Air4EU

Air Quality Assessment for Europe: from local to continental scale

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Assessment of non-exhaust PM by road traffic in urban areas

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LIST OF AIR4EU PARTNERS

Partic. no.	Participant name	Participant short name	Country
1	Netherlands Research Organisation	TNO	NL
2	Norsk Institut for Luftforskning	NILU	NO
3	Aristotle University Thessaloniki	AUT	GR
4	University of Stuttgart	IER	DE
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12	Gemeentewerken Rotterdam	GW	NL
13	Milieudienst Rijnmond	DCMR	NL
14	City of Oslo, Public Health Authority	OPHA	NO

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LIST OF CONTRIBUTORS

Steiner Larssen	NILU	
Ranjeet Sokhi	University of Hertfordshire	
Nutthida Kitwiroon	University of Hertfordshire	
Thomas Pregger	University of Stuttgart	
Ulrike Kummer	University of Stuttgart	
Fabio Nussio	City of Rome	
Sef van Elshout	City of Rotterdam	

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1. Executive Summary

A method, developed in the European Topic Centre Air Quality and Climate Change project "Street Emission Ceilings" (SEC), was used to assess non-exhaust emissions of PM (PM_{10} and $PM_{2.5}$) by road traffic. The method applies hourly monitoring data of NO_x and PM collected at an urban background location and an inner-urban road. The hourly contribution of traffic emissions to NO_x and PM concentrations was estimated from the monitoring data. Subsequently, the ratio of the measured increment PM/NO_x was compared with the ratio of calculated exhaust emissions of road traffic in the street based on local traffic flow data and emission factors. A higher ratio of the measured increments indicates the contribution of non-exhaust emissions. For Rome and Rotterdam, non-exhaust emission factors from literature were applied additionally in order to analyse if the expected contribution of non-exhaust processes can be confirmed. The SEC method is illustrated for annual data in Rome, London, Oslo and Rotterdam. In line with the results of the SEC project, the contribution of non-exhaust emissions of traffic is of the same order as exhaust emissions and mainly consists of $PM_{2.5\text{-}10}$ particles. Due to the use of studded tyres in the winter in Oslo (and other Nordic cities), in early spring the non-exhaust contribution of PM exceeds an order of magnitude average emissions.

2. Case study description

2.1 Background

PM_{10} air quality limit values are frequently exceeded, especially, in streets in urban areas: EEA, 2006 [1]. This underlines that traffic is an important local source for PM_{10} (and $PM_{2.5}$) emissions. Monitoring is hardly feasible to assess air quality in all relevant streets and therefore, monitoring is often combined with (street canyon) modelling. These models require emission factors for PM as input parameter. Traffic emits both exhaust and non-exhaust PM. The former is relatively well defined in emission inventories, e.g. HBEFA [2] or COPERT III [3] but the latter involves non-controlled friction processes (e.g. brake lining and tire wear) and re-suspension of road dust. Non-exhaust emissions depend on traffic intensity, road type and meteorology, which vary in different cities in Europe. It has been recognized in consultation with the city partners in Air4EU, that it is important for city authorities to assess the contribution of non-exhaust emissions. This contribution is one of the main local PM sources that they in principle have a possibility to control.

2.2 Aim and description

In co-operation with the cities of Rome, London, Oslo and Rotterdam, a method has been demonstrated to estimate the non-exhaust contribution of PM by road traffic in urban areas. The method was developed in European Topic Centre Air Quality and Climate Change project Street Emission Ceilings (SEC): EEA, 2004 [4] and applied by research in northern European countries: Tonnesen, 2005 [5] and Ketzel et. al. 2005 [6]. Increments (i.e. differences between street and urban background concentrations) of PM and NO_x, and their ratio are calculated using hourly monitoring data. The increment ratio PM/NO_x is compared with the ratio of PM/NO_x traffic emissions. *Emission factors based on HBEFA and COPERT only refer to exhaust emissions of PM and hence non-exhaust is initially being neglected in the emission ratio*. From the difference between measured and emitted PM/NO_x ratios the non-exhaust contribution of PM can be estimated. Subsequently, emission factors for non-exhaust PM from several published studies were applied to fit the measured data in Rome. The result is a demonstration of a city-specific evaluation of emission factors for non-exhaust PM emissions caused by urban traffic. The method was applied in Rome, London, Oslo and Rotterdam.

2.3 Relevance to recommendations in Air4EU

Recommendations on "monitoring" presented in the Air4EU-D6.2 report [14] on spatial assessment in urban areas (Part II) and at local scale (Part III) are relevant for this case study. Because it concerns the assessment of non-exhaust PM emissions by monitoring PM and NO_x at a station pair: one urban background station and one traffic station. The following basic requirements and best practices on monitoring are especially relevant:

- *Network design*; It is recommended to locate, the urban background station and the traffic station in the same area, to enhance the use of the data. An *urban background* station should have less than 2500 vehicles per day within a radius of 50 m and direct influence up-wind from industrial sources should be avoided. A *traffic* station should represent a road/street length of 100 meters or more and located at least 25 m from street junctions. It is important to describe the location of the station in terms of distance from the kerb (maximum at 10 m), the distance between the facades on each side of the street and the height of the facades;
- *Monitoring methods*; It is recommended to measure PM_{10}, $PM_{2.5}$ and NO_x It is recommended to use automated (reference) methods with a hourly time averaging. *Traffic data* should be monitored in the streets where monitoring stations are located. The traffic parameters should include average speed and number of vehicles per hour in each of several types: personal vehicles, light duty and heavy duty vehicles, and buses.
- *Data quality control and assurance (QAQC);* It is recommended that both stations meet data quality objectives and QA/QC requirements, as specified in the Directive. The monitoring instruments should be of the same type at both stations. If not, it must be shown that the reproducibility of instruments at both locations is better than 10%.

3. Methodology

In this case study, data from the cities of Rome, Rotterdam and London were analysed, while results from the city of Oslo were developed within the Street Emission Ceiling (SEC) project and utilised here in this report. In Rome and Rotterdam only PM_{10} data was available, while in London and Oslo both $PM_{2.5}$ and PM_{10} data were available. Basically, the method consists of the following steps:

- collect hourly monitoring data of PM_{10}, $PM_{2.5}$ and NO_x both at an urban background site and at a traffic location;
- carry out careful data quality control of the data and ensure that the time series of the two stations must be compatible (start and end time, number of hours);
- compute for each hour the street increment of PM_{10}, $PM_{2.5}$ and NO_x;
- distinguish two separate datasets for weekend and working days;
- calculate for each hour the ratio of PM_{10}/NO_x and $PM_{2.5}/NO_x$ from both datasets and calculate the annual diurnal average for increments ratios PM_{10}/NO_x and $PM_{2.5}/NO_x$;
- prepare graphs of the increments, as average annual variation;
- based on emission factors for the traffic flow/vehicle composition in the street in question, calculate annual average PM_{10}/NO_x and $PM_{2.5}/NO_x$ for weekend and working days and compare these emission ratios with the increment ratios of the monitoring data.

