SPECIFIC NO AND NO_2 EMISSIONS FROM A WIDE RANGE OF CURRENT AND FUTURE LD AND HD VEHICLES IN URBAN DRIVING CONDITIONS

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ABSTRACT

Despite efforts and success of NO_x reduction from vehicle engines by means of emission legislation NO_2 concentrations in busy urban traffic areas have not decreased any more.

A research of primary NO_x, NO and NO_2 emissions was made to evaluate source contribution of different vehicle categories to concentrations in urban air. The study comprised 28 pre-Euro to EEV city buses of model years 2000 - 2008, 8 trucks conforming Euro 4 emission limits, and 14 current diesel and gasoline passenger cars representing a cross-section of the current fleet in Finland. The light duty vehicles were of model years 1986 - 2007. Vehicles were run using real urban driving cycles dedicated and tailored to each engine category. NO and NO_2 were monitored on-line over transient cycles.

For the passenger cars both specific and vehicle number weighted NO_x emissions were the highest for gasoline vehicles without TWC. These currently represent 10 % of the Finnish LD in-use fleet. For primary NO_2 the evildoer is as straightforward. The share of new LD diesel vehicles with powerful oxidising catalysts and/or diesel particulate filters is already high, and increases rapidly. These are the most prominent sources of direct NO_2 from LD city traffic. Both NO_x and NO_2 emissions from the passenger cars were elevated even more as the cars were driven using a realistic rush hour driving cycle instead of warm ECE15 cycle, showing 40 % and 44 % increase, respectively. As for HD NO_x emission, g/km, the highest emitters were, as expected, mainly the Euro 2 & 3 buses, in Braunschweig and other city cycles. There were, however, also model year 2006-07 Euro 4 & EEV vehicles among the high NO_x emitters. For NO_2 several Euro 4 & EEV buses and trucks emitted 30 - 60 % NO_2 shares. NO and NO_2 emissions for HD buses, in g/km, are very dependent on the way of urban driving due to highly variable travel speed of the cycles, e.g. Braunschweig, NYBus, WTVC or Helsinki city. With the year 2007 fleet, in streets with high shares of public traffic, over 90 % of both direct NO_x and NO_2 is HD originating, due to the very high, 10 to 50 times higher, emission levels of HD vehicles compared to passenger cars. For NO_2's part the situation has, however, started to change with the fast increasing number of new diesel passenger cars. Conclusively, as regards amounts of direct NO_2 emissions, there are two problematic groups among new vehicles, both LD and HD: diesel vehicles fitted with an oxidizing catalyst and/or a particulate filter.

Keywords: *Emission factor, nitrogen oxide, nitrogen dioxide, real-world driving, light duty, heavy duty, urban environment.*

1. BACKGROUND AND INTRODUCTION

NO_2 episodes of city air have been studied more systematically since 1990's. In general, only at the beginning of 21st century it has been realised that air quality in city centres and the NO_x emissions of current and new vehicles are not necessarily improving in respect of NO_2, in parallel with development of vehicles and after-treatment technology. NO_2 is an unregulated exhaust component. In some busy kerbsides in Finland direct NO_2 emissions are threatening compliance with the forthcoming air quality legislation. EU's year 2001 limit value for NO_2 in ambient air (40 ug/m^3) is to be fulfilled in 2010.

Direct NO_x emissions from vehicles have been declining since 1990's, but this is not clearly shown in the ambient levels of NO_2 in the streets anymore. Unless traffic density has increased or atmospheric chemistry changed, the reasons must lie elsewhere. One probable reason is, that as the concentration of NO_x in air falls, partitioning between NO and NO_2 changes, larger proportion of NO being oxidised to NO_2 by available O_3 [11]. The other reason is probably the increase in direct NO_2 emissions, both relative and absolute, of new vehicles. Thirdly, the LD vehicle fleet is changing favouring new diesel powered cars. There is a tremendous boom for diesel passenger cars in many European countries. The share of first registrations of diesel passenger cars in Finland was 17.3 % in 2005, 28.5 % in 2007 and 51.9 % in March 2008.

There are very few, if any, studies unveiling realistic direct NO/NO_2 emissions of comprehensive selection of vehicles relevant for today, in busy urban driving conditions. Typically the studies involve individual vehicles, certain vehicle sizes like buses or passenger cars, vehicles are driven in standard legislative mode (NEDC or respective), or they are already outdated or of limited vehicle model years [1-5]. The most comprehensive and relevant by age work as regards passenger car emissions has been published by [8], and of HDVs by [9]. Due to the fast developing vehicle techniques, Euro 4 came into force late in 2005 and 2006, work [7] is also deficient. General conclusions of the technical developments in after-treatment device on NO_2 problem is made by [10]. There is also a recent summary concerning the new particulate trap concepts for London TfL bus fleet, the emission test of which were conducted over a dedicated real-world, hot-start Millbrook London transport bus cycle (MLTB) for a set of Euro 3 buses with retrofitted DPF/SCR+DPF and Euro 4 with SCR [11]. Another in-use compliance programme in 2005 for Euro2 to 3 for CRT retrofitted HDVs plus two OEM filters is published by [11]. Comprehensive literature surveys of sources and effects of mobile source NO_2 are made by Sjödin [31] and Defra [11]. Significance of primary NO_2 from traffic is analysed in [12-14].

