

Emissions and Immissions – The Diesel perspective

An assessment of the future of internal combustion engines



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●● Abstract

Intensive discussions about the future of the combustion engine are currently ongoing. The exceeding of PM as well as NO₂-immission values for many years has intensified the discussions, how there might be a future of the internal combustion engine.

●● Fine Dust / PM

Floating particles in the atmosphere are called fine dust or Particulate Matter (PM). Depending on their size and composition they can have an impact on the physical health. Due to this characteristic there are legal limits in Europe for PM₁₀ in the atmosphere since 2005. These limits were tightened in the last years. The current gravimetric limit is defined 40 µg/m³.

The largest anthropogenic sources for fine dust in Germany are the industry, traffic, private households, heating stations and agriculture. One part of this list is the combustion engine. Particles or the combination of particles as soot are one component of the exhaust gas of combustion engines. Due to fuel rich parts in the combustion zone, which is characteristic for diesel engines, particle formation is unavoidable. Diesel particulate filters significantly reduce the particulate concentration, which enables an ongoing improvement of the aftertreatment technic bringing the emission rate to a minimum.

The limits for particle concentration in the atmosphere must be compliant close to highly frequented roads as well. Measurement stations are placed at specific hot spots for monitoring. Since 2005 the days with too high particle concentrations are limited for every spot to 35 days per annum. “Stuttgart-Neckartor” is best known monitoring station in Germany and an excellent example due to one of the highest rates of exceedance days in former times (see figure 3 and 4).

Figure 1 shows the exceedance days for “Stuttgart-Neckartor”. The year 2005 got 187 days with higher particle concentration than 50 µg/m³. This was 152 days more than the limit of 35 days a year. After 2005 up to 2018 the numbers of exceedance days were continuously decreasing until 2018 with only 21 days in 2018 year and therefore 14 days below the annual limit.

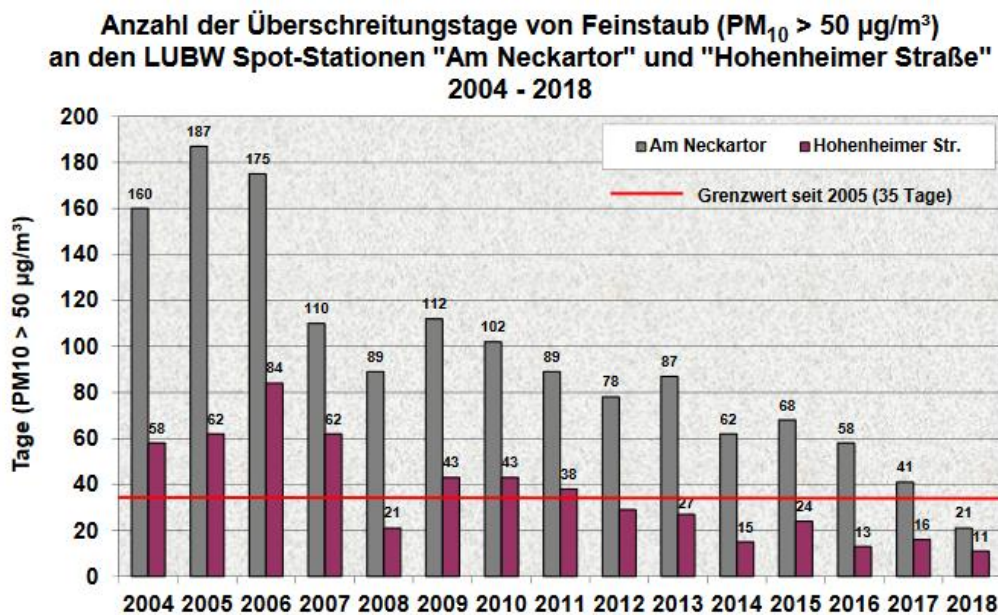


Figure 1: Exceedance days of the PM₁₀-limit of 50 µg/m³ for “Stuttgart- Neckartor” (grey), and “Hohenheimer Str” (dark red). The exceedance days limit is 35 days a year (red horizontal line). Source: LUBW, Grafik: AfU Stuttgart, Abt. 36-4

Figure 2 shows the yearly averages of the PM₁₀ particle concentration at “Stuttgart-Neckartor” for the last 15 years. The years 2004 to 2006 showed a higher concentration than 50 µg/m³. The limit was set to 40 µg/m³. After 2006 the annual averages were decreasing and for every year since 2011 not higher than the limit and still dropping.