4. Results

4.1 Traffic at monitoring sites in Rome, London, Oslo and Rotterdam

Rome; The urban background site in Rome is located in the Villa Ada, a park in the centre of Rome. The traffic site is in Magna Grecia a few kilometres from Villa Ada. Magna Grecia is a typical “street-canyon” with residential buildings on both side with an average height of about 15 - 20 m. In 2003, the daily average traffic volume in Magna Grecia was 35.000 in weekend days with an average speed of 40 km/h and 38.000 during working days with an average speed of 20 km/h. The fleet composition is: (except for two-wheelers) 75% private or passenger cars, 18% and 7% light and heavy duty trucks (working days) and 87% private cars, 10% light and 3% heavy duty trucks (weekend). In addition, the number of 2-wheelers is in the range of 15-20% of the number of private cars. The city of Rome also provided information on the fuel composition and age of the car fleet in Rome, which has been used to estimate the emissions in Magna Grecia.

London; Marylebone Road is selected as a roadside station and had the following hourly datasets available: PM_{10}, $PM_{2.5}$ and NO_x and traffic information. It is characterized as a street canyon roadside station and is situated in central London with traffic flows of over 80,000 vehicles per day on three lanes each way. In 2004, the fleet composition was 83.8% car and light duty and 13.8% heavy duty and 2.4% 2-wheelers (working days), 91.2% car and light duty and 7.3% heavy duty and 1.5 % 2-wheelers (weekend). Average speed of the traffic is about 40 km/h. Bloomsbury station was chosen as a representative urban background station. It is located in Russell Square Gardens in central London. In contrast to other urban background monitoring stations, Bloomsbury is located nearest to the Marylebone Road, with approximately 2 km distance to the East.

Oslo; The urban background station and the traffic station constituted a station pair for the main 5-lane highway road road ‘Trondheim Road’ (National road no. 4) entering Oslo from North-East. There are scattered buildings and open areas near the road (no street canyon). The stations are located within the urban area of Oslo. The traffic station is located about 6 meters from the nearest traffic lane of the highway. The urban background station was established especially for this study, about 200 m from the main roads, and is well representative as background for the traffic site. The average daily traffic was counted at the site, and was 40,500 vehicles per day during the study period, with a 6,7 % heavy duty fraction and very few 2-wheelers. Data on composition of the heavy duty fraction and on age distribution is available.

Rotterdam; The urban background site in Rotterdam is located in Schiedam, which is located a few kilometres from the traffic site at Bentinckplein. Bentinckplein is also a typical “street-canyon” similar to Magna Crecia with an average height of the residential buildings of about 10-15 m. In 2005, the average traffic volume in Bentinckplein was 28.500 during working days. The fleet composition is 94% (private cars), 2,5% (light duty), 1,5% (heavy duty) and 2% (buses) during working days.

In order to analyse the results of the case study, the following aspects should be considered: traffic locations in Rome and Rotterdam are comparable as far as the traffic volume and physical aspects are concerned. However, the fleet composition in Rome is more dominated by heavy duty vehicles plus 2-wheelers, as compared to Rotterdam, London and Oslo. In London, the traffic volume is a factor two larger than in the other cities. In Oslo, the traffic station concerns a highway, contrary to Rotterdam, Rome and London with street-canyons.

4.2 Increments of NO_x and $PM_{2.5/10}$

Following the step-wise approach, results in increments (*difference between concentration at traffic station versus urban background*) of NO_x and $PM_{2.5/10}$ concentrations at the traffic sites in Rome, Rotterdam, Oslo and London. Examples are presented in Figure 1-4.

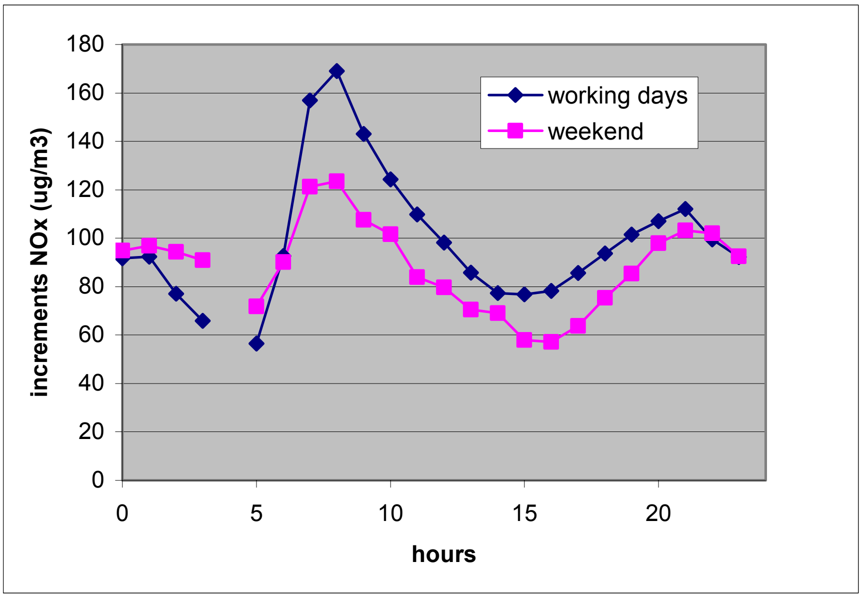

Figure 1A: <u>Rome;</u> Annual diurnal average of hourly increments in Magna Grecia street in 2003 for NO_x during working and weekend days.

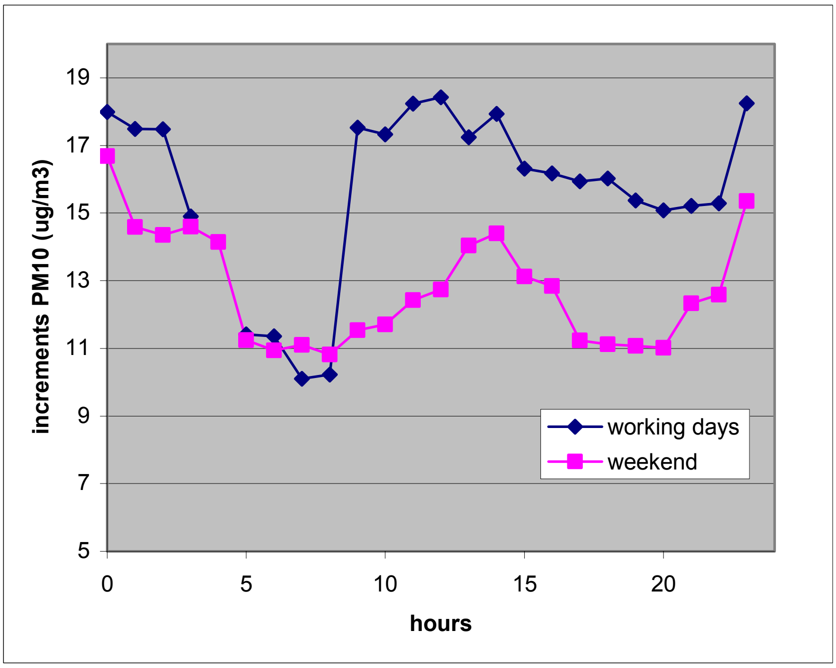

Figure 1B: Similar as Figure 1A for PM_{10}.

