Austria	351	159	-55%
Belarus	533	309	-42%
Belgium	324	144	-56%
Bulgaria	217	185	-15%
Croatia	105	90	-14%
Czech Republic	435	220	-49%
Denmark	178	85	-52%
Finland	209	130	-38%
France	2957	1100	-63%
Germany	3195	995	-69%
Greece	373	261	-30%
Hungary	205	137	-33%
Ireland	197	55	-72%
Italy	2213	1159	-48%
Latvia	152	136	-11%
Liechtenstein	1.56	0.86	-45%
Lithuania	103	92	-11%
Luxembourg	20	9	-55%
Netherlands	502	191	-62%
Norway	310	195	-37%
Poland	831	800	-4%
Portugal	640	202	-68%
Republic of Moldova	157	100	-36%
Romania	616	523	-15%
Russian Federation /b	3566		
PEMA	203	165	-19%
Slovakia	149	140	-6%
Slovenia	42	40	-5%
Spain b/	1094	669	-39%
Sweden	526	241	-54%
Switzerland	292	144	-51%
Ukraine	1369	797	-42%
United Kingdom	2555	1200	-53%
European Community	15353	6600	-57%

b/ Figures apply to the European part within the EMEP area.

Appendix 2 Distribution of Vehicle Stock and Annual Mileage

	Passenger cars incl. vans< 2t				Light duty vehicles (vans)			
	Gasoline		Diesel		Gasoline		Diesel	
	Number	Mileage/year	Number	Mileage/year	Number	Mileage/year	Number	Mileage/year
< 1970	6359	12571	335	22046				
1970	6359	12571	335	22046				
1971	6359	12571	335	22046				
1972	6359	12571	335	22046				
1973	4854	12571	256	22046				
1974	3586	12571	189	22046				
1975	5715	12571	301	22046	168	20602	642	20602
1976	10828	12571	570	22046	96	20602	367	20602
1977	13777	12571	725	22046	302	20602	1154	20602
1978	19584	12571	1031	22046	508	20602	1940	20602
1979	25725	12571	1355	22046	714	20602	2727	20602
1980	18199	12571	958	22046	920	20602	3513	20602
1981	26711	12571	1406	22046	1126	20602	4300	20602
1982	40445	12571	2130	22046	1332	20602	5086	20602
1983	70335	12571	3703	22046	1538	20602	5873	20602
1984	94422	12571	4972	22046	1744	20602	6659	20602
1985	124848	15381	6574	26974	1950	20602	7446	20602
1986	142641	15381	7510	26974	2155	20602	8232	20602
1987	110801	17113	5834	30011	2361	20602	9019	20602
1988	82016	17732	4318	31096	2567	20602	9805	20602
1989	74303	18394	3912	32258	2773	20602	10592	20602
1990	76560	19135	4031	33557	2979	20602	11378	20602
1991	80062	20809	4215	36494	3185	20602	12165	20602
1992	80448	21306	4236	37365	3391	20602	12951	20602
1993	77527	21800	4082	38232	3597	20602	13738	20602
1994	129562	24371	6822	42739	3803	20602	14524	20602
1995	127922	24789	6735	43472	4009	20602	15311	20602
1996	135828	26447	7152	46380	4215	20602	16097	20602
1997	146255	27366	7701	47992	4421	20602	16884	20602
Total	1748391	3.38E+10	92057	3.12E+09	49854	1.03E+09	190401	3.92E+09

	Lorries								Buses	
	3,5-7,5 t		7,5-16 t		16-32 t		> 32 t			
	Number	Mileage/year	Number	Mileage/year	Number	Mileage/year	Number	Mileage/year	Number	Mileage/year
-1993 EURO 0	3999	20594	7800	24039	10720	36013	9337	36013	2887	57490
1994										
1995										
1996 EURO I	1440	20594	2808	24039	3859	36013	3362	36013	1039	57490
1997 EURO II	529	20594	1032	24039	1419	36013	1236	36013	382	57490
Total	5968	1.23E+08	11641	2.80E+08	15998	5.76E+08	13934	5.02E+08	4308	2.48E+08