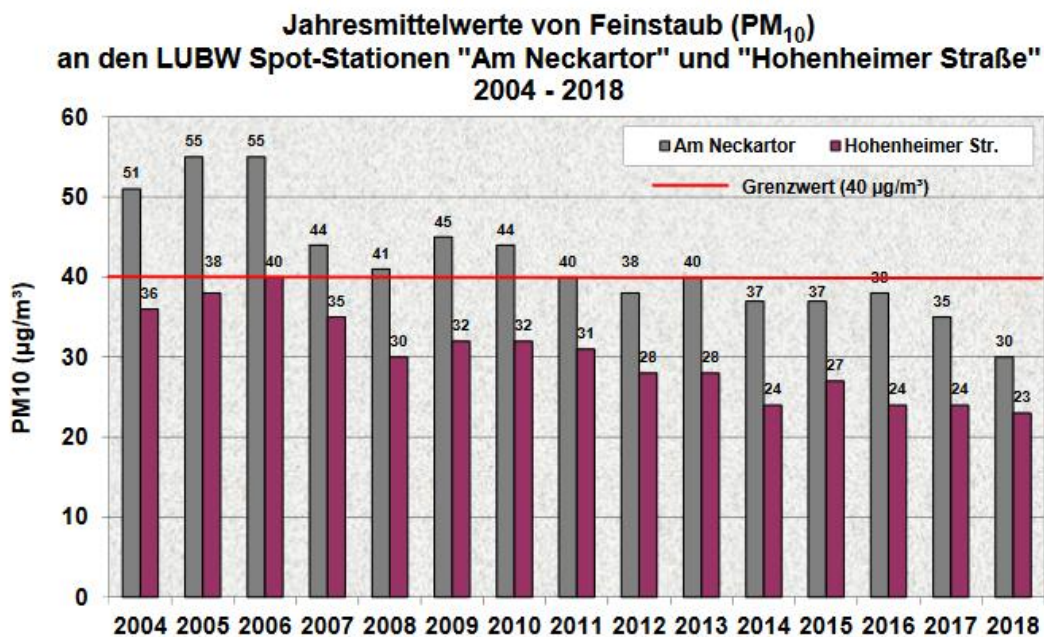


Figure 2: Annual average of the PM₁₀ for “Stuttgart- Neckartor” (grey), and “Hohenheimer Str” (dark red). The PM₁₀ limit is 40 µg/m³ (red horizontal line). Source: LUBW, Grafik: AfU Stuttgart, Abt. 36-4

Over the last 15 years a reduction of the exceedance days of 89% and the annual average of the particle concentration of 45% at the “Neckartor” was achieved and all values are below the limits. The next years a further decrease of PM10 imissions is expected due to the ongoing replacement of vehicles with older exhaust aftertreatment technic by Euro 6d vehicles. The diesel particulate filter has been introduced for all passenger car diesel vehicles in 2009.

The overall situation of the fine dust in Germany is shown in figure 3 and figure 4. The colored sections indicate the amount of days of exceedance with a limit of $50 \mu\text{g}/\text{m}^3$ for the daily average. All the blue areas are below 35 days. The dots spread throughout the map are measurement stations very close to traffic spots. In the year 2014 (figure 3) we had light and dark blue zones (below the limit) nationwide and only few spots with exceedance days of 35 to 49 (yellow color). Only one measurement station in Germany at “Stuttgart-Neckartor” counts more than 56 exceedance days. Only two years later in 2016 (figure 4) every area stay below the limit except the station at “Stuttgart-Neckartor”.

