Dr. Uwe Lahl, BMU
Udo Lambrecht, IFEU

High NO_2 Levels: Ongoing Need for Action on Diesel Emissions

Introduction

The discussion about urban air quality has been dominated in recent years by the issue of particulate matter (PM). Measures to reduce PM have been initiated and put in place on all levels. At the same time, the fact that from 2010 two air-quality limit values for nitrogen dioxide (NO_2) will have to be complied with in the EU [EU 1999] has taken something of a back seat:

- The 1-hour mean value of 200 µg/m³ – i.e. the maximum concentration of a pollutant at a monitoring station averaged over an hour – which in future may not be exceeded more than 18 times a year.
- The annual mean value of 40 µg/m.³

These values were set back in 1999 as the minimum required to protect human health.[1] Nitrogen dioxide has different effects: it can, for example, cause irritation to the mucous membranes in the respiratory tract and increase the risk of infection. NO_2 can cause poor development of the respiratory system in children and weaken their resistance to infection. In the opinion of the World Health Organisation (WHO), current research findings would justify lowering the annual mean value still further. However, since the WHO also believes that this is not yet sufficiently underpinned scientifically, their latest update to the Air Quality Guidelines do not propose any further reduction in the values at the present time [WHO 2006].

The European Commission, Council and Parliament also support this opinion. The new Air Quality Directive due to come into force in summer 2008 will therefore retain the existing air-quality limit values for nitrogen dioxide without change. Under certain conditions and in particular situations, it will also be possible to request for an extension of the deadline for compliance with the limit values until 2015 [EU 2007].

In Germany, the future 1-hour mean value was found to have been exceeded at only a small number of sites. By contrast, the future annual limit value is currently being exceeded at very many monitoring stations near traffic sources. No clear positive trend can be identified. Reduction in NO_2 concentration is therefore crucial if compliance with the limit values is to be achieved by 2010. Recent legal decisions on particulate matter have once more clearly spelt out the fact that members of the public can invoke a right to the implementation of measures to comply with limit values for particulate matter ("protection of third parties") [BVG 2007]. If limit values for nitrogen dioxide are exceeded, similar judgements are to be expected.

However, efficient reduction measures will only be possible if there is sufficient clarity about the causes of the excessively high NO_2 levels. A number of national and international studies analysing trends in emissions and ambient air quality are now available. Back in 2005, the German Federal Environment Ministry (BMU) organised a meeting of experts from the research community, civil service and industry to discuss current findings on the NO_2 problem [BMU 2005]. Other meetings between representatives from industry and research followed with a view to developing solutions to the problems. Efforts to bring about reductions centre on the transport sector. For that reason, the Environment Ministry has reached an agreement with the German Association of the Automotive Industry (VDA) that an "NO_2 action plan" will be developed, which will detail measures to be taken and include an assessment of what effect they might have. The VDA intends to submit proposals on this to the Environment Ministry in the near future.

The Environment Ministry has explored the topic intensively. This paper analyses the reasons for the unexpectedly high levels of nitrogen dioxide and discusses possible ways of reducing them.

[1] Switzerland and Austria have stricter limit values for nitrogen dioxide. The annual limit value there is 30 µg/m³

Despite a reduction in emissions of nitrogen oxides, there has been only a slight drop in NO_2 concentrations

Between 1990 and 2005, emissions of NO_x[2], i.e. the sum total of emissions of nitric oxide (NO) and nitrogen dioxide (NO_2), fell by 50% in Germany. The decrease was roughly the same whether from stationary energy generation or road traffic (Fig. 1). Today, about 45% of total NO_x emissions come from traffic.

NO_x emissions from motor traffic in towns and cities in Germany have also dropped by about 50 % since 1990 (Fig. 2, left). This reduction is mainly due to the introduction of 3-way catalytic converters for petrol cars. By contrast, emissions from HGVs (heavy goods vehicles) scarcely decreased at all. The sharp increase in mileage accounted for by diesel cars meant that emissions from this category rose, despite more stringent limit values for new vehicles.

These calculated emission reductions are reflected in the NO_x concentrations measured. For example, since 1990, there has been a sharp drop in NO_x concentrations on busy roads in Baden-Württemberg (Fig. 2, centre).

By contrast, NO_2 concentrations, which are relevant for compliance with limit values, have scarcely declined in recent years. Ambient concentrations of nitrogen dioxide are measured at over 400 monitoring stations in Germany. In Baden-Württemberg, the mean value at roadside monitoring stations has fluctuated by 60 µg/m^3 for years (Fig. 2, right). At many roadside monitoring stations in Germany, NO_2 concentrations have scarcely decreased in recent years and in some cases levels even increased (Fig. 3).

This explains why the annual mean value for nitrogen dioxide levels exceeded 40 µg/m^3 at 98 stations in 2006 (Fig. 4). The nitrogen dioxide concentrations that exceeded the limit value that will come into force in 2010 were only found at stations directly exposed to traffic; background levels in towns and cities and in rural areas are far lower.

The degree to which the limit values are being exceeded in some cases means that there will have to be a steep reduction in NO_2 levels if compliance with limit values is to be achieved by 2010. If the annual mean value will be reduced by 20 µg/m^3 it would be possible to comply with the limit value at approximately 75% of the stations that to date have been exceeding the limit value.

Furthermore, 1-hour mean values in excess of 200 µg/m^3 were measured at 44 stations in Germany in 2006. At 11 of these stations, this occurred more than 18 times per year which is the maximum allowable from 2010; at two stations, the limit value currently in force was also exceeded (maximum of 175 hours with more than 200 µg/m^3).

Reasons underlying the high levels of NO_2

Ambient NO_2 levels are made up of direct emissions of nitrogen dioxide, plus NO that has been converted into NO_2 by chemical reaction. The concentrations of NO, NO_2 and ozone are in an equilibrium (“photochemical equilibrium”), which is dependend on solar radiation or temperature changes. Ambient NO_2 levels may result from “urban background levels” and “local pollution.” Urban emission sources (e.g. industry, domestic fuel, traffic) contribute to the “urban background level” as do pollutants that have been transported over long distances.