Appendix 3 Hot and Cold Emission Factors, and Beta-factors

1995		Hot emission factors (g/km)									
		CO	NO_x	VOC-exh.	Particulates	Benzene*	N_2O	CH_4	NMVOC	VOC-RL	VOC-total
Passenger cars											
	Conventional	11.10	2.02	1.43	0.00	0.41	0.0050	0.0643	1.37	0.0907	1.53
	Catalyst	1.55	0.30	0.16	0.00	0.04	0.0530	0.0294	0.13	0.0091	0.17
	Gasoline total	7.37	1.35	0.94	0.00	0.30	0.0237	0.0506	0.89	0.0588	0.99
	Diesel	0.46	0.52	0.09	0.12	0.05	0.0270	0.0039	0.09		
Light duty vehicles (LDV)											
	Conventional	14.18	3.04	2.04	0.00	0.52	0.0060	0.1500	1.89	0.0907	2.13
	Catalyst	2.06	0.29	0.14	0.00	0.05	0.0530	0.0289	0.11	0.0091	0.15
	Gasoline total	13.10	2.79	1.87	0.00	0.48	0.0102	0.1393	1.73	0.0835	1.95
	Diesel	0.98	1.20	0.12	0.27	0.10	0.0170	0.0050	0.11		
Passenger cars and LDV											
	Gasoline	7.55	1.39	0.96	0.00	-	0.0233	0.0496	0.92	0.0596	1.02
Lorries											
	3,5-7,5 t.	2.25	2.24	1.24	0.27	0.010	0.0300	0.0814	1.16		
	7,5-16 t.	2.25	4.87	1.24	0.53	0.010	0.0300	0.0814	1.16		
	16-32 t.	2.27	9.34	1.19	0.64	0.010	0.0300	0.1601	1.03		
	> 32 t.	2.27	13.82	1.19	0.68	0.010	0.0300	0.1601	1.03		
	Total	2.27	8.87	1.20	0.58	0.010	0.0300	0.1336	1.07		
Buses		2.93	11.13	0.74	0.42	0.010	0.0300	0.1675	0.58		
Lorries and buses	Total	2.36	9.20	1.14	0.56	0.010	0.0300	0.1385	1.00		

* Benzene emission factors are not determined by the COPERT III emission model but by invert calculations by the OSPM model based on air quality measurements.

1995		Cold emission factors (g/km)									Beta factors		
		CO	NO_x	VOC	Particulates	Benzene*	CH_4	NMVOC	VOC-RL	VOC-total	Beta CO	Beta NO_x	Beta VOC
Passenger cars													
	Conventional	31.32	2.18	3.18	0.00	1.16	0.14	3.04	0.07	3.24	0.23	0.23	0.23
	Catalyst	17.74	0.93	1.20	0.00	0.46	0.07	1.13	0.01	1.20	0.23	0.23	0.23
	Gasoline total	26.02	1.69	2.40	0.00	0.95	0.11	2.29	0.04	2.45	0.23	0.23	0.23
	Diesel	0.74	0.61	0.21	0.25	0.07	0.01	0.20			0.23	0.23	0.23
Light duty vehicles (LDV)													
	Conventional	40.01	3.28	4.51	0.00	1.48	0.33	4.18	0.07	4.58	0.23	0.23	0.23
	Catalyst	16.84	1.04	1.65	0.00	0.43	0.06	1.58	0.01	1.66	0.23	0.23	0.23
	Gasoline total	37.96	3.08	4.26	0.00	1.38	0.31	3.95	0.06	4.32	0.23	0.23	0.23
	Diesel	1.58	1.41	0.26	0.57	0.16	0.01	0.25			0.23	0.23	0.23
Passenger cars and LDV													
	Gasoline	26.39	1.74	2.46	0.00	-	0.12	2.34	0.04	2.51	0.23	0.23	0.23
Lorries													
	3,5-7,5 t.	2.25	2.24	1.24	0.27	0.010	0.08	1.16					
	7,5-16 t.	2.25	4.87	1.24	0.53	0.010	0.08	1.16					
	16-32 t.	2.27	9.34	1.19	0.64	0.010	0.16	1.03					
	> 32 t.	2.27	13.82	1.19	0.68	0.010	0.16	1.03					
	Total	2.27	8.87	1.20	0.58	0.010	0.13	1.07					
Buses		2.93	11.13	0.74	0.42	0.010	0.17	0.58					
Lorries and buses	Total	2.36	9.20	1.14	0.56	0.010	0.14	1.00					

* Benzene emission factors are not determined by the COPERT III emission model but by invert calculations by the OSPM model based on air quality measurements.