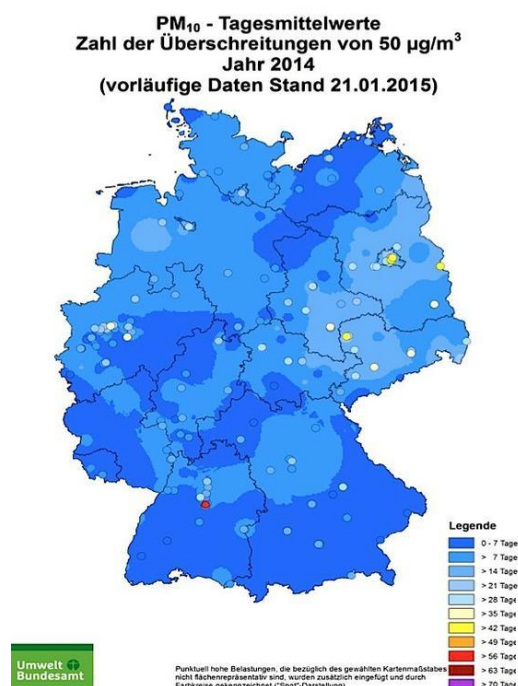
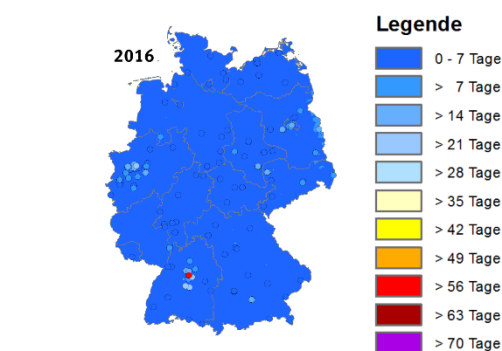


Figure 3: Number of exceedance days for PM10 in Germany with a daily average limit of $50 \mu\text{g}/\text{m}^3$ in the year 2014. Source: German Federal Office for Environment

Zahl der Überschreitungen des PM₁₀-Tagesmittelwertes von $50 \mu\text{g}/\text{m}^3$ mit Spots aus Ländermeldungen



Quelle: Umweltbundesamt 2017



Figure 4: Number of exceedance days for PM10 in Germany with a daily average limit of $50 \mu\text{g}/\text{m}^3$ in the year 2016. Source: German Federal Office for Environment

The sources for fine dust at traffic spots can be split in two sections: first the local load, caused by traffic on that road and nearby buildings, and second the background level with all the sources from the wider environment. Figure 5 shows the proportions for the single sources. The exhaust of combustion engines as PM10 source has a share of 7% overall, 6% as local load and 1% as part of the total background level. This fact therefore shows that combustion engines/Diesel contribution to fine particulate matter is

negligible.

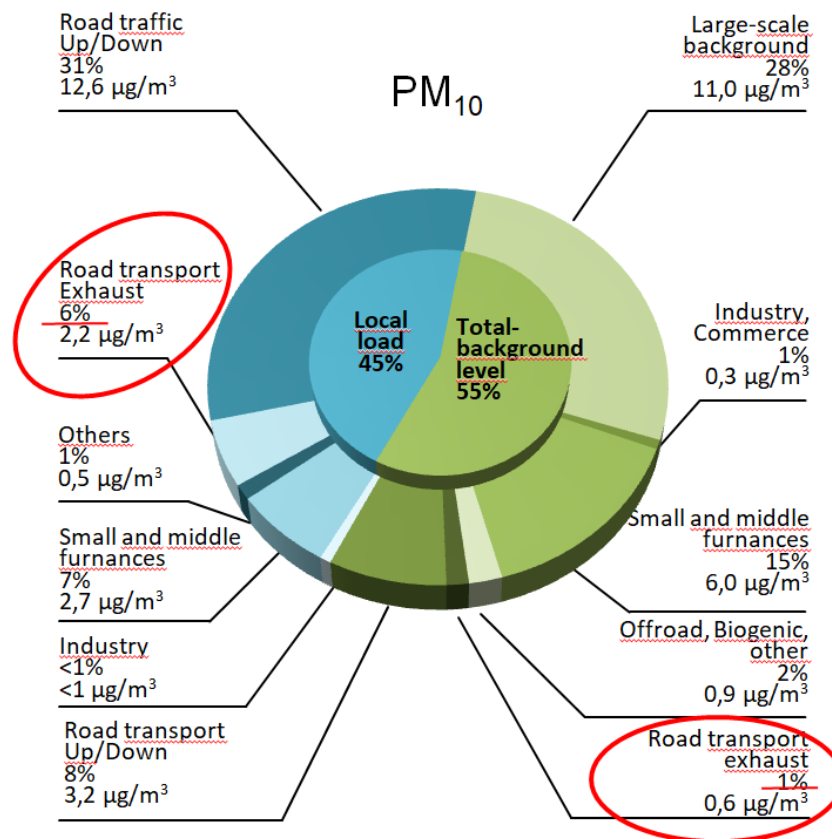


Figure 5: Shows the proportions of the PM10 sources at traffic spots. Source: Christoph Erdmenger; Ministerium für Transport und Infrastruktur Baden Württemberg; IFKM/KIT – NO_x Conference, Heidelberg, 01.2016