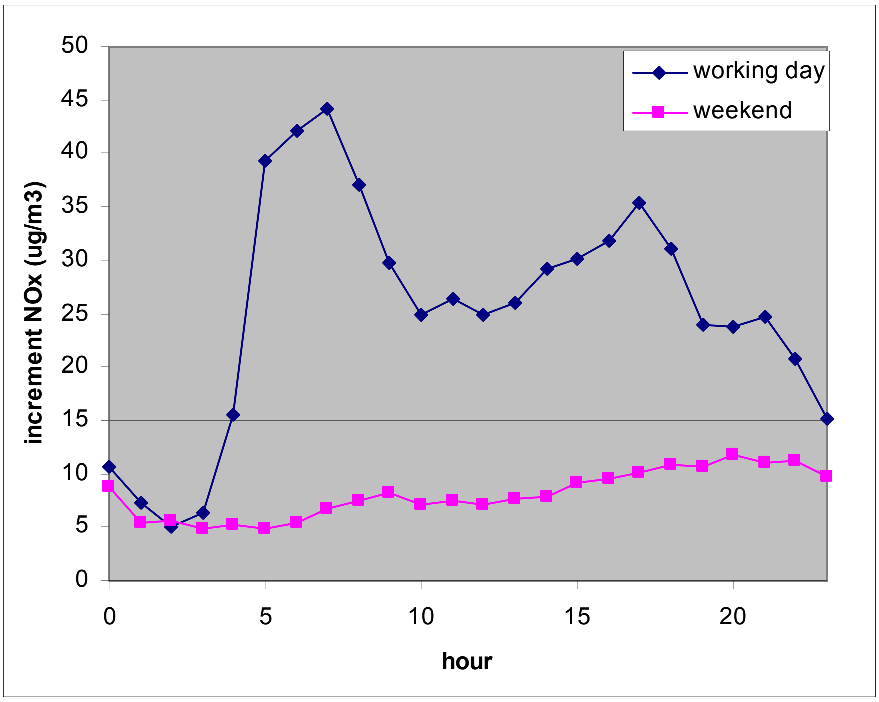

Figure 2A: Rotterdam; Annual diurnal average of hourly increments in Bentinckplein street in 2005 for NO_x during working days and weekend.

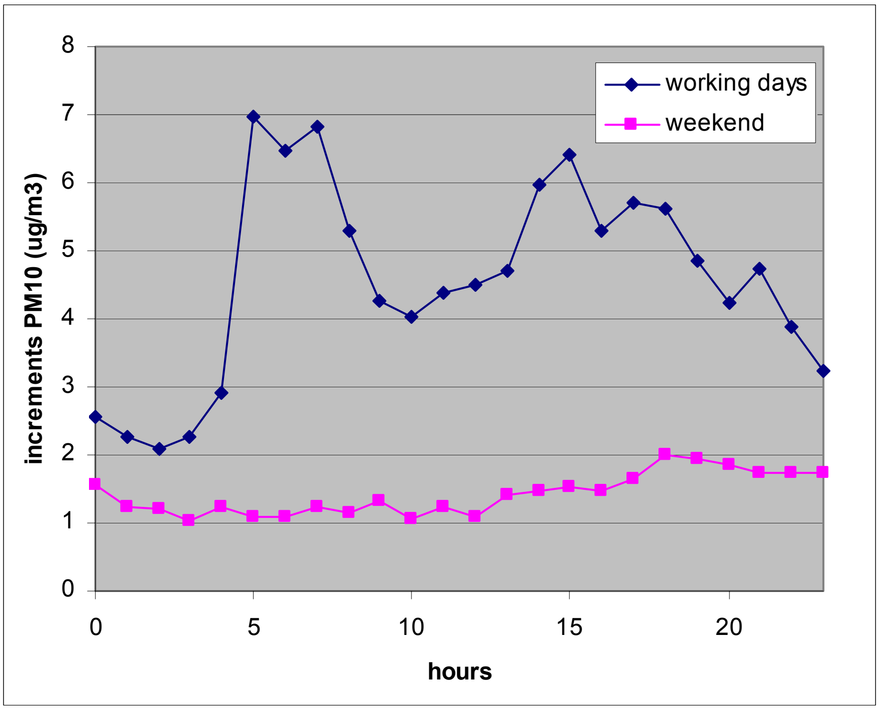

Figure 2B: Similar as Figure 2A but for PM_{10}.

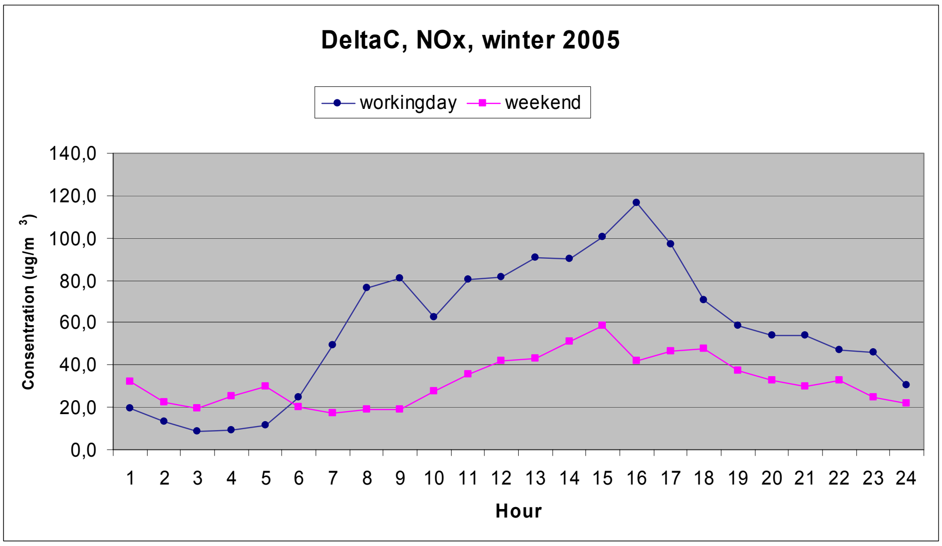

Figure 3A: Oslo; Annual diurnal average of hourly increments in Oslo in the winter 2005 for NO$_x$ *during working days and weekend.*