At roadside sites that are liable to exceed limit values, a large proportion of the ambient pollution is caused by emissions from local traffic (see Fig. 6). There are two main causes for this localized additional NO_2:

- **Primary NO_2**: nitrogen dioxide (NO_2) is emitted directly from vehicle exhaust pipes. A number of studies (e.g. [AQEG 2006]; [IFEU 2005], [Carslaw 2005], [IFEU 2006], [IFEU 2007]) have shown that the proportion of NO_2 in NO_x emissions from diesel cars has risen sharply over the last decade. This is largely due to the use of oxidation catalytic converters but also to the fact that the proportion of diesel cars on the road has climbed steeply in recent years.
- **NO_2 formed as a result of atmospheric chemical reactions**: nitric oxide from motor vehicle exhaust gas reacts with ozone to form NO_2. Other atmospheric chemical reactions

[2] The air-quality limit values apply directly to NO_2, the component that is harmful to health. In the case of emissions, however, the limit applies to the sum total of NO_x, the aim being to reduce the amount of nitrogen entering the atmosphere (consequences of which include acidification, excessive levels of nutrients entering ecosystems, formation of secondary particulate matter). Furthermore, after a certain time, even directly emitted NO is found in the atmosphere - predominantly NO_2 formed as a result of atmospheric chemical reactions.

(e.g. with OH radicals) also result in NO_2. The NO_2 concentrations in the ambient air are thus also highly dependent on NO emission levels and the availability of ozone.

NO_2 concentrations vary as a factor of emissions of primary NO_2 and NO from exhaust gas from motor traffic at the monitoring site, but also as a result of meteorological conditions (especially wind speed and height of the mixing layer). The example of a roadside station in Central Stuttgart (Fig. 7) shows that the urban background level can fluctuate over the course of a single day by a factor of two – particularly as a result of changing dispersal conditions. Contribution from local traffic (primary NO_2 and NO_2 formed by NO reacting with ozone) is highly dependent on local traffic emissions. Higher ozone concentrations in the afternoon contribute significantly to the formation of secondary nitrogen dioxide [IFEU 2007].

Emission trends to 2015

Limit values for NO_x emissions from motor vehicles have become more stringent in recent years. Euro 5/6 for cars and in the future Euro VI for HGVs will lower these limit values still further. The legislation on limit values applies to the sum parameter, nitrogen oxides (NO_x).

Little was known about how high the NO_2 component in NO_x emissions is. In the past, it was usually assumed to be 5%. Only in recent years have specific measurements of NO_2 been carried out in a number of European measuring laboratories. An analysis of current measurements of this kind [IFEU 2007] shows that the nitrogen oxides in the exhaust gas from petrol cars contains only a small proportion of primary NO_2, consisting mainly of nitric oxide.

By contrast, in the case of diesel cars, the NO_2 share in the nitrogen oxides in exhaust gas is higher - even in old cars - and there has been a particularly significant increase since Euro 3 (Fig. 8, left). One factor to which the rise in NO_2 emissions is attributed is the introduction of oxidation catalytic converters. They are used in diesel vehicles to reduce hydrocarbon and carbon monoxide emissions, but as a side effect they oxidize NO to form NO_2. The highest ratios of NO_2 to NO_x have been observed in Euro 4 diesel cars with particulate filters.

Very few measurements are currently available for the exhaust gas reduction technologies scheduled to be used in cars in the future. However, the measurements that do exist indicate that the use of different coating materials for oxidation catalytic converters and particulate filters and the use of SCR systems (“selective catalytic reduction” to reduce nitrogen oxide emissions) will bring about a drop in the NO_2 to NO_x ratio in exhaust gas.

Thus, despite the drop in NO_x emissions, vehicle-specific NO_2 emissions from diesel cars from Euro 1 to Euro 4 have increased. NO_2 emissions will not drop until the limit values set in the Euro 5 and Euro 6 emission standards take effect (Fig. 8). This assumes that NO_x emissions from diesel cars will fall in line with reductions identified in the New European Driving Cycle and in urban situations.

HGVs and buses without exhaust gas treatment technologies generally have low NO_2 emissions, which have decreased with the drop in NO_x emissions as a result of more stringent emission standards. However, vehicles that are fitted with particulate reduction systems can - depending on the system - have significantly higher specific NO_2 emissions. These are systems that actively produce NO_2 in order to regenerate the filter.

For a typical urban situation in Germany (average daily traffic (ADT): 40,000 motor vehicles, of which 4% HGVs and 0.5% buses) NO_x and NO_2 emissions were determined using TREMOD [TREMOD 2005]. This showed that, despite a sharp increase in diesel cars, NO_x emissions dropped by 40% between 1995 and 2005 (Fig. 9). Without the introduction of the limit values to be phased in with Euro 5 and Euro 6 (Fig. 9, red line), emissions would drop by a further 48% between 2005 and 2020. This indicates that with the introduction of the Euro 5 & 6 emission standards for cars, it will be possible to achieve a 61% reduction.

A totally different trend has been calculated for NO_2 emissions: although they did drop until 1999, after that they rose significantly. A marked reduction in NO_2 emissions will not be achieved until Euro 5 are introduced (in the calculations beginning at the end of 2008) and Euro 6 cars (from 2013) are introduced.

In a specific suburban setting, the emissions situation may deviate from this. For example, studies in Stuttgart [IFEU 2007] have revealed that if the traffic using a road has a high proportion of buses that are fitted with certain kinds of particulate reduction systems an increase in NO_2 emissions can result. According to these calculations, bus traffic accounts for over 1/3 of the NO_2 emissions from traffic at the Central Stuttgart monitoring station.

The introduction of Euro-VI HGVs, which has not yet been taken into account in the calculations, would further reduce NO_x emissions from 2015 onwards. The effect on NO_2 will not be as great, since HGVs account for only a small share of overall NO_2 emissions.

Future trends in nitrogen dioxide concentrations

Calculations normally used to ascertain NO_2 concentrations determine firstly the locally NO_x concentrations by using dispersion modelling; secondly the concentration of NO_2 formed was estimated using Romberg's formula [Romberg 96]. This formula is based on statistical analyses of NO_2/NO ratios measured in past years. As a result of the changes in the proportion of NO_2 in car exhaust gases alone, a rigid formula such as this one did not provide an accurate depiction of ambient concentrations in recent years. It will therefore certainly not be able to adequately estimate future NO_2 concentrations.

IFEU and AVISO looked at the Central Stuttgart roadside monitoring station and carried out detailed calculations of both past NO_2 and NO emissions and those to be expected in the future. Using a chemistry box model, they then estimated nitrogen dioxide concentrations for 2010 – 2020. By simulating individual processes in the model, the contributions made to the overall ambient concentrations by different causal factors was ascertained [IFEU 2007].

According to these calculations, NO_x emissions from local traffic will continue to fall in Central Stuttgart between 2005 and 2020; this takes into account the positive effects of the more stringent exhaust gas limit values for cars (Euro 5/Euro 6) scheduled to come into force. Based on this assumption, the NO_2 concentration at the monitoring station would drop from 72 $\mu g/m^3$ to 50 $\mu g/m^3$ (Fig. 10, left). The contribution made by primary NO_2 would initially rise until 2010 and then fall continuously. The NO_2 contribution resulting from atmospheric chemical reactions decreases from the outset.