●● NO_x

Nitrogen oxides (NO_x) are gases with harmful properties for the respiratory organs and their output must be minimized. Since 2010 the annual emissions of NO_x in Germany are limited. In opposition to PM immissions, Diesel engines are the main cause of the NO₂-Situation.

Again the measurement station “Stuttgart-Neckartor” is a good example for the evaluation of the NO₂-immission situation in Germany as highest values in Germany had been detected here. Figure 6 is a map of the periphery of “Stuttgart Neckartor” measurement station and the colored dots show the NO₂ concentration of spots next to the roads in this area. The position of the measuring station (red square) is at the hotspot.

Figure 7 shows the profile crossing, the street and the building (grey square) of the area around the measurement station of “Stuttgart-Neckartor” and the colored parts depict the annual average of the NO_x concentration in this atmosphere. The highest values (red area) are directly around the road (black lines) mainly caused by internal combustion engines of the vehicles. The values of the measuring station indicate that the position of this station is very close to this road. The figure also depicts that the building next to the road blocks the wind to carry the NO_x away from the hotspot, which causes increased local concentrations. Sections around this spot only a few meters away from the road reveal much lower

values of the NO₂ concentration.

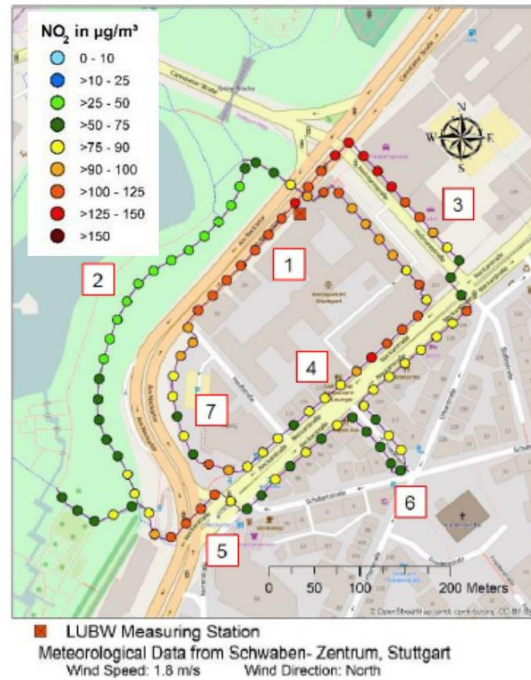


Figure 6: Map in the periphery of “Stuttgart-Neckartor” depicting the NO₂ concentrations (colored dots) next to the roads. The red square shows the position of the measuring station. Source: Vogt et. al. Universität Stuttgart, 25. ALS-Kolloquium “Stickstoffoxide und Feinstaub in Städten”

Figure 8 shows the exceedance hours per annum since 2004 with a limit of 200 µg/m³ NO_x in the atmosphere. The annual limit for exceedance hours had been 175 hours until 2009 and was reduced to 18 hours in 2010. In 2005 and 2006 the measurement station “Am Neckartor” counts over 800 exceedance hours. Since then the values dropped by about 99 percent until 2018. Since 2017 the annual exceedance hours are below the limit of 18 hours.