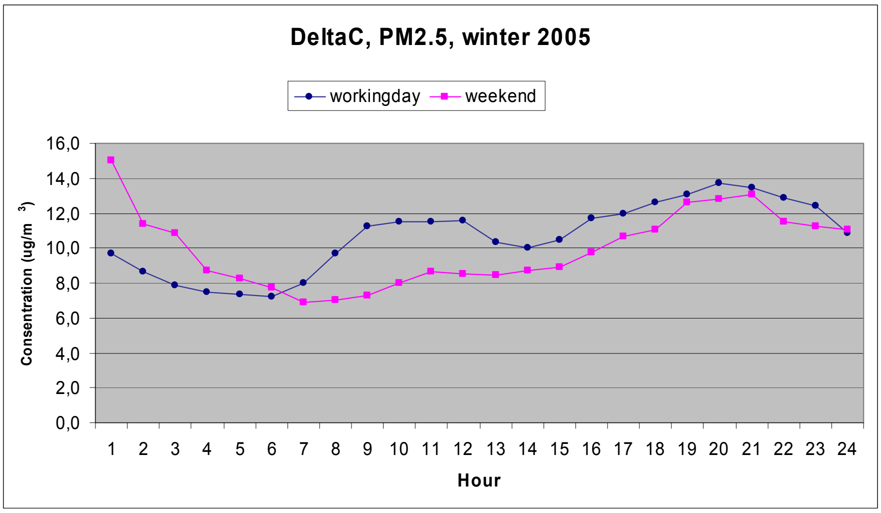

Figure 3B: Similar as Figure 3A but for PM$_{2.5}$*.*

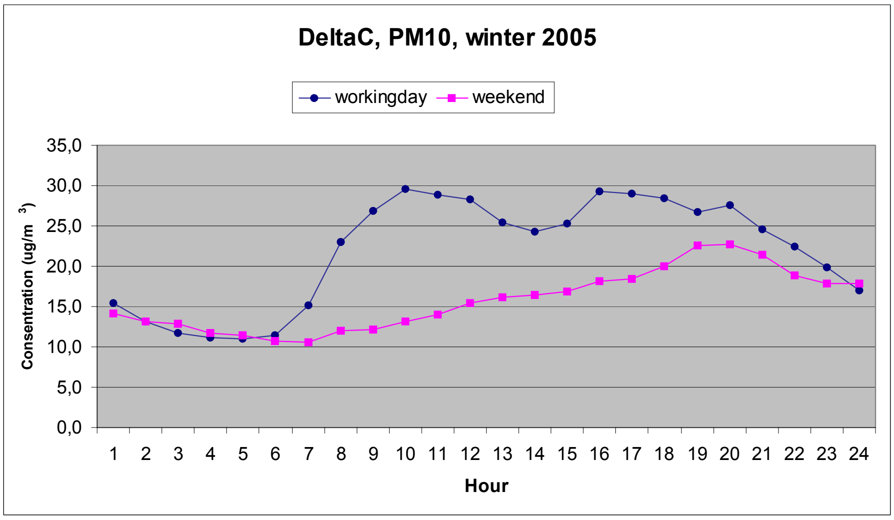

Figure 3C: Similar as Figure 3A but for PM_{10}.

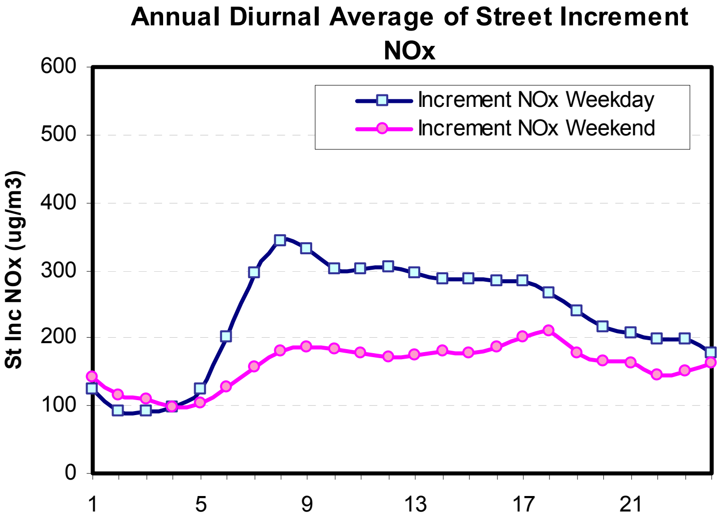

Figure 4A: London; Annual diurnal average of hourly increments in Marylebone Road street in 2004 for NO_x during working and weekend days.

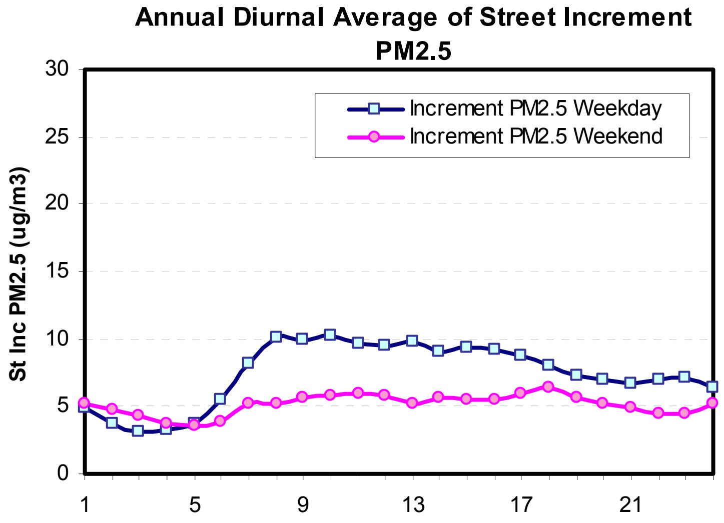

Figure 4B: Similar as Figure 4A but for PM2.5.

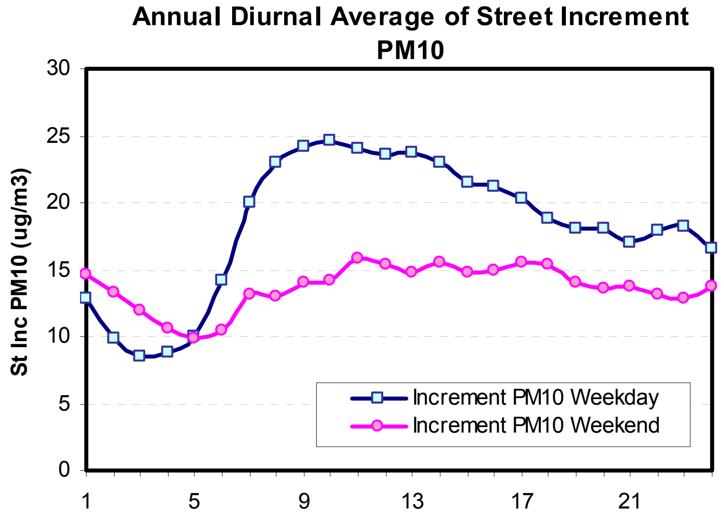

Figure 4C: Similar as Figure 4A but for PM_{10}.

Increments of NO_x and PM in Figures 1-4 illustrate the impact of morning and evening traffic peaks on NO_x concentrations, especially for working days. With the exception of Rome, the graphs indicate that lower traffic volume in the weekend and lower percentage of heavy duty traffic in the weekend results in lower contributions of NO_x and PM.

Differences in increments in the four cities are related to traffic volume (highest in London), fleet composition (highest fraction of heavy duty in Rome), dispersion of air pollution (highest around the highway in Oslo), meteorology (wind speed and rainfall) and monitoring period (only winter period in Oslo, while in the other cities an annual period).

4.3 Increments of measured ratio PM/NO_x

In order to eliminate the effect of traffic volume and dispersion on the increments of PM and NO_x in Figure 1-4, the ratio of these increments for PM and NO_x have been calculated. The results for the annual diurnal average in the four cities are shown in Figure 5-8.