1997		Hot emission factors (g/km)									
		CO	NO_x	VOC-exh.	Particulates	Benzene*	N_2O	CH_4	NMVOC	VOC-RL	VOC-total
Passenger cars											
	Conventional	10.15	2.02	1.39	0.00	-	0.0050	0.0643	1.33	0.0907	1.48
	Catalyst	1.76	0.35	0.16	0.00	-	0.0530	0.0245	0.14	0.0091	0.17
	Gasoline total	5.44	1.08	0.70	0.00	-	0.0320	0.0419	0.66	0.0448	0.75
	Diesel	0.41	0.54	0.08	0.10	-	0.0270	0.0039	0.08		
Light duty vehicles (LDV)											
	Conventional	13.67	3.03	2.02	0.00	-	0.0060	0.0050	2.02	0.0907	2.11
	Catalyst	2.32	0.42	0.17	0.00	-	0.0530	0.0050	0.16	0.0091	0.18
	Gasoline total	10.79	2.37	1.55	0.00	-	0.0179	0.0050	1.55	0.0700	1.62
	Diesel	0.87	1.17	0.12	0.23	-	0.0170	0.0050	0.11		
Passenger cars and LDV											
	Gasoline	5.59	1.12	0.73	0.00	-	0.0316	0.0408	0.69	0.0456	0.77
Lorries											
	3,5-7,5 t.	2.04	2.09	1.18	0.25	-	0.0300	0.0776	1.11		
	7,5-16 t.	2.04	4.54	1.18	0.48	-	0.0300	0.0776	1.11		
	16-32 t.	2.08	8.48	1.08	0.57	-	0.0300	0.1454	0.93		
	> 32 t.	2.08	12.55	1.08	0.62	-	0.0300	0.1454	0.93		
	Total	2.06	8.58	1.11	0.54	-	0.0300	0.1269	0.98		
Buses		2.65	10.36	0.71	0.38	-	0.0300	0.1598	0.55		
Lorries and buses	Total	2.15	8.84	1.05	0.52	-	0.0300	0.1316	0.92		

* Benzene emission factors are not determined by the COPERT III emission model but by invert calculations by the OSPM model based on air quality measurements.

1997		Cold emission factors (g/km)									Beta factors		
		CO	NO_x	VOC	Particulates	Benzene*	CH_4	NMVOC	VOC-RL	VOC-total	Beta CO	Beta NO_x	Beta VOC
Passenger cars													
	Conventional	28.65	2.18	3.09	0.00	-	0.14	2.94	0.07	3.15	0.23	0.23	0.23
	Catalyst	20.16	1.07	1.27	0.00	-	0.05	1.22	0.01	1.28	0.21	0.21	0.21
	Gasoline total	23.88	1.56	2.07	0.00	-	0.09	1.97	0.03	2.10	0.22	0.22	0.22
	Diesel	0.66	0.63	0.19	0.20	-	0.01	0.18			0.22	0.22	0.22
Light duty vehicles (LDV)													
	Conventional	38.59	3.28	4.48	0.00	-	0.33	4.15	0.07	4.55	0.23	0.23	0.23
	Catalyst	18.92	1.50	2.03	0.00	-	0.06	1.96	0.01	2.03	0.23	0.23	0.23
	Gasoline total	33.60	2.83	3.86	0.00	-	0.26	3.60	0.05	3.91	0.23	0.23	0.23
	Diesel	1.39	1.38	0.26	0.49	-	0.01	0.25			0.23	0.23	0.23
Passenger cars and LDV													
	Gasoline	24.16	1.60	2.12	0.00	-	0.10	2.02	0.03	2.15	0.22	0.22	0.22
Lorries													
	3,5-7,5 t.	2.04	2.09	1.18	0.25	-	0.08	1.11					
	7,5-16 t.	2.04	4.54	1.18	0.48	-	0.08	1.11					
	16-32 t.	2.08	8.48	1.08	0.57	-	0.15	0.93					
	> 32 t.	2.08	12.55	1.08	0.62	-	0.15	0.93					
	Total	2.06	8.58	1.11	0.54	-	0.13	0.98					
Buses		2.65	10.36	0.71	0.38	-	0.16	0.55					
Lorries and buses	Total	2.15	8.84	1.05	0.52	-	0.13	0.92					

* Benzene emission factors are not determined by the COPERT III emission model but by invert calculations by the OSPM model based on air quality measurements.