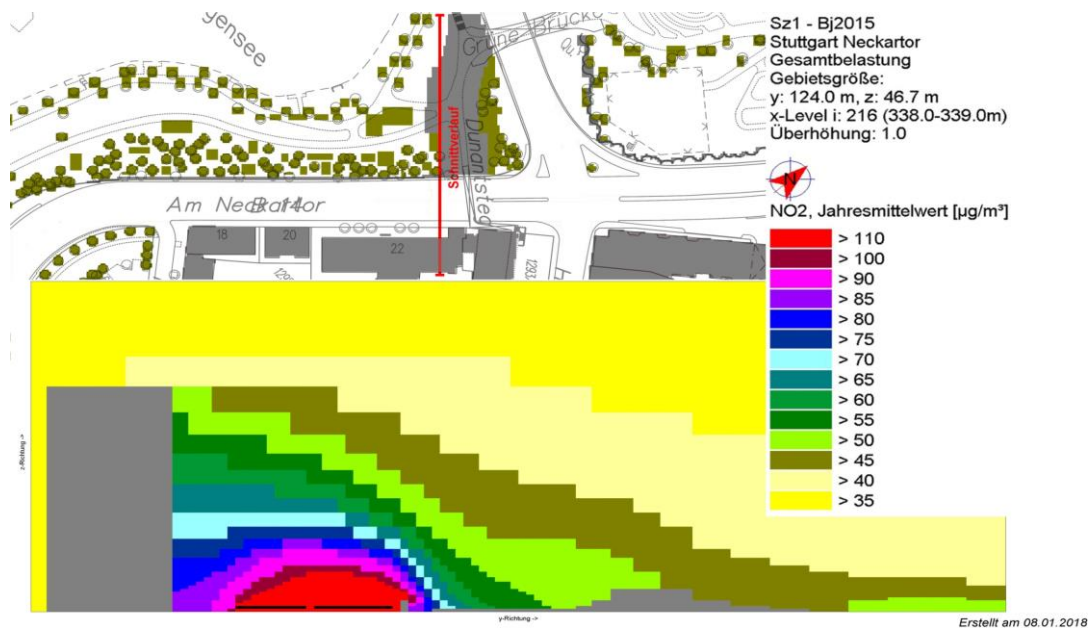


Figure 7: Sectional view of the yearly average NO₂ immissions shown in a profile of the area around the measurement station “Stuttgart-Neckartor”. Source: Aviso GmbH

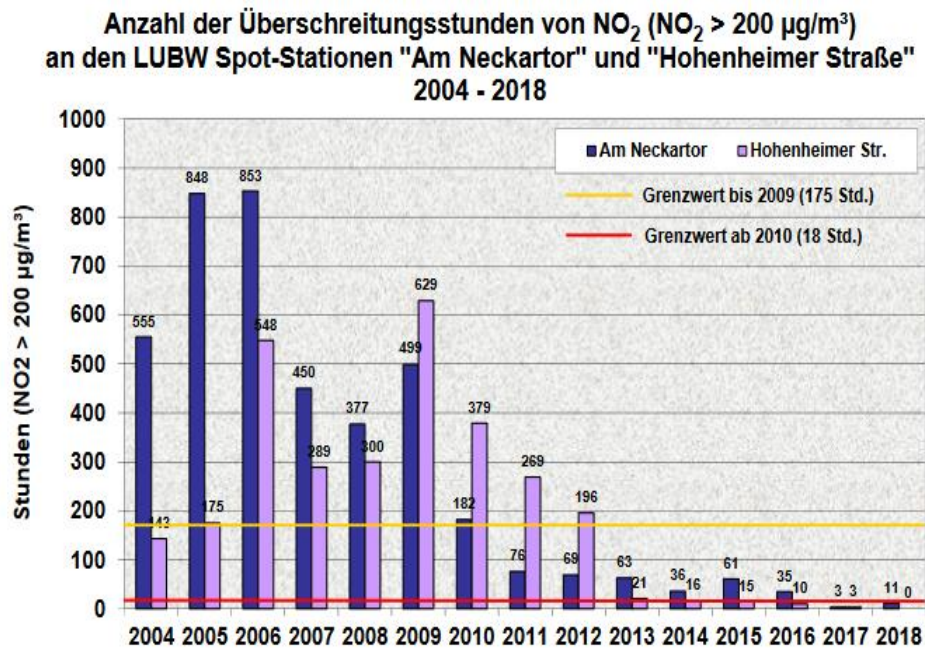


Figure 8: Exceedance hours of the NO₂-limit of 200 µg/m³ for “Stuttgart- Neckartor” (grey), and “Hohenheimer Str.” (dark red). The exceedance hour limit was 175h a year (yellow horizontal line) and is 18h a year since 2010 (red horizontal line). Source: LUBW, Grafik: AfU Stuttgart, Abt. 36-4

The yearly average of NO₂ concentration in the air is limited to 40 µg/m³ nationwide. Figure 9 shows the values for the annual average at “Stuttgart-Neckartor” from 2004 to 2018. Since 2006 with the highest concentration of 121 µg/m³ the value has been decreasing continuously by about 40 percent. However even in 2018 the yearly average of NO₂ immission at this spot is still not low enough to meet the requested limit.