These calculations thus indicate that even in 2020 Central Stuttgart will not comply with the NO_2 limit value for ambient air quality that enters into force in 2010. Even if an extension to the compliance deadline by the maximum of 5 years were granted, the limit value would still not be complied with here. To achieve compliance with the limit value by 2015 massive reductions are therefore necessary that go far beyond the assumptions made in the scenarios used.

This would involve huge reductions in both primary and secondary NO_2 from local sources and in the background level with its numerous NO_x emission sources. An initial estimate of pollution sources made at the Central Stuttgart monitoring station (Fig. 10, right) reveals that the proportion contributed by traffic to the NO_2 levels will be about ¾ in 2015. Diesel vehicles are the main culprit, accounting for over 80% of this share.

The same assumption must be made for other heavily polluted areas in Germany, namely that traffic is the main cause and that without additional measures NO_2 concentrations in 2015 will still exceed the air quality limit value for NO_2 that will be in force at that time. A more precise estimate of the proportionate contributions from individual causal factors would have to take local conditions into consideration.

Approaches to reducing NO_2 concentrations

Basically any effective lowering of NO_2 concentrations relies on primary NO_2 and NO emissions from traffic and other sectors being reduced.[3] In view of its high contribution to ambient NO_2 levels, this discussion will focus on possibilities for reducing emissions from road traffic.

Recently, the question of what reduction possibilities exist and what instruments can be used to implement corresponding measures to facilitate compliance with air quality limit values has been under more intense discussion. A number of approaches are listed below. They differ in the effects they would have on emissions and air quality. (Fig. 11).

Cars/light commercial vehicles

With the tightening up of EU limit values for motor vehicle exhaust gases (Euro 5/6 for cars) and the growing proportion of this category of vehicle in the overall fleet, NO_x emissions from car traffic will continue to fall in the near future. The German federal government has made a particularly strong case for the introduction of a stringent limit value for diesel cars (Euro 6). However, the Euro 6 emission standard for cars is not scheduled to become binding until 2014 and therefore will not have had any great impact on emissions by 2015. Placing vehicles that meet Euro 6 criteria on the market before the mandatory deadline [A1] would help to lower NO_2 concentrations. To encourage this, the federal government is considering preferential motor tax rates for Euro-6 cars on the road ahead of the deadline. It is expecting the automobile indus-

[3] Measures to reduce ozone levels can also have the knock-on effect of reducing nitrogen dioxide concentrations. These indirect effects – that impact on NO_2 from atmospheric chemical reactions – have not been taken into account here.

try to make these vehicles available as soon as possible.

However, it is crucial to ensure that NO_x and NO_2 emissions from Euro 5/6 cars are dramatically reduced not only in the latest test cycle but in real urban driving situations. For that reason, some thought must be given at European level to refining registration procedures [A2].

A workshop organised by the Commission entitled “Impact of direct emissions of NO_2 from road vehicles on NO_2 concentrations” also discussed the possibility of limiting NO_2 emissions [A3]. The successive lowering of NO_x emissions under Euro 4, Euro 5, Euro 6 was the result of a political decision. To achieve an additional contribution to NO_2 reduction, e.g. a voluntary commitment on the part of the automobile industry might be useful.

Until diesel cars’ NO_x and NO_2 emissions levels match the lower level of petrol cars in all driving situations, preventing the proportion of new registrations of diesel cars from rising will help to lower emissions [A4]. Given the CO_2 targets that also need to be met, producing a range of fuel-efficient petrol cars is important.

Especially in highly polluted urban areas, replacing vehicles with combustion engines with (partially) electrically powered vehicles can help to improve air quality [A5]. Here the federal government has initiated a number of research programmes to look at the increased use of electric and fuel-cell vehicles.

HGVs/buses

The proposal for the Euro VI limit values for HGVs envisages an 80% NO_x reduction compared with Euro V. The federal government is making every effort to have this limit value enter into force as soon as possible. As in the case of cars, introducing Euro VI [B1] sooner and replacing the HGVs more quickly [B2] can help reduce emissions and in turn improve air quality. The federal government has therefore launched an HGV innovation programme to encourage people to buy Euro V HGVs by 30.09.2009 [BMVBS 2007]. After that, Euro VI HGVs will be promoted until the Euro VI standard becomes binding. With its scale of toll charges reflecting different emission classes, the federal government has also created a powerful incentive to purchase low-emission vehicles before the mandatory date.

In the future, more attention must be paid to ensuring that primary NO_2 emissions do not increase unacceptably as a result of technologies used. In California, and now also in the rest of the USA, a regulation has come into force that limits NO_2 emissions from exhaust gas treatment systems [CARB 2007; EPA 2007]. Possibilities of restricting NO_2 emissions must also be discussed more intensively in Europe.

In some towns and cities, bus traffic makes a significant contribution to ambient NO_2 levels. Transport operators and local authorities must in future define tighter NO_x requirements for the purchase of vehicles to ensure that public transport does not lose its environmentally friendly edge [B4]. Also in tendering processes for transport services or routes, the purchaser (e.g. district authorities) can set NO_x standards. The federal government has commissioned research projects and pilot projects on this subject [VCD 2001]. Retrofitting buses with appropriate systems can bring about a reduction in NO_x emissions of over 80%. A number of different systems are being trialled at present.

Transport organisation

NO_x emissions arise in particular during acceleration and at high speeds. A speed limit – especially on urban motorways – can reduce emissions in towns and cities [C1]. Measures to keep traffic flowing in towns and cities also help reduce NO_x emissions [C2].

Whether benefits should be introduced from 2010 in areas with high ambient levels of NO_2 for users of vehicles with low NO_x and NO_2 emissions (environment zone) is a political decision [C3]. All measures to reduce private motor traffic (e.g. increasing the number of passengers travelling in a car, changing the modal split in favour of bicycles and public transport) [C4] can only help to reduce air pollution.

Shipping

Shipping contributes to widespread nitrogen oxide pollution and to local pollution, particularly in problem areas such as docks. The mineral oil industry has agreed to ensure a wider range of sulphur-free marine diesel, which would create the basic conditions for using exhaust gas treatment technologies such as particulate filters and NO_x reduction technology for shipping on inland waterways too. The federal government has given its backing to the construction of a river/sea vessel that is equipped with the latest exhaust gas reduction technology (“Futura Carrier”).

Other sectors

It will only be possible to effectively reduce background levels of nitrogen oxides if emissions from non-traffic sources such as industry, power stations and domestic households also continue to fall. To that end, the federal government is planning to introduce secondary legislation to ensure compliance with air quality requirements (37. BimschV – 37th Regulation implementing the Federal Pollution Control Act). The aim of this Regulation is to counter the increased emission of nitrogen oxides from large combustion plants.