In this study the role of current urban vehicle fleet on direct NO_2 emissions was analysed. Issues of high importance for understanding the causes for local (increased) NO/NO_2 concentrations in street environments are the inclusion of (a) a representative vehicle set, (b) a realistic driving pattern for emission measurements. In our survey a total of 50 city buses, trucks and passenger cars of pre-Euro to Euro 5/EEV emission levels were analysed using dedicated urban driving cycle for each vehicle group. Specific NO_2 and NO_x emissions were measured for the passenger cars and HD trucks and buses, and vehicle category (age, fuel, after-treatment) weighed emission factors were determined for passenger cars.

2. EXPERIMENTAL

The studied fleet included 28 buses of Euro 2 to EEV emission level, 14 passenger cars of pre-Euro 1 to Euro 5, and 8 trucks of Euro 4 with no after-treatment device, with OEM catalysts or with commercial retrofitted catalysts. There were different driving patterns for city buses, trucks in delivery service or in long-range transit and for passenger cars in city traffic during busy driving hours. For emissions of the vehicles this real driving in city, highways or motorways was simulated on a chassis-dynamometer.

The passenger cars were of model years 1986 - 2007. The oldest gasoline vehicles were without exhaust after-treatment, the newest LD vehicles had either lean direct injection technique for gasoline or DPF with post injection regeneration for diesel. All LD vehicles were of medium or small size, **Table 1**. The break-down of the passenger car test fleet, as well as their respective shares among registered cars in Finland at the end of year 2006 are also shown in **Table 1**. In vehicle category weighed emission calculations only vehicles less than 18.5 years old were taken into account. This is the average service time of both gasoline and diesel passenger cars in Finland. Therefore, excluded were 1/3 of older than 10 years old diesel vehicles and 54 % of gasoline vehicles without catalyst in **Table 1**. It was estimated that in 2007 1 % of the LD fleet were both the newest lean-burn gasoline cars and the newest DPF equipped diesel passenger cars.

Table 1: Passenger cars for urban NO_2 and NO_x emission study

	GASOLINE					DIESEL				
	# in tests	Techniques of the period	Displacement dm^3	Year	Percentage of LD registered %	# in tests	Techniques of the period	Displacement dm^3	Year	Percentage of LD registered %
OLD > 10 v	2	carburettor, no aftertreatment 1- or MPi inj., no aftertreatment TWC (from 1991)	1.6 2	1986 1990	**22** (no cat) **16** (TWC)	1	IDI no aftertreatment	2	1989	**7**
MEDIUM AGED 5 - 10 v	1	stoichiometric TWC (lean burn GDI)	1.3	1997	**20**	1	TD +EGR TDI+EGR+ox cat	1.9	1995	**7**
NEW < 5 v	1	stoichiometric TWC FSI, GDI lean burns FSI stoichiom. direct inj. (< 3 a)	1.4	2006	**21**	2	commonrail DI+ox cat+EGR TDI+ox cat+EGR	1.9	2004, 2005	**6**
BRAND-NEW < 1 v	1 1	FSI stoichim., direct inj. PFI stoichiom. + TWC FSI lean burn CNG + TWC	1.4 1.8	2007 2007	**1** (estimate)	4	cDPF and FBC+DPF Bluetec/D-Kat (DPF+NOx reduction) cDPF (intelligent engine cntrl)	1.6 - 2.0	2006-08	**1** (estimate)

Comparative emission tests for the light duty vehicles were made from warm engine driving according to UDC cycle and from a real crowded street driving pattern constructed from repeated city driving during rush hours in Helsinki, **Figure 1**.