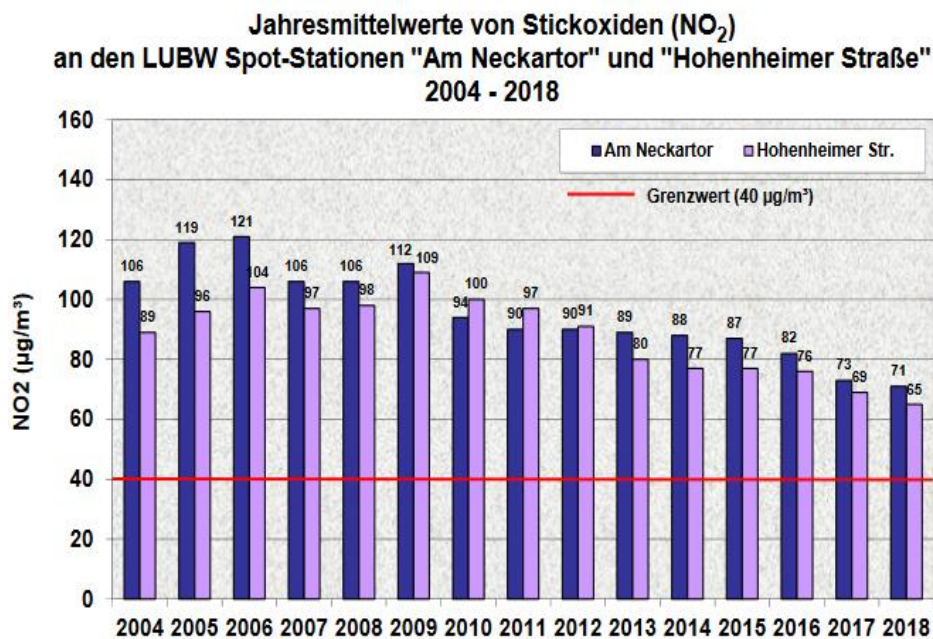


Figure 9: Annual average of the NO₂ for “Stuttgart- Neckartor” (grey), and “Hohenheimer Str” (dark red). The NO_x limit is 40 µg/m³ (red horizontal line). Source: LUBW, Grafik: AfU Stuttgart, Abt.36-4

The increased NO₂-immission values led to stricter emission limits for combustion engines. The exhaust

aftertreatment systems for current newly registered vehicles have been improved. Recent studies show that Euro 6d Diesels typically meet the limit of 80 mg/km and even stay far below the critical value (see figure 10). That points out the further decreasing of NO₂ immissions in the next years.

Diesel-Pkw:

Modell	Abgas-norm	Mess-temperatur	RDE: NO _x in mg/km
Audi A8 50 TDI	6c	23,4° C	15
BMW 520d Steptronic	6c	14,0° C	5
BMW 520d Touring	6d-TEMP	5,4° C	1
BMW X2 xDrive 20d	6d-TEMP	6,8° C	23
Citroen Berlingo BlueHDI 130	6d-TEMP	5,8° C	7
Honda Civic 1.6 i-DTEC	6d-TEMP	24,9° C	101
Kia Ceed 1.6 CRDi	6d-TEMP	18,8° C	22
Mercedes A 180 d	6d-TEMP	1,2° C	40
Mercedes C 220 d	6d-TEMP	19,5° C	0
Opel Astra 1.6 D	6d-TEMP	3,3° C	1
Peugeot 308 SW BlueHdi 180	6d-TEMP	13,3° C	30
Volvo XC60 D5 AWD	6d-TEMP	7,9° C	56
VW Golf 1.6 TDI SCR	6d-TEMP	-0,4° C	14

Figure 10: NO_x-values of a RDE-study of Euro 6 Diesel-passenger cars of different manufacturers. Source: ADAC

●● *Exposition / Measures*

The debate about pollutant thresholds is equivalent to a never ending story. The federal government of Germany was seeking scientific advice from experts in Halle*. The study of the national academy of Science Leopoldina came to the solution that a further reduction of NO₂ immissions is always appreciated but stricter legal limits for human health are not recommended**.