2000		Hot emission factors (g/km)									
		CO	NO_x	VOC-exh.	Particulates	Benzene*	N_2O	CH_4	NMVOC	VOC-RL	VOC-total
Passenger cars											
	Conventional	8.87	2.03	1.33	0.00	0.18	0.0050	0.0643	1.27	0.0907	1.42
	Catalyst	1.72	0.31	0.12	0.00	0.02	0.0530	0.0155	0.11	0.0091	0.13
	Gasoline total	3.95	0.84	0.50	0.00	0.09	0.0380	0.0307	0.47	0.0345	0.53
	Diesel	0.37	0.55	0.08	0.08	0.02	0.0270	0.0039	0.07		
Light duty vehicles (LDV)											
	Conventional	12.88	3.04	1.99	0.00	0.26	0.0060	0.1500	1.84	0.0907	2.08
	Catalyst	2.32	0.49	0.17	0.00	0.02	0.0530	0.0208	0.14	0.0091	0.17
	Gasoline total	7.91	1.84	1.13	0.00	0.15	0.0281	0.0893	1.04	0.0523	1.18
	Diesel	0.71	1.13	0.12	0.18	0.04	0.0170	0.0043	0.11		
Passenger cars and LDV											
	Gasoline	4.07	0.87	0.52	0.00	-	0.0378	0.0324	0.49	0.0350	0.55
Lorries											
	3,5-7,5 t.	1.72	1.83	1.10	0.21	0.004	0.0300	0.0723	1.03		
	7,5-16 t.	1.72	3.97	1.10	0.41	0.004	0.0300	0.0723	1.03		
	16-32 t.	1.79	7.19	0.93	0.46	0.004	0.0300	0.1254	0.80		
	> 32 t.	1.79	10.63	0.93	0.49	0.004	0.0300	0.1254	0.80		
	Total	1.77	7.30	0.98	0.44	0.004	0.0300	0.1109	0.86		
Buses		2.24	9.08	0.66	0.32	0.004	0.0300	0.1488	0.51		
Lorries and buses	Total	1.84	7.56	0.93	0.42	0.004	0.0300	0.1164	0.81		

* Benzene emission factors are not determined by the COPERT III emission model but by invert calculations by the OSPM model based on air quality measurements.

2000		Cold emission factors (g/km) CO	NO_x	VOC	Particulates	Benzene*	CH_4	NMVOC	VOC-RL	VOC-total	Beta factors Beta CO	Beta NO_x	Beta VOC
Passenger cars													
	Conventional	25.03	2.19	2.95	0.00	0.51	0.14	2.81	0.07	3.02	0.23	0.23	0.23
	Catalyst	19.79	0.94	0.98	0.00	0.20	0.03	0.95	0.01	0.99	0.19	0.19	0.17
	Gasoline total	21.42	1.33	1.60	0.00	0.33	0.07	1.53	0.03	1.62	0.20	0.20	0.19
	Diesel	0.60	0.65	0.17	0.17	0.04	0.01	0.16			0.20	0.20	0.19
Light duty vehicles (LDV)													
	Conventional	36.34	3.29	4.41	0.00	0.74	0.33	4.08	0.07	4.48	0.23	0.23	0.23
	Catalyst	18.91	1.76	1.98	0.00	0.19	0.05	1.94	0.01	1.99	0.20	0.20	0.19
	Gasoline total	28.15	2.57	3.27	0.00	0.48	0.20	3.07	0.04	3.31	0.22	0.22	0.21
	Diesel	1.14	1.33	0.26	0.26	0.07	0.01	0.25			0.22	0.22	0.21
Passenger cars and LDV													
	Gasoline	21.62	1.37	1.65	0.00	-	0.07	1.57	0.03	1.67	0.20	0.20	0.19
Lorries													
	3,5-7,5 t.	1.72	1.83	1.10	0.21	0.004	0.07	1.03					
	7,5-16 t.	1.72	3.97	1.10	0.41	0.004	0.07	1.03					
	16-32 t.	1.79	7.19	0.93	0.46	0.004	0.13	0.80					
	> 32 t.	1.79	10.63	0.93	0.49	0.004	0.13	0.80					
	Total	1.77	7.30	0.98	0.44	0.004	0.11	0.86					
Buses		2.24	9.08	0.66	0.32	0.004	0.15	0.51					
Lorries and buses	Total	1.84	7.56	0.93	0.42	0.004	0.12	0.81					

* Benzene emission factors are not determined by the COPERT III emission model but by invert calculations by the OSPM model based on air quality measurements.