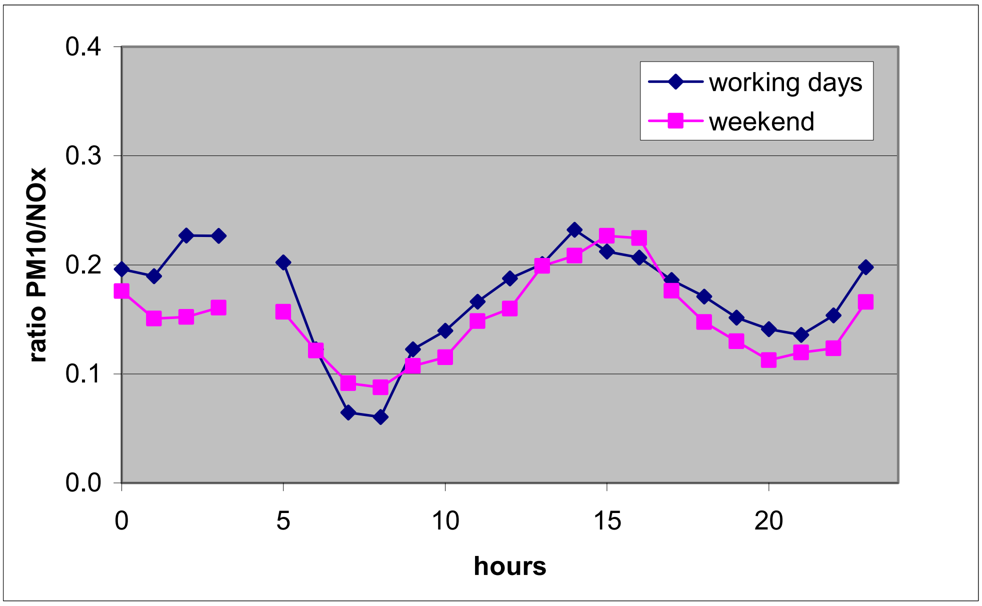

Figure 5: Rome; Annual diurnal average of hourly increments in Magna Grecia street in 2003 for PM_{10}/NO_x during working and weekend days.

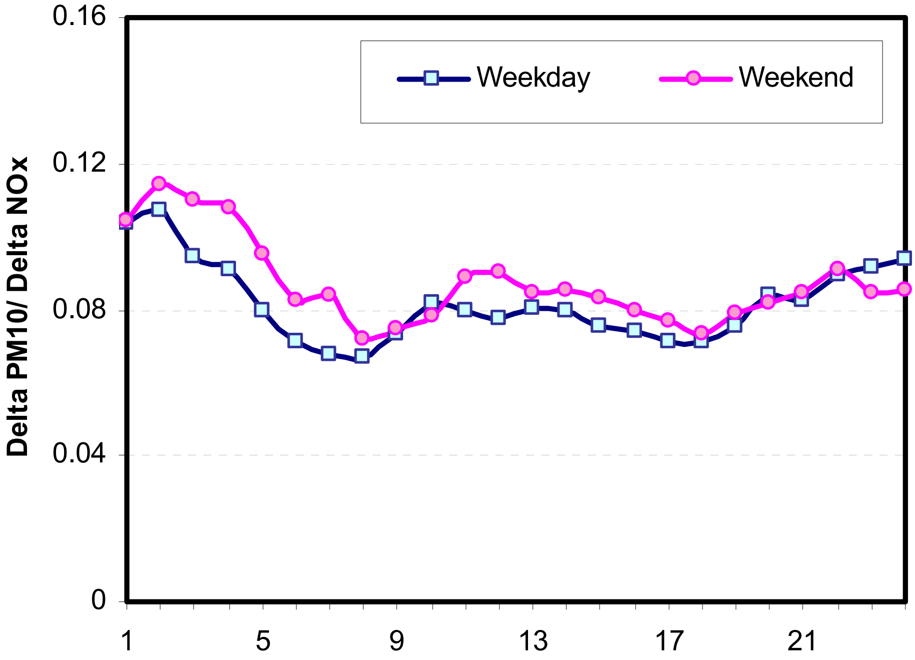

Figure 6A: London; Similar as Figure 5 but for Marylebone Road in 2004.

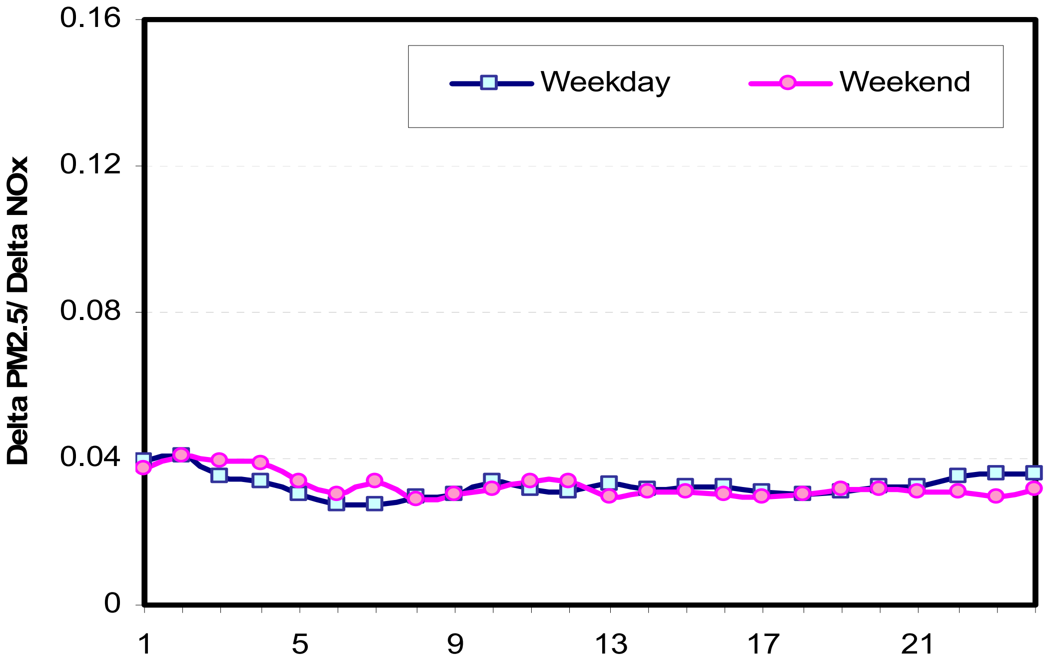

Figure 6B: London; Similar as 6A but for $PM_{2.5}/NO_x$.