Not only the limits at all need to be discussed, but also the measurement method. It is obvious that pollutant concentrations around the roads depend on the distance to the exhaust source and the air circulations in this environment. Figure 12 shows NO₂-values close to a highly frequented road in Reutlingen. The immission concentration significantly depends on the distance to the road. It is obvious, that the measurement position has a strong impact on the measured results. Unfortunately there is no recommendation for the distance of the measuring station to the road in Germany, but a maximum distance of 10 meters (figure 11). This leads to close measurement distances. In opposite to Germany there is a recommendation in the USA within 20 meters and the maximum distance is 50 meters.

	Distance of measurement station form road		High		Source
	Empfehlung	max.	min.	max.	
Deutschland	-	10 m	1,5 m	4 m	39. BImSchV
USA	innerhalb 20 m	50 m	2 m	7 m	EPA Technical Document

Figure 11: Comparison of parameters of the positioning of traffic-related measurement stations

*Source: <https://www.mdr.de/nachrichten/politik/inland/schadstoff-grenzwerte-leopoldina-100.html>

**Source: Nationale Akademie der Wissenschaften Leopoldina (2019): Saubere Luft. Stickstoffoxide und Feinstaub in der Atemluft: Grundlagen und Empfehlungen. Halle (Saale).

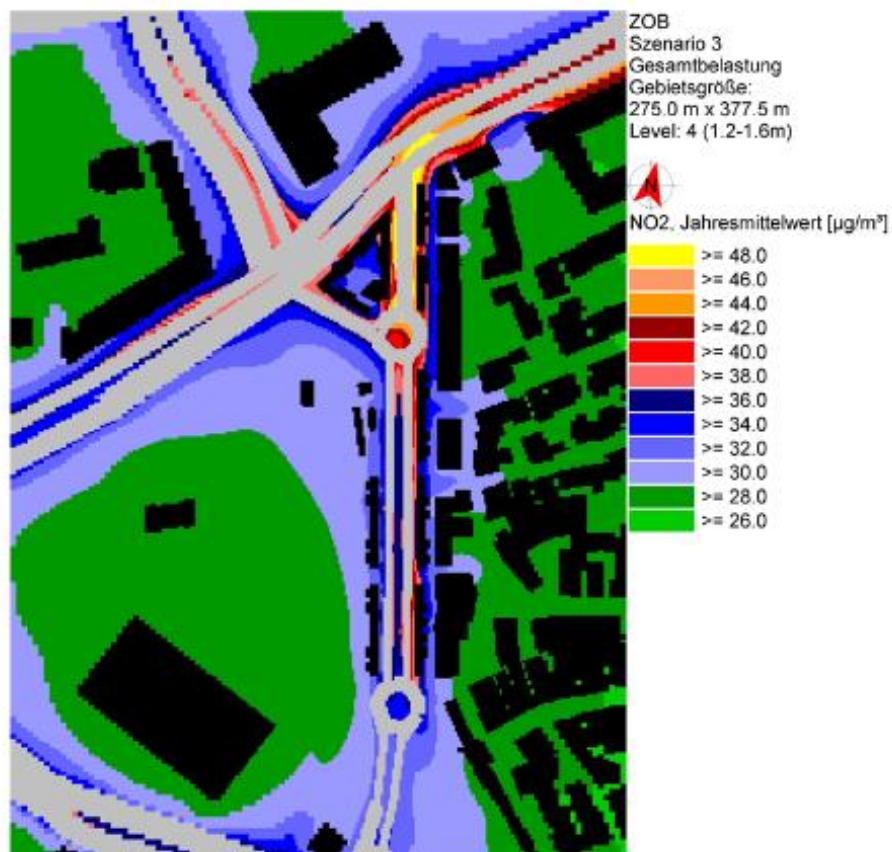


Figure 12: NO₂-values on a high traffic road. Colored sections show the annual average of NO₂ immissions. Source: Aviso GmbH

As a results of this complex discussion it is clear, that even today the internal combustion engine technology contributes to the immissions inside cities. Nevertheless there is a strong decay and with most modern engine technology the immission impact of internal combustion engines can be neglected.