At European level, the “Thematic strategy on air pollution” is a programme to reduce permissible emission volumes of key pollutants in individual member states. In connection with negotiations on the new Air Quality Directive, the Commission has also issued a declaration announcing measures to reduce emissions [EC 2007]. These measures are intended to support the member states in their efforts to comply with air-quality limit values. The Commission cites the following principal measures:

A Directive on Industrial Emissions (successor directive to the IPPC Directive), which aims to further reduce emissions from industry, agriculture and smaller industrial combustion plants;

- Directive on national emission ceilings (NEC);
- Lowering emissions from mobile machinery;
- Activities to reduce emissions from shipping.

Summary

The annual limit value for nitrogen dioxide that will be effective from 2010 is currently exceeded on many busy roads in Germany. The main contributing factor is NO_2 emitted directly from motor traffic using the road. In addition to that, NO_2 is formed as a result of an atmospheric chemical reaction with the ozone from the NO emissions of local traffic. NO_2 emissions from urban and regional background sources also contribute to ambient NO_2 levels on main roads.

The significance of primary NO_2 emissions in ambient NO_2 levels has only been recognised in recent years. For example, the exhaust gas limit values for road traffic that have been continually tightened up have only ever applied to NO_x, the sum of NO and NO_2 emissions; no limit is imposed on the NO_2 component of the NO_x emitted. However, as a result of new exhaust gas treatment technologies, the NO_2 component has increased, particularly in the case of modern diesel cars. This has caused NO_2 emissions to rise. This is part of the reason why NO_2 concentrations have not fallen, despite lower NO_x emissions.

Since emissions of direct NO_2 will also continue to rise until 2010, NO_2 concentrations at many places will scarcely decrease despite the fact that limit values for motor vehicle exhaust gas are becoming tougher. Many local authorities will only be able to achieve compliance with air-quality limit values for NO_2 if they implement additional measures.

Only when the vehicle fleet has a high enough proportion of vehicles that fulfil Euro 5/6 or Euro VI standards will a decline in NO_2 emissions be possible. Nevertheless, even in 2015, i.e. if full use is made of the deadline extension provided for in the EU’s new Air Quality Directive, it will not be possible to comply with the air quality limit value even if measures already passed are implemented.

Achieving compliance with the air-quality limit values for NO_2 will only be possible if, in addition to further tightening of the limit values for motor vehicles emissions, effective measures to reduce ambient urban concentrations and widespread background levels are taken. The automobile industry – as the manufacturer of the vehicles that contribute to the main source of pollution – must be called upon to develop concepts and strategies for reducing NO_2.

Acknowledgment

The authors would like to thank the Ministry of Environment Baden-Württemberg and LUBW for providing of data and the possibility of using results of different studies.

Bibliography

AQEG 2006 **Air Quality Expert Group: Trends in Primary Nitrogen Dioxide in the UK – Draft report for comment – August 2006**

BMU 2005 **Unexpectedly small decreases or even increases in ambient NO_2 levels – Expert meeting at the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) 15.9.2005; http://www.bmu.de/luftreinhaltung/feinstaub/doc/36369.php**

BMVBS 2007 **Programme to promote purchase of low-emission heavy goods vehicles; see http://www.bmvbs.de/artikel-,302.1007901/Foerderung-der-Anschaffung-emi.htm**

BVG 2007 **German Federal Administrative Court; Judgement of 27.09.2007; [Reference: BVerwG 7 C 36.07]**

CARB 2007 **California Code of Regulation; Title 13, Section 2701 – 2709**

Carslaw 2005 **Carslaw, D.C.: Evidence of an increasing NO_2/NO_x emissions ratio from road traffic emissions. Atmospheric Environment, 39 (26), 4793 – 4802, 2005.**

EC 2007 **Declaration by the commission accompanying the adoption of the new directive on ambient air quality and cleaner air for Europe; in [EU 2007]**

EPA 2007 **Diesel Oxidation Catalysts: Informational Update; EPA420-F-07-068, November 2007; http://epa.gov/otaq/diesel/documents/420f07068.htm**

EU 1999 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 (OJ No. L 163 p. 41)

EU 2006 EU level workshop: "The impact of direct emissions of NO_2 from road vehicles on NO_2 concentrations" run by the Commission in Brussels on 19.9.2006

EU 2007 European Parliament: Legislative resolution on the Council common position for adopting a directive of the European Parliament and of the Council on ambient air quality and cleaner air for Europe (16477/1/2006 – C6 – 0260/2007 – 2005/0183 (COD))

IFEU 2005 "Ursachen hoher verkehrsbedingter Stickstoffdioxid-Immissionen – Analyse an einer Autobahn-Messstelle." U. Lambrecht et al., IFEU Heidelberg: commissioned by the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU; Heidelberg 2005.

IFEU 2006 "Analyse der Ursachen für hohe NO_2-Immissionen in baden-württembergischen Städten." F. Dünnebeil, U. Lambrecht and S. Buchholz, IFEU Heidelberg; commissioned by the Baden-Württemberg Environment Ministry, Heidelberg 2006.

IFEU 2007 "Zukünftige Entwicklung der NO_2-Emissionen des Verkehrs und deren Auswirkung auf die NO_2-Luftbelastung in Städten in Baden-Württemberg." F. Dünnebeil, U. Lambrecht, IFEU Heidelberg. With the collaboration of C. Kessler (Aviso Aachen). Commissioned by the Baden-Württemberg Environment Ministry; Heidelberg 2007.

LNUV 2005 North Rhine-Westphalian Agency for Nature, the Environment and Consumer Protection (LNUV), Simulationen zur Beurteilung der Luftqualität, annual report (2005)

Romberg 96 Romberg, E., Bösinger, R., Lohmeyer, A., Ruhnke, R., Röth, E. (1996): NO-NO_2-Umwandlung für die Anwendung bei Immissionsprognosen für Kfz-Abgase. Gefahrstoffe-Reinhaltung der Luft, vol. 56, no. 6, pp. 215-218.

TREMOD 2005 TREMOD – Transport Emission Model, Update 4.1. Fortschreibung des Daten- und Rechenmodells Energieverbrauch und Schadstoffemissionen des motorisierten Verkehrs in Deutschland 1960-2030." W. Knörr, Ch. Reuter et al., IFEU Heidelberg. commissioned by the Federal Environment Agency (UBA), Berlin/Heidelberg 2005.