2005		Hot emission factors (g/km)									
		CO	NO_x	VOC-exh.	Particulates	Benzene*	N_2O	CH_4	NMVOC	VOC-RL	VOC-total
Passenger cars											
	Conventional	9.47	2.02	1.36	0.00	0.18	0.0050	0.0643	1.29	0.0907	1.45
	Catalyst	1.63	0.27	0.10	0.00	0.02	0.0530	0.0124	0.09	0.0091	0.11
	Gasoline total	2.20	0.39	0.19	0.00	0.04	0.0495	0.0161	0.18	0.0150	0.21
	Diesel	0.30	0.51	0.06	0.05	0.03	0.0270	0.0036	0.05		
Light duty vehicles (LDV)											
	Conventional	11.53	3.06	1.92	0.00	0.22	0.0060	0.1500	1.77	0.0907	2.01
	Catalyst	1.95	0.33	0.10	0.00	0.02	0.0530	0.0120	0.09	0.0091	0.11
	Gasoline total	4.36	1.01	0.56	0.00	0.07	0.0412	0.0467	0.51	0.0296	0.59
	Diesel	0.49	1.03	0.10	0.11	0.04	0.0170	0.0028	0.10		
Passenger cars and LDV											
	Gasoline	2.26	0.41	0.20	0.00	-	0.0493	0.0170	0.19	0.0154	0.22
Lorries											
	3,5-7,5 t.	1.23	1.38	0.91	0.15	0.004	0.0300	0.0595	0.85		
	7,5-16 t.	1.23	2.99	0.91	0.29	0.004	0.0300	0.0595	0.85		
	16-32 t.	1.32	5.13	0.68	0.30	0.004	0.0300	0.0923	0.59		
	> 32 t.	1.32	7.59	0.68	0.32	0.004	0.0300	0.0923	0.59		
	Total	1.29	5.25	0.74	0.29	0.004	0.0300	0.0834	0.66		
Buses		1.60	6.84	0.54	0.23	0.004	0.0300	0.1226	0.42		
Lorries and buses	Total	1.34	5.48	0.72	0.28	0.004	0.0300	0.0890	0.63		

* Benzene emission factors are not determined by the COPERT III emission model but by invert calculations by the OSPM model based on air quality measurements.

2005		Cold emission factors (g/km) CO	NO_x	VOC	Particulates	Benzene*	CH_4	NMVOC	VOC-RL	VOC-total	Beta factors Beta CO	Beta NO_x	Beta VOC
Passenger cars													
	Conventional	26.72	2.18	3.01	0.00	0.51	0.14	2.87	0.07	3.07	0.23	0.23	0.23
	Catalyst	18.78	0.82	0.82	0.00	0.20	0.03	0.79	0.01	0.83	0.17	0.14	0.13
	Gasoline total	19.36	0.92	0.98	0.00	0.23	0.04	0.94	0.01	0.99	0.18	0.15	0.14
	Diesel	0.49	0.60	0.13	0.10	0.04	0.01	0.12			0.18	0.15	0.14
Light duty vehicles (LDV)													
	Conventional	32.53	3.31	4.26	0.00	0.62	0.33	3.93	0.07	4.33	0.23	0.23	0.23
	Catalyst	15.94	1.17	1.24	0.00	0.17	0.03	1.21	0.01	1.25	0.17	0.14	0.13
	Gasoline total	20.11	1.71	2.00	0.00	0.28	0.10	1.90	0.02	2.02	0.19	0.16	0.16
	Diesel	0.79	1.21	0.23	0.23	0.07	0.01	0.22			0.19	0.16	0.16
Passenger cars and LDV													
	Gasoline	19.38	0.94	1.01	0.00	-	0.04	0.97	0.01	1.02	0.18	0.15	0.14
Lorries													
	3,5-7,5 t.	1.23	1.38	0.91	0.15	0.004	0.06	0.85					
	7,5-16 t.	1.23	2.99	0.91	0.29	0.004	0.06	0.85					
	16-32 t.	1.32	5.13	0.68	0.30	0.004	0.09	0.59					
	> 32 t.	1.32	7.59	0.68	0.32	0.004	0.09	0.59					
	Total	1.29	5.25	0.74	0.29	0.004	0.08	0.66					
Buses		1.60	6.84	0.54	0.23	0.004	0.12	0.42					
Lorries and buses	Total	1.34	5.48	0.72	0.28	0.004	0.09	0.63					

* Benzene emission factors are not determined by the COPERT III emission model but by invert calculations by the OSPM model based on air quality measurements.