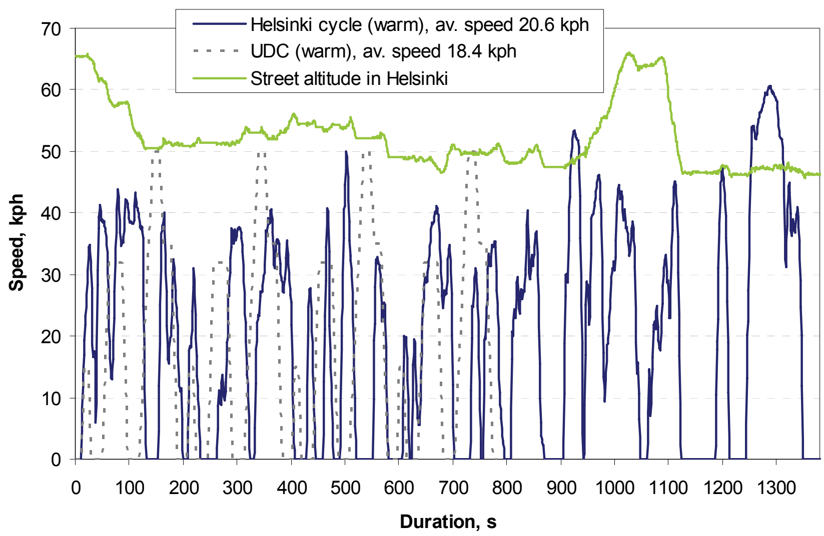

Figure 1: Busy traffic driving cycle for passenger cars in Helsinki

Emissions for buses were monitored in most cases by application of the oldest and most commonly used city bus cycle in Europe "Braunschweig City Driving Cycle", using warm engine and bus mainly at 50 % nominal load. Some individual tests have been performed using other warm city cycles like ECE15, Ademe (Paris downtown), Orange county city cycle (California), WTVC (worldwide transient vehicle cycle, targeted as a global standard), Nybus (New York city) and Helsinki city specific cycles like Hel 1, Hel 3 and Jokeri. As these cycles have different driving and travel speeds, they also yield different emission factors (**Figure 2**); which is also due to different engine and exhaust temperatures. The average driving speeds of the main cycles used varied between 18 - 27 km/h. The speeds of Nybus and WTVC are at extremes, 6 and 40 km/h, respectively, and their results were not included within emission factors; some results of Ademe (11 km/h) for comparison.

Real truck driving patterns were obtained from delivery driving in suburbs, in highway and in motorway with warm engine. Speed, road gradient of the pathway and vehicle loading were taken into account. Results represent average driving in the previous, and are more or less typical of relatively fast suburb driving.

NO and NO_x specific emissions and emission factors from HD vehicles were calculated from continuous measurements from the CVS tunnel (vol-ppm, diluted gas), CLD analyser was used for NO and NO_x monitoring, either in parallel or from consecutive tests. NO and NO_x emissions of LD vehicles were calculated from the continuously measured raw exhaust concentrations using 3 parallel CLD measurement systems of raw emission (vol-ppm, 2 for NO_x, 1 for NO). When converting NO volume share to an emission factor [mg/km] mass multiplication factor for $NO \rightarrow NO_2$ was taken into account.

3. RESULTS

3.1. Primary emissions of the fleet

The direct tailpipe emissions of NO_2 and NO_x of the studied population of vehicles are in **Figure 2**. Vehicles are organised according to the rising absolute NO_2 per g/km. Percentage figure above the bar is the share of NO_2 of NO_x. From engine technology and after-treatment point of view it might be reasonable to organize the results according to (rising) NO_2 share, instead, which has been customary in many previous researches. However, from practical and causative point of view, NO_2 emissions are at best expressed as absolute numerical values. As what ever the NO_2/NO_x ratio is, it does not reflect the actual and effective emission quantity into air, nor it is comparable due to relativity.

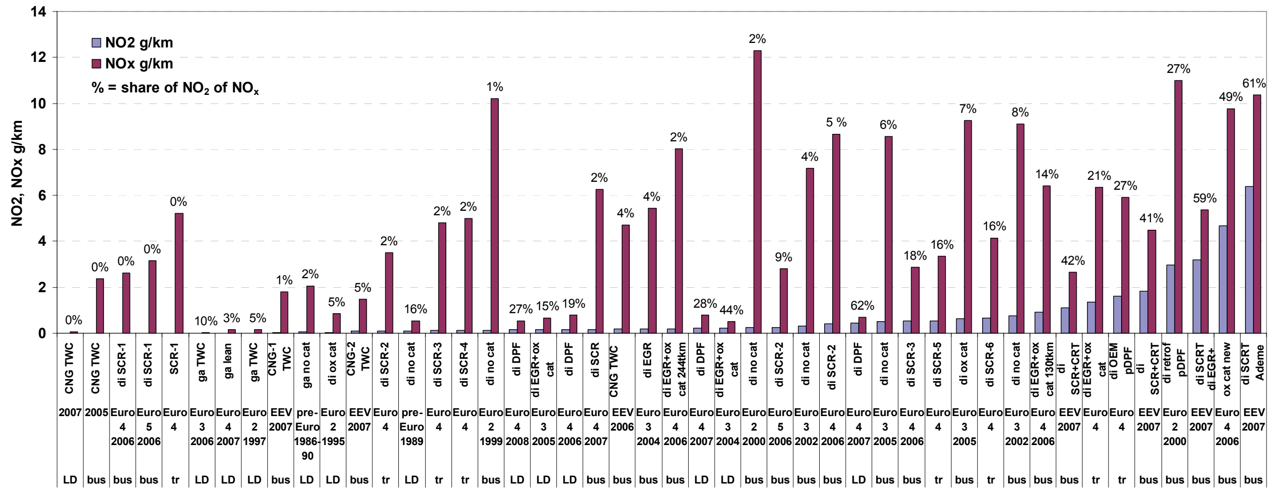

Figure 2: Absolute exhaust emissions of NO_2 and NO_x from current and future LD and HD vehicles in real city driving (trucks highway also). Percentage is the share of NO_2 of NO_x