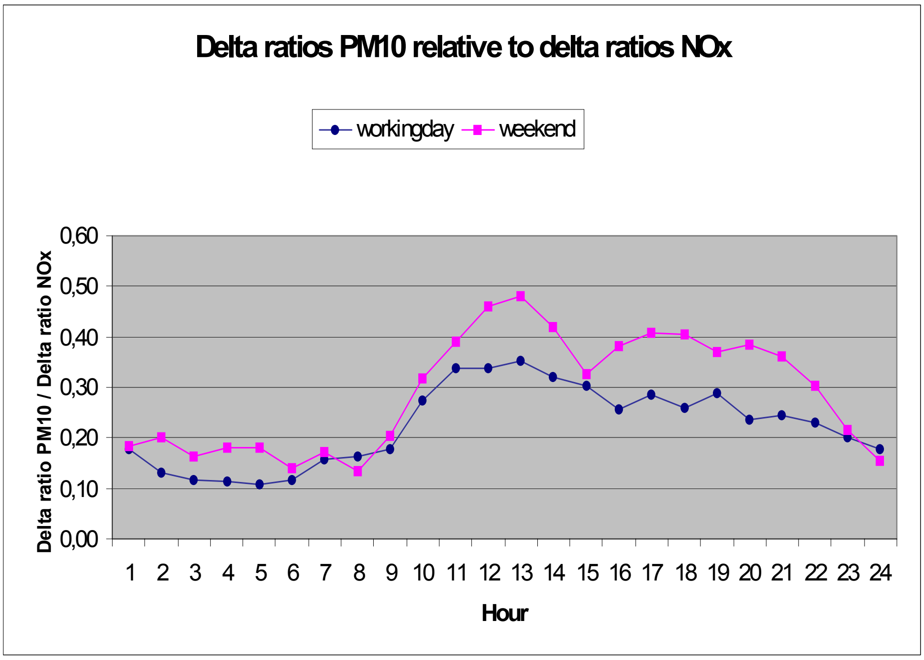

Figure 7A: Oslo; Similar as Figure 5 but for PM_{10} in winter 2005.

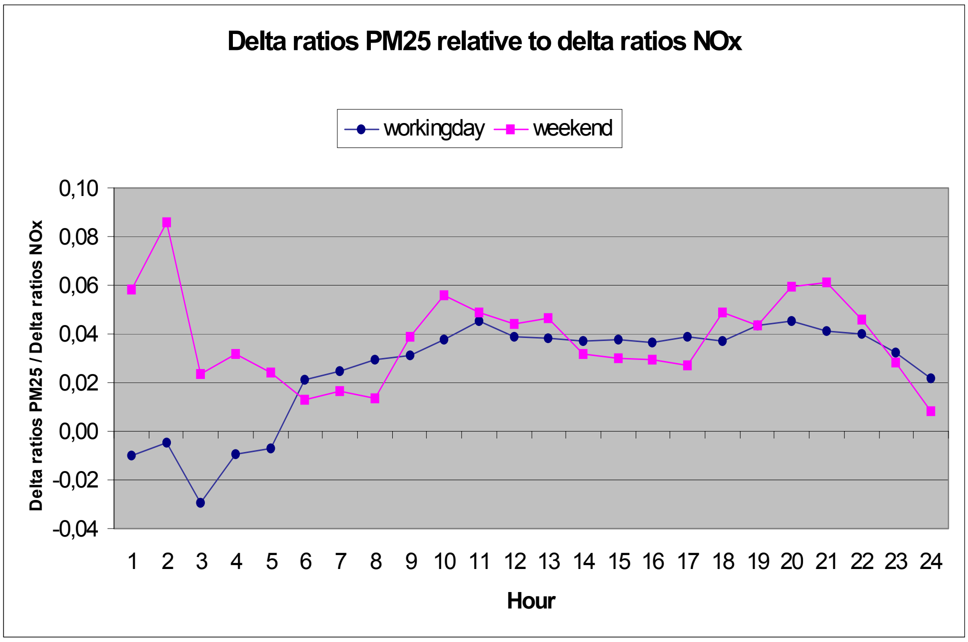

Figure 7B: Oslo; Similar as 7A but for $PM_{2.5}$.

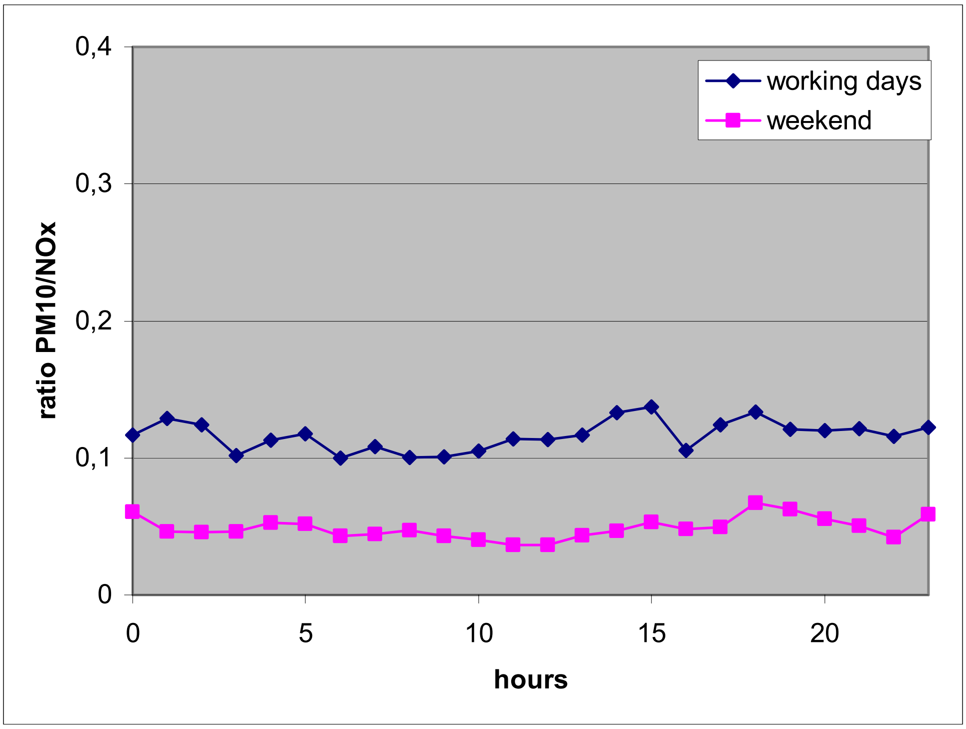

Figure 8: Rotterdam; Similar as Figure 5 but for Bentinckplein street in 2004.

The increments of the ratio PM_{10}/NO_x in Figure 5-8 indicate that the ratio PM_{10}/NO_x emitted by local traffic varies between 0.1 – 0.2 in Rome and 0.1 – 0.4 in Oslo for both weekend and working days, while 0.08 in London for both weekend and working days. In Rotterdam the ratios vary between 0.05 (weekend) and 0.1 (working days). The increments of the ratio of **$PM_{2.5}$**/NO_x in London (Figure 6B) and in Oslo (Figure 7B) are almost a factor 4 and a factor 2 lower than the ratio **PM_{10}**/NO_x in London and Oslo, respectively. As exhaust emissions of PM are mainly $PM_{2.5}$, the larger ratios of PM_{10}/NO_x as compared to $PM_{2.5}$/NO_x indicate a non-exhaust source of PM_{10} emissions. This is further discussed in the next section on increments of emitted PM/NO_x.

4.4. Increments of measured and emitted ratio PM/NO_x

From the traffic flow data, IER-Stuttgart calculated the emission ratio PM/NO_x for Rome using HBEFA [2] and COPERT III [3] emission factors (with additional assumptions for PM from gasoline cars, and a PM_{10} size factor of 0.99 for diesel engines), while in Rotterdam and London national emission factors were applied (see also Section 4.5). *It is noted that these emission factors only involve exhaust-pipe emissions and concern average urban traffic flow not considering the effects of stagnation during rush hours*. In Table 1 the results of measured and emitted ratio PM/NO_x are summarized for Rome, London, Oslo and Rotterdam.