VCD 2001 Umweltstandards im ÖPNV; Ein Leitfaden für Entscheidungsträger; published by Verkehrsclub Deutschland (association for sustainable mobility); with funding from BMU and UBA, 2001

WHO 2006 World Health Organisation: Air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide; Global update 2005; Summary of risk assessment

Graph and table appendix

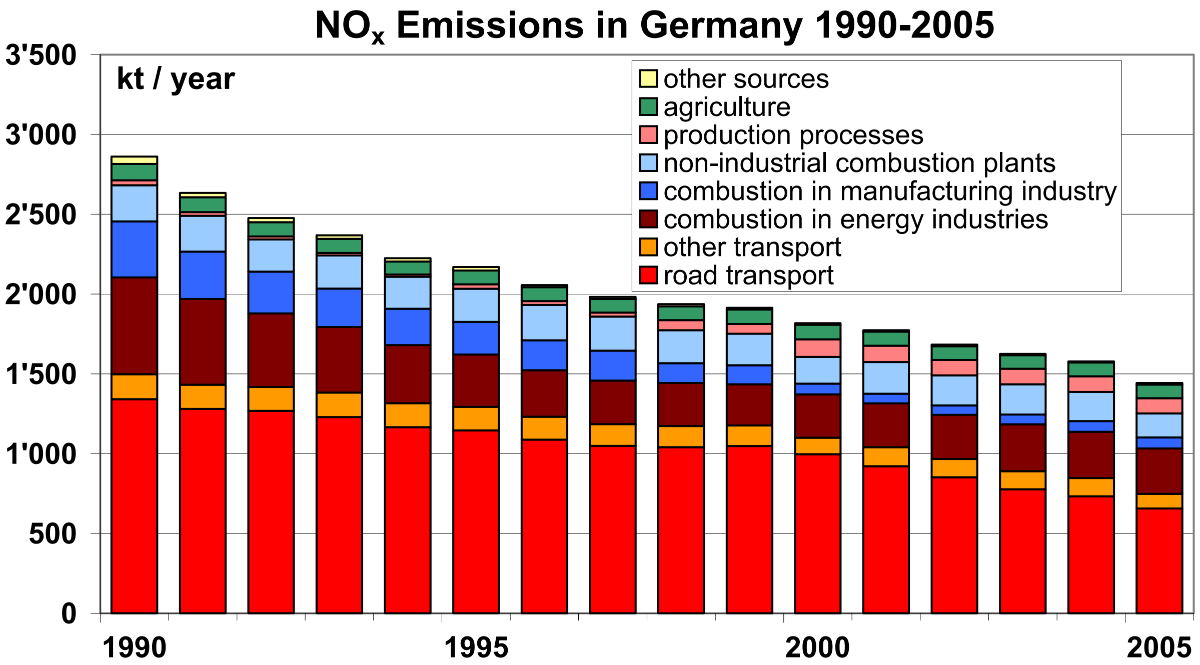

Fig. 1: NO$_x$ emissions in Germany by source category 1990 – 2005 (Source: Federal Environment Agency – UBA)

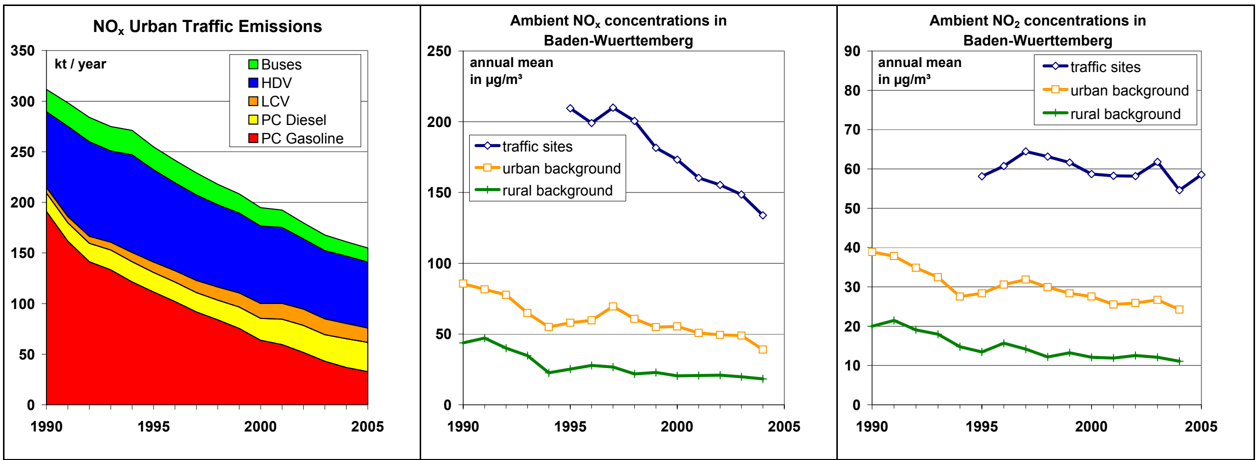

Fig. 2: NO$_x$ emissions and ambient air concentrations

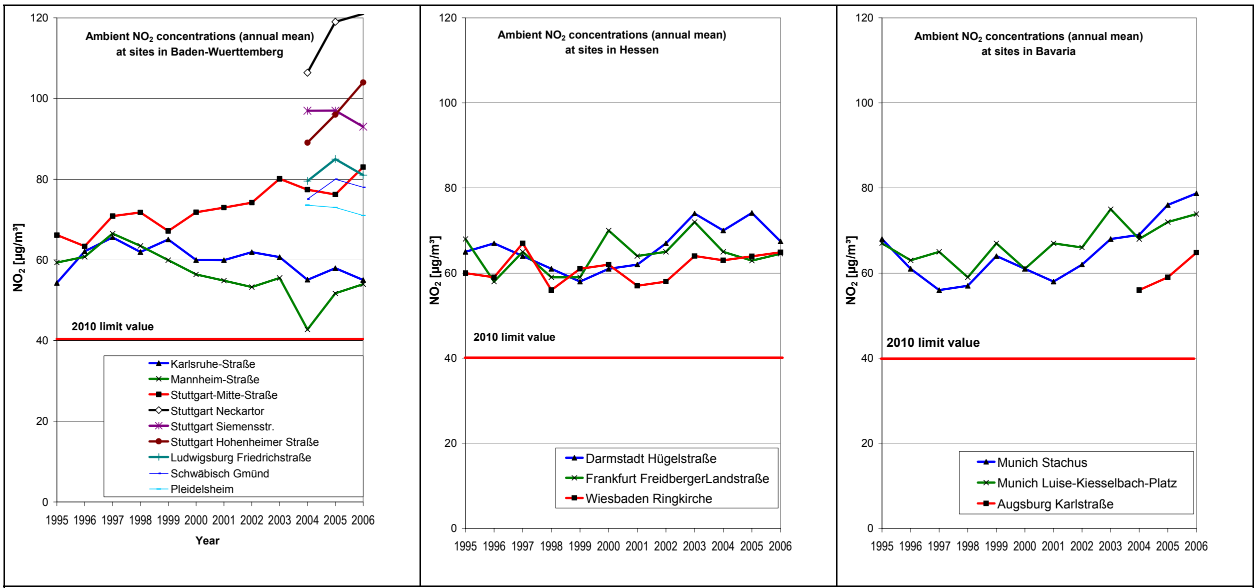

Fig. 3: Ambient NO_2 concentrations – roadside sites in Germany (Source: IFEU on the basis of data provided by the monitoring networks in the German states