In **Figure 2** it is seen that even though NO_x emission level decreases with legislation the same is not all true for exhaust NO_2, which it is not a controlled emission. Instead, in some cases, absolute NO_2 emissions have started to increase. This has happened after the introduction of HD Euro 2 - 4 diesel vehicles with both OEM and retrofitted oxidative after-treatment device, that is, oxidation catalysts, partial DPFs and wall-flow type traps. Even NO_x reduction device (SCR), especially associated with DPFs produced high absolute NO_2 emissions. Also among plain SCRs some showed as high as 15 - 20 % NO_2 shares. In these the NO_2 generation by oxidation may have been needed for low temperature operation. In DPFs NO_2 is needed for filter regeneration. These phenomena have come very distinctive even with Euro 4 and EEV level vehicles with the before mentioned after-treatment principles. On the other side, properly working SCR catalysts (if there are any, in the long run), CNG and gasoline with TWC yield the lowest NO_x. In Europe one trend is to optimize HD engine-out PM and remove NO_x with a catalyst like SCR. Stoichiometric CNG buses with TWC showed NO_x emissions of 1.5 - 5 g/km for 4 buses (EEV limit being 2 g/kWh). With stoichiometric combustion and TWC the level of NO_2 is, all in all, very low. With 3 homogenous lean-burn or lean-mix Euro 5/EEV CNG HD SI buses and trucks NO_x was not especially low, 5.3 - 8.8 g/km. With these lean combustion systems NO_2/NO_x proportions are also expected to be increased. Well functioning gasoline and CNG vehicles with TWCs should not pose any problems, with both low absolute NO_x and NO_2 shares.

With LD diesel vehicles the problems with oxidative OEM after-treatments related to DPFs and oxidation catalysts are the same as with HDs, but on a smaller scale. For stoichiometric SI engine passenger cars certification tests have shown, that lower than Euro 4 NO_x levels (0.08 g/km in NEDC) are achievable in the future. However, if it is a correct finding [14] that with lowering of NO_x in the atmosphere partitioning between NO and NO_2 changes, so that increase in NO_2/NO_x will be expected, the straightforward decrease of NO_2 levels in kerbside environments is not ascertained with improving engine, fuel and after-treatment technology.

In UK first attempt for determining typical NO_2 fractions for different vehicle classes (2-whl, gas/di cars, HGV, buses, gas/di LGV) and Euro classes (pre-Euro to Euro 4+) have been developed [11] from data available by early 2006. National Atmospheric Emissions Inventory in UK has also estimated the development of NO_2 share in future vehicles, and hypothesizes that the NO_2 share of LD's keeps rising fast until 2010 and exceeds 30 % by 2013, and HDVs will go down from NO_2 share of 16 % now to half 8 % by 2025 [11]. According to data of this study, the latter may still be increasing and peaking before coming down, due to the present development status retrofits, traps and combined SCR+CRTs.

3.2. LD Vehicle emissions and emission indexes

In real city driving with warm engine absolute NO_x levels of diesel passenger cars have not systematically come down, emission levels in the study varied between 0.5 - 0.8 g/km NO_x for all vehicle ages of 1989 - 2008. Instead, due to launching of oxidative and DPF after-treatment devices, NO_2/NO_x ratios have increased since Euro 3 emission legislation (year 2000) remaining on a high, 20-60 % level. In the study NO_2 shares of gasoline and diesel vehicles without (oxidative) after-treatment were typically below 10 %. When Euro 5 comes into force during 2009, DPFs will be unavoidable in diesel passenger cars.

Engine-out and exhaust gas temperatures are linked with the operation of the car, which determine the absolute NO_x, the effectiveness of exhaust gas after-treatment systems and the conversion rate to NO_2. There was a distinctive effect of driving pattern to all passenger car emissions, **Figure 3**. As NO_2 formation is temperature driven and high combustion temperatures favor low NO_2 formation, it was natural that NO_2 emissions of older diesel passenger cars decreased with the increasing intensity or dynamics of the driving cycle, UDC compared with Hki city cycle in **Figure 3**. Due to the improving activity of oxidative after-treatment systems with temperature, the situation is reversed with newer diesels having either oxidation catalyst or catalytically regenerative particle filter. The shift to higher absolute NO_2 was prominent for all these diesels. Also, those new engine techniques targeting at lowering NO_x with engine optimisation yield lower temperatures, which promote shift to high engine-out and tailpipe NO_2. This was the case with EGR, among the tested vehicles. Also the total NO_x emissions of passenger cars were higher in Helsinki busy traffic cycle than in UDC: the vehicle category weighed increase in NO_x (g/km) was 40 % and that of NO_2 44 %.