Table 1: The ratio of increments PM/NO_x of monitoring data and exhaust pipe emission factors in Magna Grecia (Rome; 2003), Marylebone Road (London; 2004); highway (Oslo; winter 2005) and Bentinckplein (Rotterdam; 2005).

	Measured ratio PM_{10}/NO_x		Measured ratio $PM_{2.5}$/NO_x		Emitted ratio exhaust PM^*/NO_x
	Weekend	Working	Weekend	Working	
Rome	0.15	0.17	-	-	0.05
London	0.08	0.08	0.03	0.03	0.05
Oslo (winter)	0.40	0.30	0.04	0.04	0.03
Rotterdam	0.05	0.12	-	-	0.05

*: Exhaust emissions are measured as PM (without distinction in particle size), but actually only concern $PM_{2.5}$.

Table 1 illustrates that the *measured* ratio PM_{10}/NO_x is in the order of a factor 2 (Rotterdam and London) and a factor 3 (Rome) larger than the *emitted* ratio PM/NO_x. This indicates an additional source of PM_{10} than exhaust emissions such as re-suspension of road dust and friction processes. In Oslo even a factor 10 is encountered but Oslo is a special case due to the use of studded tyres in Nordic countries in the winter period. The lower measured ratio PM_{10}/NO_x during the weekend in Rotterdam shows the importance of heavy duty traffic (trucks and buses) for non-exhaust emissions, as in the weekend in Rotterdam the number of heavy duty trucks is practically zero and the number of buses is reduced.

Table 1 also shows that the measured ratio $PM_{2.5}$/NO_x is in the same order as the ratio of emitted PM/NO_x of urban traffic. This illustrates that exhaust emissions are mainly $PM_{2.5}$ and hardly any $PM_{2.5-10}$. It also shows that non-exhaust emissions is mainly in the size range of $PM_{2.5-10}$.

4.5 Assessment of non-exhaust PM_{10} emissions

In the following, non-exhaust emissions for Rome were calculated based on literature data in order to verify, if abrasion processes and re-suspension of road dust may be responsible for the difference in PM/NO_x ratio between concentration increments and traffic emissions. The focus is on non-exhaust PM_{10} as in the current EU legislation involves limit values for PM_{10}. Application of PM_{10} emission factors including both non-exhaust and exhaust emissions were used to fit the traffic data with the monitoring data.

For Rome, exhaust emission factors were selected according to the driving situation from HBEFA and COPERT III. Additional PM_{10} emission factors for gasoline cars were taken from literature (values applied: 24 mg/km for pre-Euro passenger cars, 4.2 mg/km for Euro passenger cars, 23.8 mg/km for pre-Euro light duty vehicles, 4.6 mg/km for Euro light duty vehicles, 59.4 for 2-stroke motorcycles and 10.2 for 4-stroke motorcycles). Non exhaust emission factors were derived for tyre wear (Gebbe et al.; 1997 [7] and Rauterberg-Wulff; 1998 [8]), brake wear (Garg et al.; 2000 [9]) and road dust suspension (Duering et al.; 2005 [10], Gehrig et al.; 2003 [11], and a modified formula based on EPA; 2003 [12] and Venkatram; 2000 [13]).

As non-exhaust emissions from re-suspension depend on a number of different parameters a commonly accepted emission factor data set applicable at a large range of different situations does not exist. The measured German and Swiss emission factors for re-suspension may lead to an underestimation of PM_{10} emissions in Rome, probably due to different meteorological factors and different road and traffic conditions. The resulting PM_{10}/NO_x ratio is between 0.10 and 0.13 applying these values. In addition, a modification of the US-EPA AP-42 model for paved road emissions was applied using plausible model constants for usual road conditions derived from [13] and assumptions for the model variables in urban areas. The purely statistical US-EPA model is based on the observed correlation between measured emission factor (e.g. by tracer or upwind/downwind measurements) and possible explanatory variables such as silt loading and vehicle weight. Even the modified US EPA model seems to rather overestimate re-suspension in Rome (PM_{10}/NO_x ratio 0.18-0.25).

In Rome, assuming emission factors of 100 mg/km for PC/LDV and 550 mg/km for HDV, an emission ratio of 0.145 to 0.184 results, similar to the monitored PM_{10}/NO_x ratio of 0.15 to 0.17. It has to be noted, that an emission factor of 100 mg/km for private cars/light duty vehicles is relatively high compared to available values from literature and can e.g. not be confirmed by measurements in Germany and Switzerland. Therefore additional studies of the local conditions in Rome are necessary taking into account e.g. silt load, humidity, mineral fraction of traffic related PM_{10} emission/increments near the monitoring station and the additional measurement of $PM_{2.5}$ concentration and the $PM_{2.5}/NO_x$ ratio. If there is not such an indicator for actually high non-exhaust contributions an emission factor of 100 mg/km is rather not plausible and the analysis shows that there might be an additional significant PM source influencing the PM_{10}/NO_x ratio of the Magna Grecia station. Obviously, the relatively large number of two-wheelers and the uncertainty about there actual emissions may be part of this explanation. The uncertainty of tyre and brake wear emission factors might contribute as well to an underestimated PM_{10}/NO_x ratio. Used emission factors for non-exhaust PM_{10} are to be found in Table 2. Further information on non-exhaust emissions and emission factors can be found in the AIR4EU Milestone Report 6.4.

In Rotterdam, including the Dutch national emission factors for non-exhaust emissions only increased the ratio PM_{10}/NO_x from 0.05 to 0.07. As compared to the measured value of 0.12 for working days this indicates that non-exhaust emissions are underestimated in the Netherlands. The reason is that non-exhaust only comprises tyre wear and friction processes and *no* re-suspension is included in non-exhaust emissions in the Netherlands. Re-suspension is regarded a too erratic process that no reliable emission factor can be established as function of traffic volume, fleet composition, speed, road type and meteorological conditions.

Table 2a: PM_{10} Non-exhaust emission factors [mg/km] used for the case study in Rome (brake/tyre wear plus re-suspension on urban roads).

	Data source	**PC**	**LDV**	**HDV**	**MC**
Tyre wear	[7], [8]	6	12	31	3
Brake wear	[9]	3	5	8	3
Suspension of road dust	[10]	41		410	15**
Suspension of road dust	[11]	54		540	15**
Suspension of road dust	[12], [13]*	160			

* assumed value for road surface silt load (PM_{75}) = 0,18 g/m^2, assumed average weight of vehicle fleet = 1,65 t, model constants: k=0.18, p=0.52, b=2.14

** assumption

Table 2b: PM_{10} Non-exhaust emission factors [mg/km] used for the case study in Rotterdam (brake/tyre wear and re-suspension on urban roads).

	Data source	**PC**	**LDV**	**HDV**
Tyre and brake wear	*	10		70
Suspension of road dust	*	-		-

* Dutch National Environmental Agency (2000): In the Netherlands, re-suspension of PM_{10} is *not* modelled as there are large uncertainties about the effect of traffic intensity, fleet composition, type of road, impact of meteorology etc. on re-suspension.

Table 3: Results of emission calculations for PM_{10}/NO_x Magna Grecia street in the year 2003.