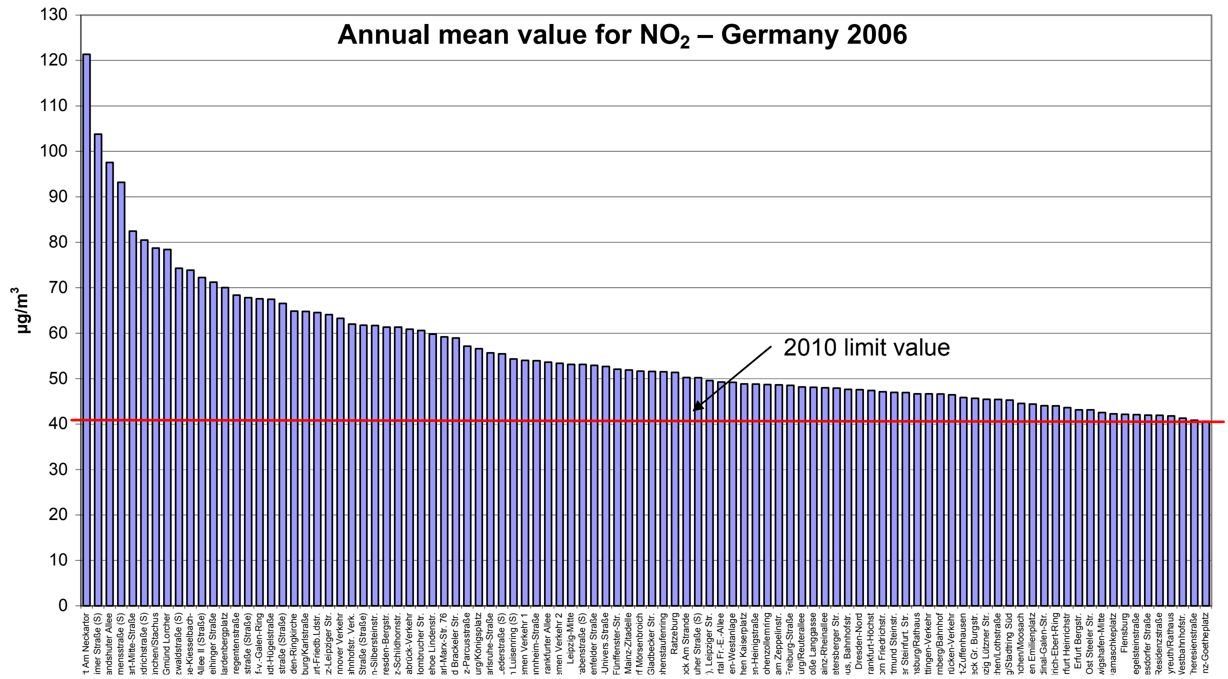

Fig. 4: Sites with annual NO_2 concentrations > 40 µg/m^3 in 2006 (Data source: Federal Environment Agency – UBA)

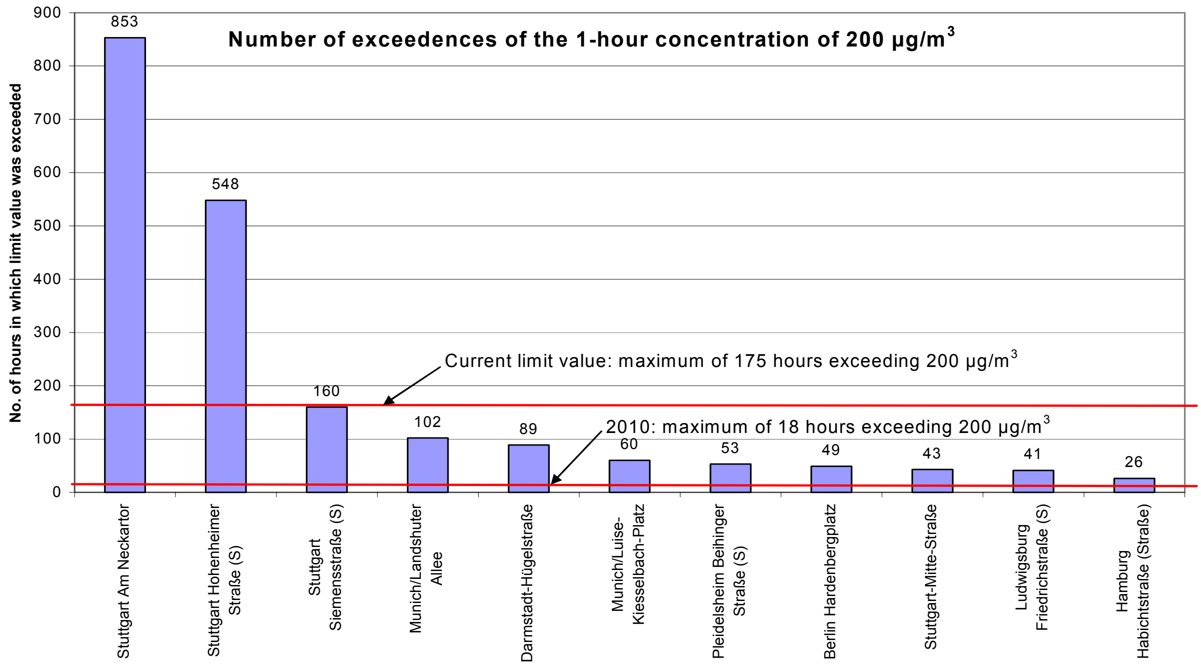

Fig. 5: **Number of exceedences of the 1-hour limit value of 200 µg/m³ for NO_2 in 2006 (Data source: Federal Environment Agency – UBA)**