2010		Hot emission factors (g/km)									
		CO	NO_x	VOC-exh.	Particulates	Benzene*	N_2O	CH_4	NMVOC	VOC-RL	VOC-total
Passenger cars											
	Conventional	9.77	2.02	1.39	0.00	0.18	0.0050	0.0643	1.33	0.0907	1.48
	Catalyst	1.21	0.15	0.04	0.00	0.02	0.0530	0.0050	0.04	0.0091	0.05
	Gasoline total	1.41	0.19	0.07	0.00	0.02	0.0519	0.0065	0.07	0.0110	0.09
	Diesel	0.29	0.42	0.05	0.03	0.04	0.0270	0.0032	0.05		
Light duty vehicles (LDV)											
	Conventional	11.13	3.07	1.90	0.00	0.21	0.0060	0.1500	1.75	0.0907	1.99
	Catalyst	1.71	0.20	0.07	0.00	0.02	0.0530	0.0072	0.06	0.0091	0.07
	Gasoline total	2.43	0.42	0.21	0.00	0.04	0.0494	0.0182	0.19	0.0153	0.22
	Diesel	0.33	0.89	0.07	0.06	0.04	0.0170	0.0015	0.07		
Passenger cars and LDV											
	Gasoline	1.44	0.20	0.08	0.00	-	0.0518	0.0068	0.07	0.0111	0.09
Lorries											
	3,5-7,5 t.	0.83	0.95	0.69	0.09	0.004	0.0300	0.0455	0.65		
	7,5-16 t.	0.83	2.06	0.69	0.17	0.004	0.0300	0.0455	0.65		
	16-32 t.	0.92	3.35	0.47	0.15	0.004	0.0300	0.0639	0.41		
	> 32 t.	0.92	4.96	0.47	0.16	0.004	0.0300	0.0639	0.41		
	Total	0.89	3.46	0.53	0.15	0.004	0.0300	0.0589	0.47		
Buses		0.95	4.21	0.40	0.15	0.004	0.0300	0.0901	0.31		
Lorries and buses	Total	0.90	3.56	0.51	0.15	0.004	0.0300	0.0633	0.45		

* Benzene emission factors are not determined by the COPERT III emission model but by invert calculations by the OSPM model based on air quality measurements.

2010		Cold emission factors (g/km)									Beta factors		
		CO	NO_x	VOC	Particulates	Benzene*	CH_4	NMVOC	VOC-RL	VOC-total	Beta CO	Beta NO_x	Beta VOC
Passenger cars													
	Conventional	27.56	2.18	3.08	0.00	0.51	0.14	2.94	0.07	3.15	0.23	0.23	0.23
	Catalyst	13.87	0.45	0.35	0.00	0.20	0.01	0.34	0.01	0.36	0.11	0.09	0.09
	Gasoline total	14.19	0.49	0.42	0.00	0.21	0.01	0.40	0.01	0.43	0.11	0.10	0.09
	Diesel	0.46	0.49	0.11	0.07	0.06	0.01	0.10			0.11	0.10	0.09
Light duty vehicles (LDV)													
	Conventional	31.40	3.32	4.21	0.00	0.58	0.33	3.88	0.07	4.28	0.23	0.23	0.23
	Catalyst	13.92	0.70	0.79	0.00	0.19	0.02	0.77	0.01	0.80	0.12	0.10	0.09
	Gasoline total	15.26	0.90	1.05	0.00	0.22	0.04	1.01	0.01	1.06	0.13	0.11	0.10
	Diesel	0.53	1.04	0.16	0.16	0.07	0.00	0.16			0.13	0.11	0.10
Passenger cars and LDV													
	Gasoline	14.23	0.51	0.44	0.00	-	0.02	0.42	0.01	0.44	0.11	0.10	0.09
Lorries													
	3,5-7,5 t.	0.83	0.95	0.69	0.09	0.004	0.05	0.65					
	7,5-16 t.	0.83	2.06	0.69	0.17	0.004	0.05	0.65					
	16-32 t.	0.92	3.35	0.47	0.15	0.004	0.06	0.41					
	> 32 t.	0.92	4.96	0.47	0.16	0.004	0.06	0.41					
	Total	0.89	3.46	0.53	0.15	0.004	0.06	0.47					
Buses		0.95	4.21	0.40	0.15	0.004	0.09	0.31					
Lorries and buses	Total	0.90	3.56	0.51	0.15	0.004	0.06	0.45					

* Benzene emission factors are not determined by the COPERT III emission model but by invert calculations by the OSPM model based on air quality measurements.