	Data source	PM_{10}/NO_x ratio (weekend/working)
Exhaust	HBEFA [2]	0.05/0.05
Exhaust	COPERT III [3]	0.05/0.08
Sum	HBEFA [2], [7], [8], [9], [10]	0.12/0.10

5. Conclusion and discussion

5.1 Assessment of the case study

The case study in Rome, London, Oslo and Rotterdam on the assessment of non-exhaust emissions of $PM_{10/2.5}$ demonstrate the applicability of the methodology earlier developed in the Street Emission Ceiling project. Earlier findings were confirmed that non-exhaust emissions mainly consist of $PM_{2.5\text{-}10}$, while exhaust emissions are $PM_{2.5}$. Presently, non-exhaust emissions are in the same order as exhaust emissions in urban areas with the exception of Nordic countries where studded tyres in early spring result in additional high PM_{10} emissions. More specific conclusions:

- *Rome;* The results indicate that in Rome non-exhaust emissions of traffic are significantly higher than in Rotterdam and London. This may be caused by a number of factors: a relatively high fraction of heavy duty vehicles in the fleet composition, meteorological conditions in southern Europe and a significantly higher fraction of two-wheelers.
- *London*; The results in London underline that non-exhaust emissions mainly consist of $PM_{2.5\text{-}10}$. This finding, which is consistent with the SEC project, is probably representative for other cities in Europe.
- *Oslo;* The results in Oslo, earlier presented as part of the SEC project, illustrate the large impact of studded tyres as an additional source of non-exhaust PM_{10} emissions, especially in spring time. Due to this effect, annual non-exhaust emissions in Nordic countries are significant higher, compared to other European countries.
- *Rotterdam;* The results in Rotterdam illustrate the importance of light and heavy duty traffic on non-exhaust emissions by comparing data for working and weekend days. Also, the case study in Rotterdam stresses the need in the Netherlands to include re-suspension of road dust in non-exhaust emissions by road traffic in the Netherlands. However, more research is required on factors affecting re-suspension of road dust.

5.2 Improvements in assessment derived from case study

The case study demonstrates a method to assess non-exhaust emissions from road traffic in the cities of Oslo, Rotterdam, London and Rome. The case study in Air4EU stresses the importance of adequate network design and quality objectives of monitoring. The importance to monitor both PM_{10} and $PM_{2.5}$ have been shown, as exhaust and non-exhaust emissions can be best differentiated by $PM_{2.5}$ (exhaust) and PM_{10} (non-exhaust). Finally, the need to collect traffic data both for weekend and working days is underlined.

5.3 Recommendations resulting from the case study

The assessment of increments in $PM_{10}/PM_{2.5}$ and NO_x at the traffic station strongly depends on the reproducibility of the monitoring equipment applied both at the urban background station as well as at the traffic station. Adequate implementation of quality control procedures is a critical factor for this type of exercise.

A related issue is the area of representativeness of the urban background station. It is recommended to ensure that the urban background station is not influenced by local traffic, though this is considered a basic requirement (see also section 2.3).

Finally, it is recommended to perform more research on factors controlling re-suspension of road dust such as traffic volume, traffic speed, fleet composition, road type, dispersion and meteorological conditions.

5.4 Suitability for implementation in other cities

The method is simple and only needs monitoring data and (limited) traffic data (i.e. traffic volume and composition of car fleet) and emission factors available from HBEFA or COPERT emission factor data base. Any city with hourly monitoring data at an urban and a traffic station of $PM_{10}/PM_{2.5}$ and NO_x may apply the method.

6. References

1. EEA – 2006: European Environment Agency (EEA): Technical Report No1/2006: “Air pollution at street level in European cities”.

2. UBA 2004: Umweltbundesamt (UBA) Berlin (Ed.): Handbuch Emissionsfaktoren des Straßenverkehrs (Handbook Emission Factors for Road Transport (HBEFA)). INFRAS AG Bern im Auftrag von Umweltbundesamt Berlin und Bundesamt fuer Umwelt, Wald und Landschaft (BUWAL) Bern, Version 2.1, April 2004 (s. www.hbefa.net).

3. Ntziachristos, L. & Samaras, Z. 2000: COPERT III Computer Programme to calculate Emissions from Road Transport. Methodology and emission factors. EEA Technical Report No. 49, European Envi-ronment Agency (EEA) Copenhagen (s. also http://vergina.eng.auth.gr/mech/lat/copert/copert.htm).

4. EEA- 2004: European Environment Agency (EEA): Street Emission Ceilings Phase 2 subreport: “Report on Data Analysis and comparison with Emissions Estimates.

5. Tonnesen, D. 2005: Emission model for roadside emissions of PM_{10}. In Proceedings 5th International Conference on Urban Air Quality; Valencia 2005.

6. Ketzel, M.; Omstedt, G;.Johansson, C.; During, I.; Gidhagen, L.; Lohmeyer, A.; Berkowicz, R. and Wahlin, P. 2005: Estimation and validation of PM2.5/PM10 exhaust and non-exhaust emission factors for street pollution modeling. In Proceedings 5th International Conference on Urban Air Quality; Valencia 2005.

7. Gebbe, Hartung & Berthold 1998: Quantifizierung des Reifenabriebs von Kraftfahrzeugen in Berlin. ISS-Fahrzeugtechnik, TU Berlin, report for Senatsverwaltung fuer Stadtentwicklung Berlin (D).

8. Rauterberg-Wulff, A. 1998: Beitrag des Reifen- und Bremsenabriebs zur Rußimmission an Straßen. Dissertation am Fachgebiet Luftreinhaltung der TU Berlin.

9. Garg, B.D., Cadle, S.H., Mulawa, P.A., Groblicki, P.J. 2000: Brake Wear Particulate Matter Emissions. Environ. Science and Technology, Vol. 34 (21), pp 4463-4469.

10. Duering, I. et al 2005: Emission factors for vehicle induced non exhaust PM. Paper presented at 14th International Symposium Transport and Air Pollution, 1-3 June 2005, Graz (A).

11. Gehrig, R., Hill, M., Buchmann, B., Imhof, D., Weingartner, E., Baltensperger, U. 2003: Verifikation von PM10-Emissionsfaktoren des Straßenverkehrs. Final report Eidgenoessische Materialpruefungs- und Forschungsanstalt (EMPA) and Paul Scherrer Institut (PSI), Forschungsprojekt ASTRA 2000/415. July 2003 (www.empa.ch/plugin/template/empa/700/5750/---/l=1).

12. EPA 2003: United States Environmental Protection Agency (EPA): Compilation of Air Pollutant Emission Factors. AP-42, Fifth Edition, Vol. I: Stationary Point and Area Sources, Section 13.2.1. Paved Roads. Office of Air Quality Planning and Standards, Washington (USA).

13. Venkatram, A. 2000: A Critique of Empirical Emission Factor Models: a Case Study of the AP-42 Model for Estimating PM10 Emissions from Paved Roads. Atmospheric Environment, Vol. 34(1), pp 1-11.

14. Air4EU-D6.2: Final recommendations for AQ assessment

    Part I: Overview and structure

    Part II: Spatial assessment in urban areas

    Part III: Spatial assessment at local/hot spot scale

    Part IV: Spatial assessment at regional/continental scale