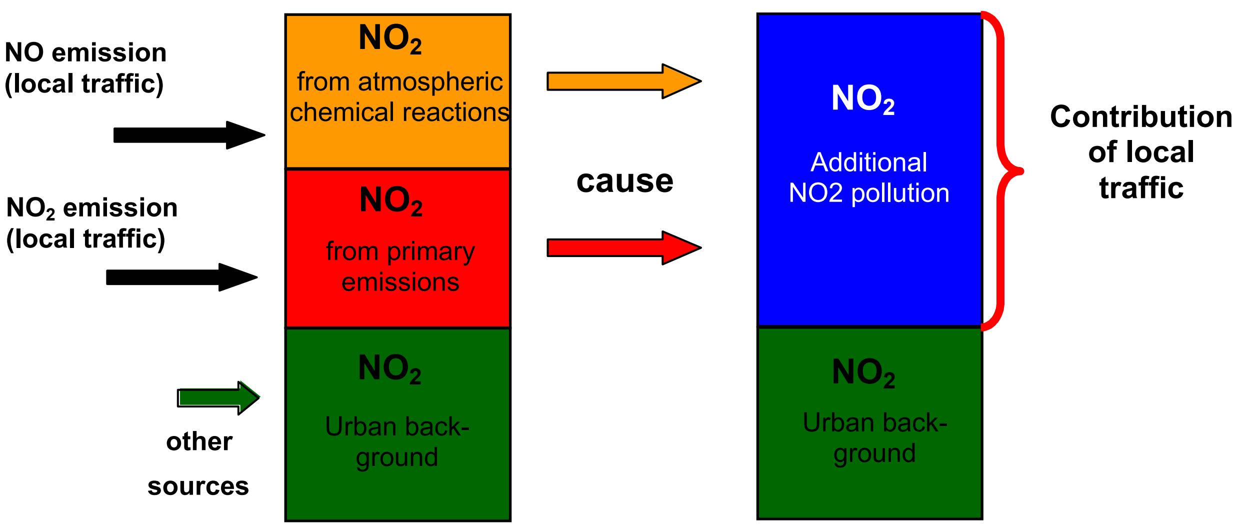

Fig. 6: **Causes of NO_2 levels at roadside monitoring sites (schematic representation)**

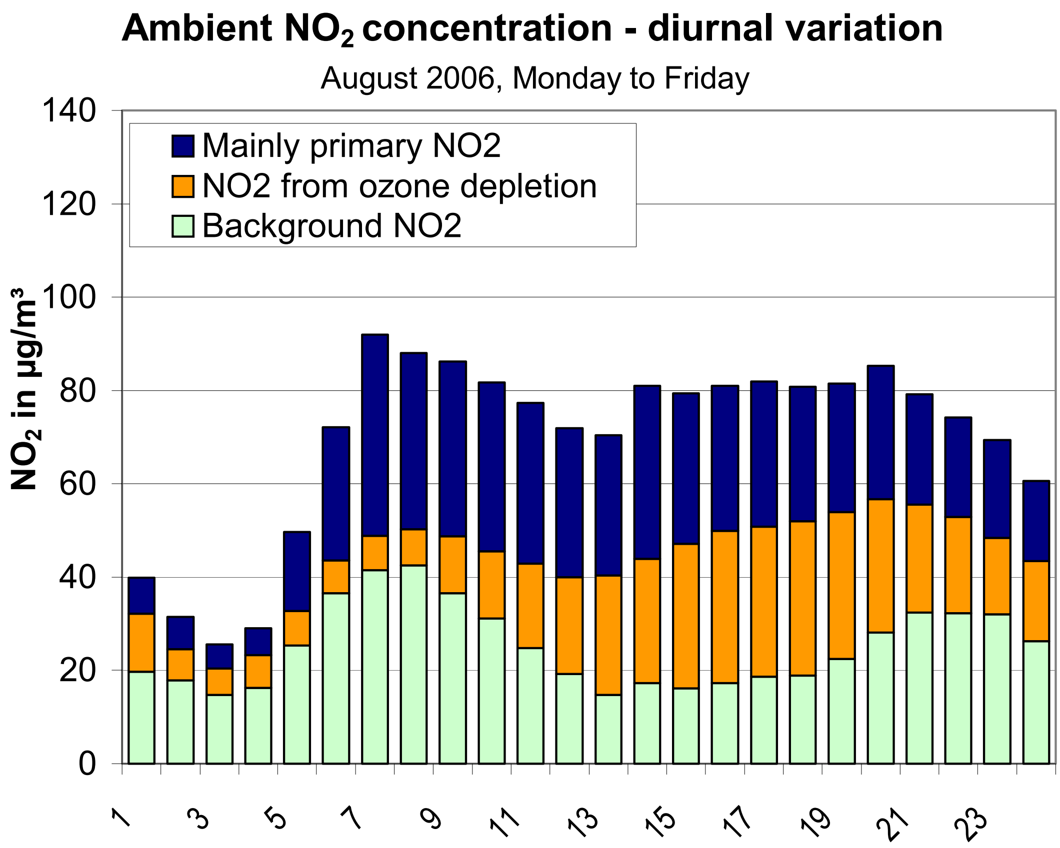

Fig. 7: **Contribution of different causes to NO_2 concentration – diurnal variation (Source: IFEU 2007)**