Emission measurements of model year 2004 to 2008 diesel passenger cars also provided evidence of increasing direct NO_2. These less than 5 years old Euro 3 to 4 vehicles had very high direct NO_2 percentages: 30 to 44 % for the previous and 27 to 62 % for the latter group in real warm city driving. Looking at **Figure 3** these vehicles may have a tremendous effect on direct NO_2 increase of passenger cars in years to come, when their share in fleet icreases.

With the gasoline vehicles it is notable, despite their absolute emission levels are low, that NO_2 and NO_x emission of the newest < 5 year old vehicles were strongly linked with the cycle, NO_2 concentration increased 50 - 100 % and NO_x concentration 130 - 220 % for the Helsinki city cycle, compared with UDC. The rise was most prominent for the brand new, model year 2007 lean-burn gasoline vehicle.

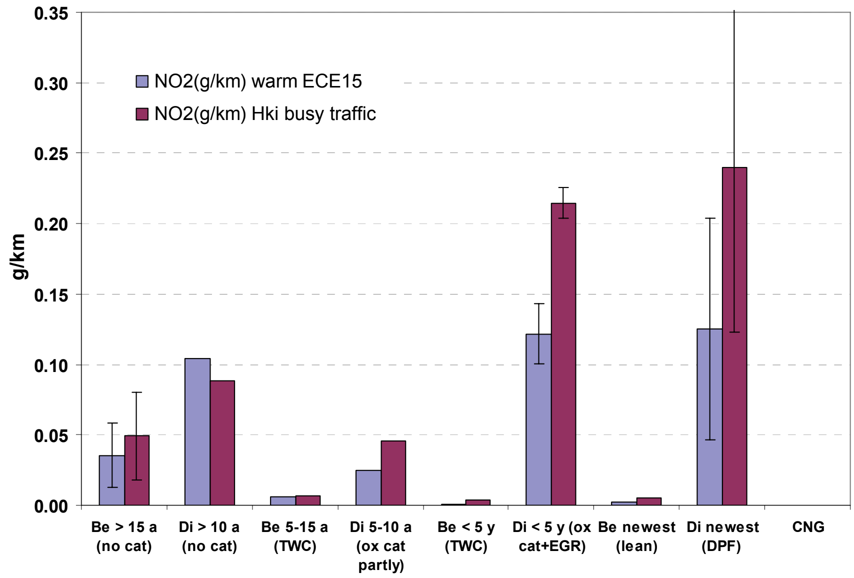

Figure 3: Specific NO_2 emissions of current light duty vehicles (n = 14) in warm city driving

Even though gasoline engines still mainly have a stoichiometric combustion system and TWC catalysts, yielding low NO_x and NO_2, it should be remembered that the introduction of leaner burn gasoline engine technologies, e.g. gasoline direct injection and stratified fuel injection (GDI, FSI), give possible implications to the exhaust NO_2/NO_x balance. In **Figure 3** the newest gasoline vehicle was of that type. Even if engine-out NO_x from SI engine may be higher than from diesel, the "purity" of the gasoline emission is until now made by the very effective TWC. However, will this continue to be true remains to be seen, as leaner combustion technologies are also associated with generation of more primary NO_2.

The relative effect of different passenger car categories on emitted NO_2 is shown in **Figure 4**. The results were obtained in at times when new diesel car sales in Finland fluctuated between 17 - 21 % during years 1999 to 2006. The calculations in **Figure 4** were based on actual in-use vehicles according to registration percentages for each vehicle type in Finland, this also shown in figure. According to **Figure 4** the 8 % fleet share of < 5 years old diesel passenger cars corresponded to 50 % of the direct NO_2 emissions from LD vehicles into ambient in 2007. In March 2008 the percentage of new registrations of diesel passenger cars was 52 % in Finland. Their contribution is expected to be even more important, as new cars are usually driven much more than older cars. Due to the very high relative NO_x as well as absolute NO_x emission of old gasoline vehicles without TWC, 2 to 6 times higher than for any diesel (**Figure 4**), they may also be problematic in congested urban areas.