2015		Hot emission factors (g/km)									
		CO	NO_x	VOC-exh.	Particulates	Benzene*	N_2O	CH_4	NMVOC	VOC-RL	VOC-total
Passenger cars											
	Conventional	7.42	2.04	1.27	0.00	0.18	0.0050	0.0643	1.20	0.0907	1.36
	Catalyst	0.95	0.09	0.02	0.00	0.02	0.0530	0.0026	0.02	0.0091	0.03
	Gasoline total	1.01	0.11	0.03	0.00	0.02	0.0525	0.0032	0.03	0.0098	0.04
	Diesel	0.28	0.36	0.04	0.02	0.05	0.0270	0.0029	0.04		
Light duty vehicles (LDV)											
	Conventional	11.13	3.07	1.90	0.00	0.27	0.0060	0.1500	1.75	0.0907	1.99
	Catalyst	1.37	0.11	0.04	0.00	0.02	0.0530	0.0040	0.03	0.0091	0.05
	Gasoline total	1.42	0.12	0.05	0.00	0.02	0.0528	0.0048	0.04	0.0095	0.06
	Diesel	0.25	0.79	0.05	0.03	0.04	0.0170	0.0007	0.05		
Passenger cars and LDV											
	Gasoline	1.02	0.11	0.03	0.00	-	0.0526	0.0032	0.03	0.0098	0.04
Lorries											
	3,5-7,5 t.	0.62	0.61	0.55	0.04	0.004	0.0300	0.0361	0.51		
	7,5-16 t.	0.62	1.32	0.55	0.09	0.004	0.0300	0.0361	0.51		
	16-32 t.	0.69	2.09	0.36	0.07	0.004	0.0300	0.0480	0.31		
	> 32 t.	0.69	3.10	0.36	0.07	0.004	0.0300	0.0480	0.31		
	Total	0.67	2.16	0.41	0.07	0.004	0.0300	0.0448	0.36		
Buses		0.74	2.73	0.31	0.14	0.004	0.0300	0.0690	0.24		
Lorries and buses	Total	0.68	2.25	0.39	0.08	0.004	0.0300	0.0482	0.35		

* Benzene emission factors are not determined by the COPERT III emission model but by invert calculations by the OSPM model based on air quality measurements.

2015		Cold emission factors (g/km)									Beta factors		
		CO	NO_x	VOC	Particulates	Benzene*	CH_4	NMVOC	VOC-RL	VOC-total	Beta CO	Beta NO_x	Beta VOC
Passenger cars													
	Conventional	20.93	2.20	2.81	0.00	0.51	0.14	2.67	0.07	2.88	0.23	0.23	0.23
	Catalyst	10.91	0.29	0.18	0.00	0.19	0.01	0.17	0.01	0.18	0.08	0.06	0.06
	Gasoline total	11.01	0.31	0.20	0.00	0.20	0.01	0.19	0.01	0.21	0.08	0.06	0.06
	Diesel	0.46	0.42	0.10	0.05	0.08	0.01	0.09			0.08	0.06	0.06
Light duty vehicles (LDV)													
	Conventional	31.40	3.32	4.21	0.00	0.76	0.33	3.88	0.07	4.28	0.23	0.23	0.23
	Catalyst	11.15	0.38	0.44	0.00	0.19	0.01	0.43	0.01	0.45	0.08	0.07	0.06
	Gasoline total	11.26	0.40	0.46	0.00	0.19	0.01	0.45	0.01	0.47	0.08	0.07	0.06
	Diesel	0.40	0.92	0.11	0.11	0.07	0.00	0.11			0.08	0.07	0.06
Passenger cars and LDV													
	Gasoline	11.02	0.31	0.21	0.00	-	0.01	0.20	0.01	0.22	0.08	0.06	0.06
Lorries													
	3,5-7,5 t.	0.62	0.61	0.55	0.04	0.004	0.04	0.51					
	7,5-16 t.	0.62	1.32	0.55	0.09	0.004	0.04	0.51					
	16-32 t.	0.69	2.09	0.36	0.07	0.004	0.05	0.31					
	> 32 t.	0.69	3.10	0.36	0.07	0.004	0.05	0.31					
	Total	0.67	2.16	0.41	0.07	0.004	0.04	0.36					
Buses		0.74	2.73	0.31	0.14	0.004	0.07	0.24					
Lorries and buses	Total	0.68	2.25	0.39	0.08	0.004	0.05	0.35					

* Benzene emission factors are not determined by the COPERT III emission model but by invert calculations by the OSPM model based on air quality measurements.