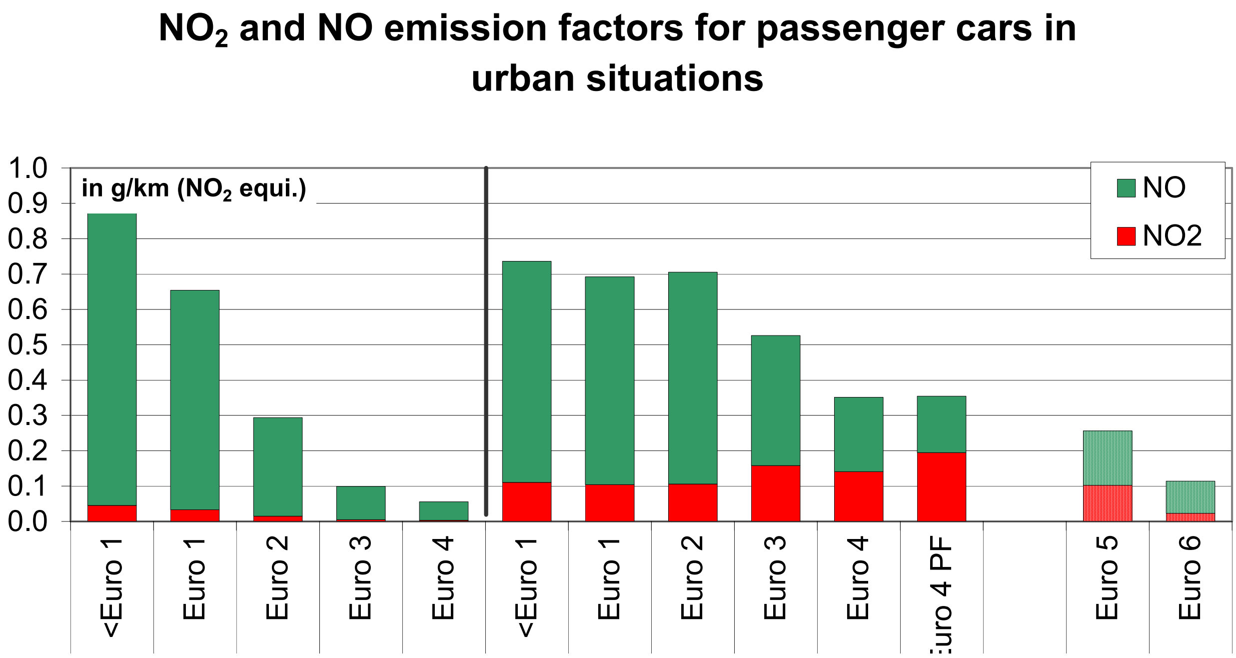

Fig. 8: **NO_2 and NO emission factors for passenger cars in urban situations (Source: IFEU 2007)**

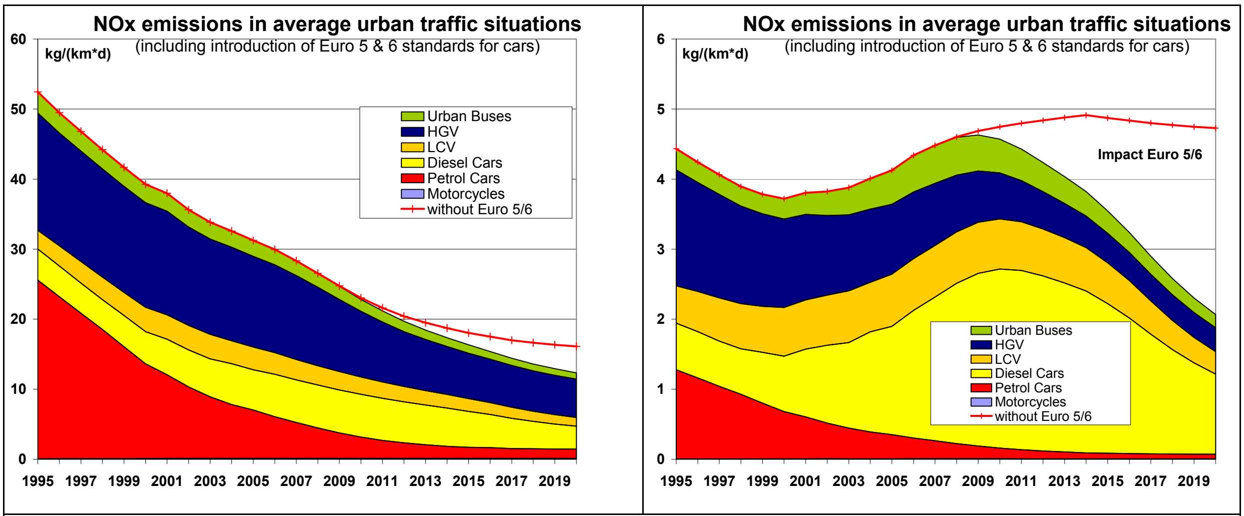

Fig. 9: Emissions of NO_x and NO_2 - average urban traffic situation (source: IFEU 2007)

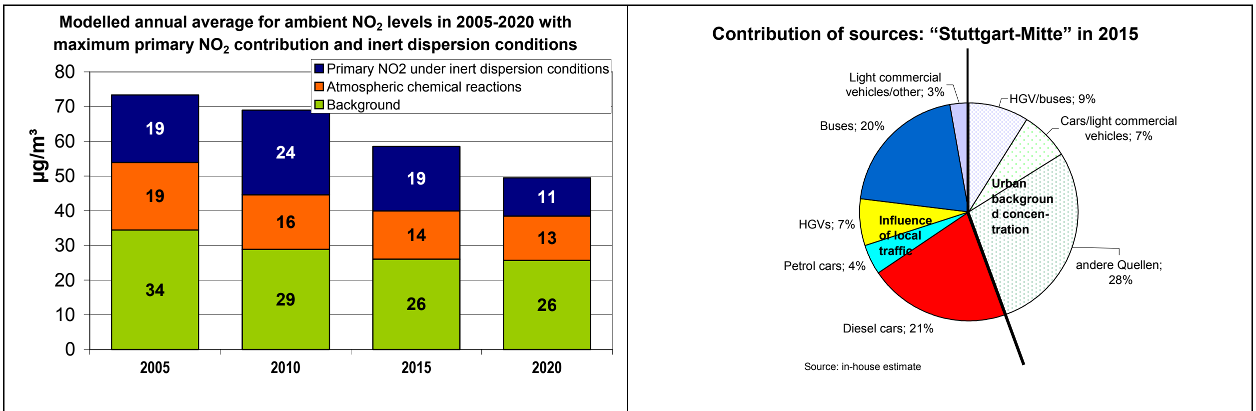

Fig. 10: NO_2 concentrations and contributory factors in 2005, 2010, 2015 and 2020 at the Central Stuttgart roadside monitoring site

	Impact on emissions (Main effects)		**Impact on air quality (Main effect on NO_2)**	
Approach	***NO_x***	***NO_2***	***Ambient urban levels***	***National back-ground level***
A) Cars/light commercial vehicles				
1. Early introduction of Euro 6 for cars and light commercial vehicles	X	X	X	X
2. Ensure that emissions are reduced in real world driving conditions	X	X	X	
3. Limit NO_2 emissions		X	X	
4. No further increase in new registrations of diesel cars	X	X	X	X
5. Increase the share of vehicles with electric drive	X	X	X	
B) HGVs/buses				
1. Early introduction of Euro VI for HGVs	X		X	X
2. Accelerate renewal of the HGV fleet	X		X	X
3. Limit NO_2 emissions		X	X	
4. Minimum standards for public service buses (NO_x, NO_2)	X	X	X	
5. Retrofit buses with NO_x reduction technology	X	X	X	X
C) Traffic organisation				
1. Speed limit on federal motorways	X	X	(Urban motor-ways)	X
2. Measures to optimize traffic flow in towns and cities	X	X	X	
3. Benefits from 2010 for users of vehicles with low NO_x and NO_2 emissions	X	X	X	
4. Reduce traffic volume in towns and cities	X	X	X	
D) Other means of transport				
1. NO_x reduction technology for shipping on inland waterways	X			X

Fig. 11: Approaches to reducing emissions of NO_x and NO_2 from transport