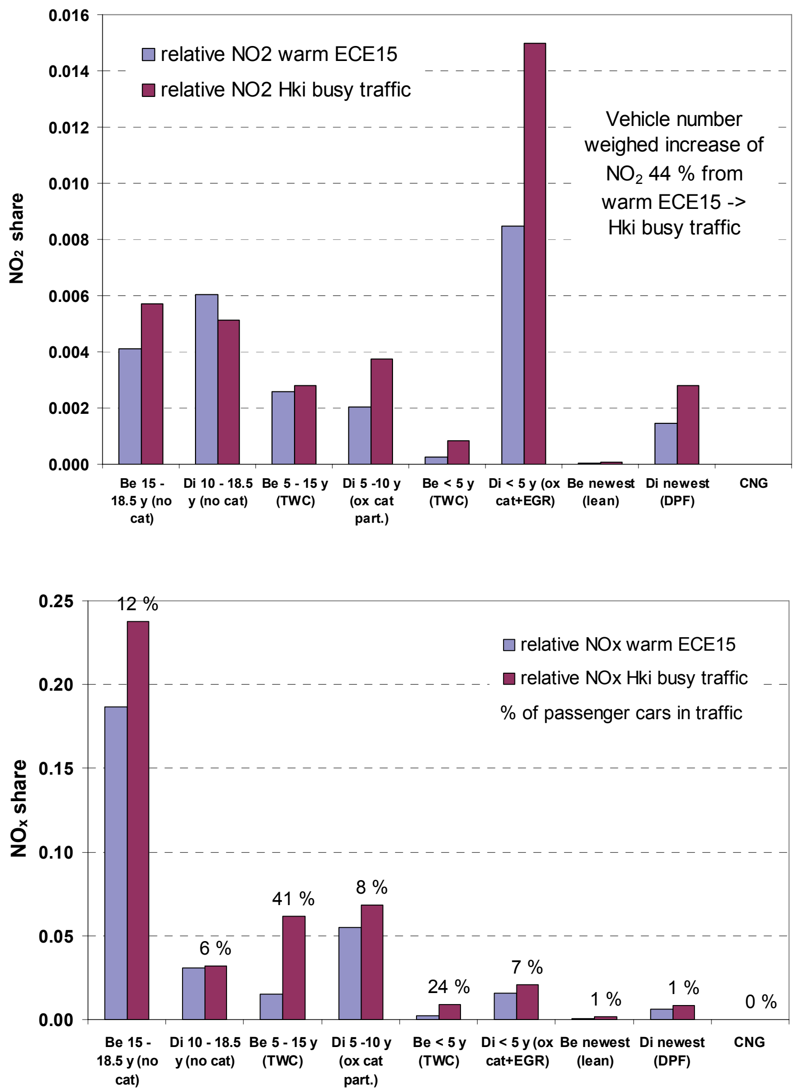

Figure 4: Vehicle number weighed relative NO_2 and NO_x emissions of current < 18.5 year old light duty fleet (n=14) in two city driving patterns

3.3. HD Vehicle emissions and emission indexes

Naturally, due to the generally higher engine output of bus and truck engines make these vehicle categories to the highest absolute emitters of both NO_2 and NO_x. In such streets where public bus (& truck) traffic is dense, the share of these vehicles can easily rise up to 20 % which makes HD category also as the major source of absolute emissions of NO_x and NO_2 into ambient air. More than 90 % of NO_x and NO_2 may be HD originated. In kerbsides where LD traffic is dominating the share of light duty vehicles may be of the order of 96-98 %. With these high percentages, according to the emission levels observed, LD vehicles give an equivalent or even larger source of direct NO_2 into air than HD buses and trucks. When looking at **Figure 2** one should also be bear in mind that all LD vehicles measured were also small or medium size passenger cars with 1.3 - 2.0 dm^3 engine displacement, and missing are larger vans and pick-ups common for delivery and maintenance service in urban areas.

Euro 4 limits for NO_x are 3.5 g/kWh for HD engines, 0.25 g/km for diesel passenger cars and 0.08 g/km for gasoline passenger cars. Certification test for HD is engine, not vehicle based. Euro 4 emission limits do not yet necessitate OEM or other diesel particulate filter to HDVs. Therefore, many vehicle makes use SCRs, which is supposed to be a more mature technology. Only in few cases increased NO_2 problem was experienced them in the study. When OEM DPFs are coming (Euro 6) the NO_2 problem with them, as seen today, will basically be the same as with retrofitted partial DPFs (PM-Kat, POC, PDPF etc.), NO_2 formation by oxidation in the cell for trapped PM regeneration. With trucks there were no systematic differences in emissions, NO_x or NO_2, as regards different driving cycles, highway, freeway or delivery cycle.

The NO_x emission factors (g/km) in **Figure 2** for heavy duty diesel buses and trucks are approximately 10 times higher than those for diesel passenger cars. The factor is much higher than what can be justified by their relative energy consumption. If these emissions are expressed as emission indexes, emission as g/kg used fuel, HD emissions are 2 to 3 times higher than those for LD. This is hypothesized be due to the concurrence and comparison of LD diesels with gasoline cars that have very low NO_x and no PM emission limits. This has resulted, relatively speaking, in much tougher emission limits for LD diesel than for HD diesel engines for vehicles. Hence, in the literature it has been reasoned that additional emission limits could be justifiable for direct NO_2 with HD [3].