2020		Hot emission factors (g/km)									
		CO	NO_x	VOC-exh.	Particulates	Benzene*	N_2O	CH_4	NMVOC	VOC-RL	VOC-total
Passenger cars											
	Conventional	-	-	-	-	-	-	-	-	-	-
	Catalyst	0.79	0.07	0.01	0.00	0.02	0.0530	0.0014	0.01	0.0091	0.02
	Gasoline total	0.79	0.07	0.01	0.00	0.02	0.0530	0.0014	0.01	0.0091	0.02
	Diesel	0.28	0.32	0.04	0.02	0.05	0.0270	0.0027	0.04		
Light duty vehicles (LDV)											
	Conventional	-	-	-	-	-	-	-	-	-	-
	Catalyst	1.12	0.05	0.02	0.00	0.02	0.0530	0.0022	0.02	0.0091	0.03
	Gasoline total	1.12	0.05	0.02	0.00	0.02	0.0530	0.0022	0.02	0.0091	0.03
	Diesel	0.23	0.73	0.03	0.02	0.04	0.0170	0.0004	0.03		
Passenger cars and LDV											
	Gasoline	0.80	0.07	0.01	0.00	-	0.0530	0.0015	0.01	0.0091	0.02
Lorries											
	3,5-7,5 t.	0.55	0.45	0.49	0.03	0.004	0.0311	0.0324	0.46		
	7,5-16 t.	0.55	0.98	0.49	0.05	0.004	0.0311	0.0324	0.46		
	16-32 t.	0.62	1.54	0.32	0.04	0.004	0.0311	0.0428	0.27		
	> 32 t.	0.62	2.28	0.32	0.04	0.004	0.0311	0.0428	0.27		
	Total	0.61	1.60	0.36	0.04	0.004	0.0311	0.0400	0.33		
Buses		0.65	1.95	0.27	0.16	0.004	0.0300	0.0600	0.21		
Lorries and buses	Total	0.61	1.65	0.35	0.06	0.004	0.0310	0.0429	0.31		

* Benzene emission factors are not determined by the COPERT III emission model but by invert calculations by the OSPM model based on air quality measurements.

2020		Cold emission factors (g/km) CO	NO$_x$	VOC	Particulates	Benzene*	CH_4	NMVOC	VOC-RL	VOC-total	Beta factors Beta CO	Beta NO$_x$	Beta VOC
Passenger cars													
	Conventional	-	-	-	-	-	-	-	-	-	-	-	-
	Catalyst	9.00	0.22	0.09	0.00	0.19	0.00	0.09	0.01	0.10	0.05	0.05	0.05
	Gasoline total	9.00	0.22	0.09	0.00	0.19	0.00	0.09	0.01	0.10	0.05	0.05	0.05
	Diesel	0.45	0.38	0.09	0.04	0.09	0.01	0.08			0.05	0.05	0.05
Light duty vehicles (LDV)													
	Conventional	-	-	-	-	-	-	-	-	-	-	-	-
	Catalyst	9.11	0.19	0.24	0.00	0.19	0.00	0.24	0.01	0.25	0.05	0.05	0.05
	Gasoline total	9.11	0.19	0.24	0.00	0.19	0.00	0.24	0.01	0.25	0.05	0.05	0.05
	Diesel	0.36	0.86	0.08	0.08	0.07	0.00	0.08			0.05	0.05	0.05
Passenger cars and LDV													
	Gasoline	9.01	0.22	0.10	0.00	-	0.00	0.09	0.01	0.10	0.05	0.05	0.05
Lorries													
	3,5-7,5 t.	0.55	0.45	0.49	0.03	0.004	0.03	0.46					
	7,5-16 t.	0.55	0.98	0.49	0.05	0.004	0.03	0.46					
	16-32 t.	0.62	1.54	0.32	0.04	0.004	0.04	0.27					
	> 32 t.	0.62	2.28	0.32	0.04	0.004	0.04	0.27					
	Total	0.61	1.60	0.36	0.04	0.004	0.04	0.33					
Buses		0.65	1.95	0.27	0.16	0.004	0.06	0.21					
Lorries and buses	Total	0.61	1.65	0.35	0.06	0.004	0.04	0.31					

* Benzene emission factors are not determined by the COPERT III emission model but by invert calculations by the OSPM model based on air quality measurements.