Even though emission factors for HD buses were calculated from Braunschweig city cycle, it is good to remember the significance of the driving mode on results, not only due to the variations in temperatures but also the effect of speed. The effect of different city driving cycles on NO_x emissions are shown in **Figure 5**. In **Figure 2** emission factors from Braunschweig cycle for buses, truck driving in delivery and in highway and passenger car driving in busy city traffic have been compared. To be indicative the cycle should be as realistic as possible, otherwise interpretation of the results and conclusions can be misleading. As an illustration of the effect of the way of expressing results, very uniform NO_x and NO_2 emissions per time driven are shown for Nybus and WTVC cycles in **Figure 6**.

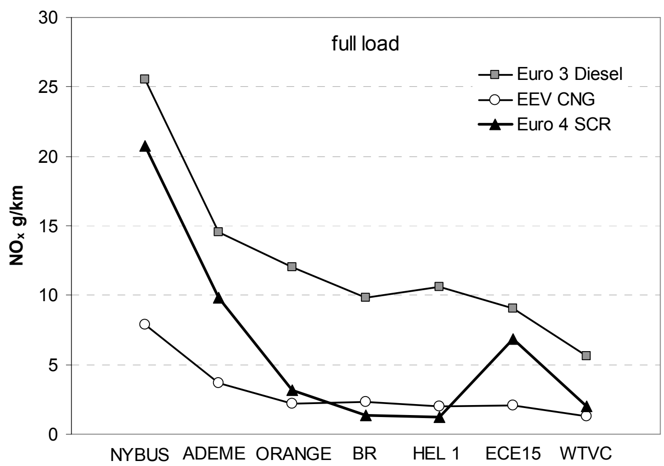

Figure 5: NO_x emissions from typical city bus driving cycles [15]. Average speed varied from 6 km/h (Nybus) to 40 km/h (WTVC). The mostly used Braunschweig cycle speed is 22 km/h

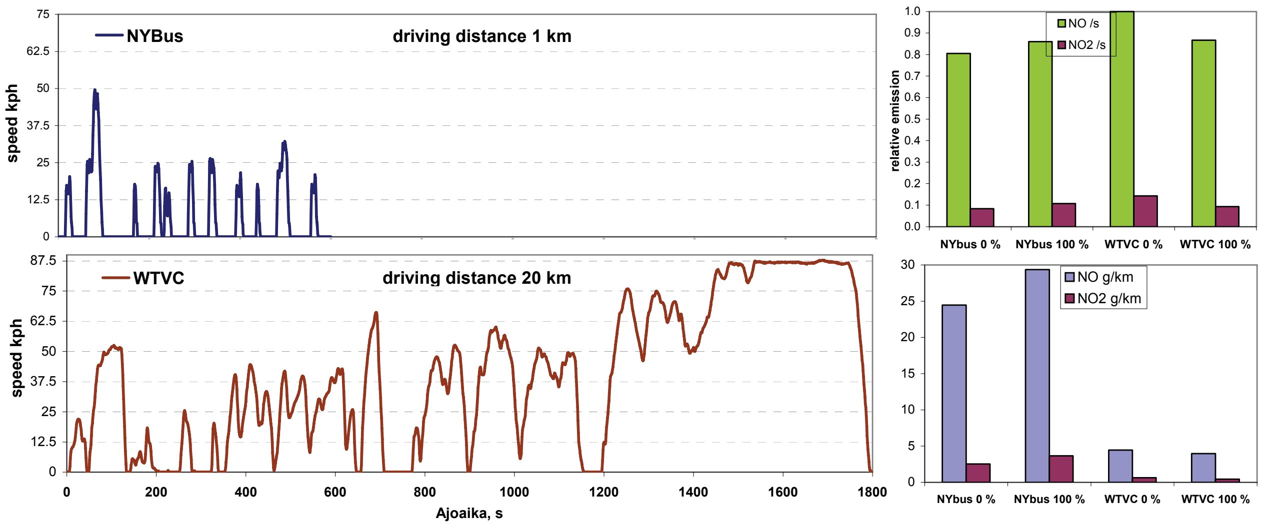

Figure 6: Emissions per second and per km in highly different city driving patterns. Euro 4 model year 2006 SCR bus. Travel speed for Nybus 5.9 km/h, speed for WTVC 40.1 km/h

4. CONCLUSIONS & SUMMARY

In the studied time-series many reasons are found for possible increase of both NO_2 share and absolute NO_2 emissions in street attainment areas. The observations may not be totally conclusive for different vehicle and after-treatment technology groups, but are quite indicative, pointing out:

a. Legislative certification and type approval tests may be too far away from reality, not realistically mimicing real driving in urban environments.

b. Decreased combustion temperatures due to EGR or leaner combustion mixtures with diesel, gasoline and CNG favour intensified NO_2 formation in the engine.

c. Inclusion of more powerful oxidative after-treatment device, some of which oxidise NO to NO_2.

d. Attractiveness of diesel in the new passenger car market; percentage in the fleet is rising.

e. Inclusion of LD and HD diesel pollution control technologies that require primary NO_2 formation to be functional (wall flow cDPFs & partial PM traps at low Ts, CRT, low T SCR reactions, even SCRT), both OEM and retrofitted.

f. Even new gasoline technologies tend to have higher NO_2 emission on busy city driving compared to certification test.

g. NO_x emissions of HD diesel engines are still very high in relation to fuel consumption compared with those of LD diesel vehicles. Currently, new HD engines are in many cases optimised for PM reduction, high NO_x is removed with after-treatment. The best results for both low absolute NO_x and low NO_2 share are associated with the maturity of the HD after-treatment technology: there are e.g. well functioning SCR catalysts for diesel (at least as new) and TWCs for CNG.

h. Decreasing NO_x emission into air favour the NO/NO_2 balance to shift towards higher NO_2 concentrations.

5. REFERENCES

[1] Soltic, P. & Weilenmann, M. NO_2/NO emissions of gasoline passenger cars and light-duty trucks with Euro-2 emission standard. Atm. Env. 37(2003)5207-5216.

[2] Karlsson, H.L. Measurement of Emissions from Four Diesel Fuelled Passenger Cars Meeting Euro 4 Emission Standards. Report MTC 5505. AVL MTC AB. 2005/10.

[3] Sjödin, Å., Pihl-Karlsson, G., Johansson, M., Forsberg, B., Ahlvik, P. & Erlandsson, L. Vägtrafikens utsläpp av kväveoxider - reglering, utsläpp och effekter. IVL Svenska Miljöinstitutet AB. Publikation B1597 (Vägverket 2004:135), 107 s.

[4] Geivanidis, S. & Samaras, S. Evaluation of the actual NO2/NOx ratio of recent vehicle technologies. Laboratory of Applied Thermodynamics. Thessaloniki. 5/04/2006.

[5] Ricardo. Emission factors for cars. Q40240/VSE Project S0135/VB. March 2003.

[6] Gense, R., Vermuelen, R. Weilenmann, M. & McRae, I. NO_2 emissions from passenger cars. 2nd Conf. Environment & Transport, Reims, France, 12-14 June 2006.Vol.1, p. 175-182.

[7] Latham, S., Boulter, P. & Barlow, T. The effects of traffic management schemes on emissions from heavy-duty vehicles. TRL Project report PR/SE/960/04. TRL. UK.

[8] Kessler, C. Niederau, A. & Scholz, W. Estimation of NO_2/NO_x relations of traffic emissions in Baden-Württemberg from 1995 to 2005. 2nd Conf. Environment & Transport, Reims, France, 12-14 June 2006.Vol.2, p. 101-105.

[9] Scholz, W. & Rabl, P. Unexpectedly low decrease of NO_2 air pollution - Correlation with ozone concentration and altered exhaust emissions. 2nd Conf. Environment & Transport, Reims, France, 12-14 June 2006.Vol.2, p. 264-269.

[10] Hörmandinger, G. The issues of NO_2 from cars: Overview of the 2006 workshop. International Conference on Transport and Environment: A global challenge, Technological and Policy Solutions, 19-21 March 2007, Milan, Italy.

[11] Trends in Primary Nitrogen Dioxide in the UK. Air Quality Expert Group. Department for Environment, Food and Rural Affairs, Scottish Executive, Welsh Assembly Govenrment & Department of the Environment in Northern Ireland. London UK. 140 p.

[12] Carslaw, D.C. & Beevers, S.D. New Directions: Should road vehicle emissions legislation consider primary NO_2? Atm. Env. 38 (2004)1233-1234.

[13] Carslaw, D.C. Evidence of an increasing NO_2/NO_x emissions ratio from road traffic emissions. Atm. Env. 39 (2005) 4793-4802.

[14] Carslaw, D.C. & Beevers, S.D. Investigating the potential importance of primary NO_2 emissions in a street canyon. Atm. Env. 38 (2004) 3585-3594.

[15] Erkkilä, K., Nylund, N-O., Clark, N. & Rideout, G. Evaluation of duty cycles for heavy-duty urban vehicles. Final Report of IEA AMF Annex XXIX. VTT Tiedotteita - Research Notes 2396. 82 p. + App. 10 p.

[x] Carslaw, D.C. Risks of exceeding the hourly EU limit value for nitrogen dioxide resulting from road transport emissions of primary nitrogen dioxide. 2nd Conf. Environment & Transport, Reims, France, 12-14 June 2006.Vol.1, p. 183-190.

[x] Lambrecht, U., Dünnebeil, F. & Höpfner, U. Findings in Germany. NO_x: Development of emissions and air quality. Causes for unexpected values of ambient concentrations of NO_2. EU level workshop on The impact of direct emissions of NO_2 from road vehicles on NO_2 concentrations, Brussels, September 19th, 2006.

[x] Kessler, C. Niederau, A. & Scholz, W. Estimation of NO_2/NO_x relations of traffic emissions in Baden-Württemberg from 1995 to 2005. 2nd Conf. Environment & Transport, Reims, France, 12-14 June 2006.Vol.2, p. 101-105.