The effect of passage blocking for old diesel vehicles on NO2-immissions at two street lines in Hamburg (Germany)

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Highlights

- Effect of old diesel passage blocking to reduce NO2-immission at two traffic sites could be isolated from other NO2-reduction causes.
- Passage blocking alone reduced NO2-immission by 13% -16 % of the sum of NO2- + NO-reduction.
- Modelling the effect of traffic measures could project measured NO2-immission changes in a rather appropriate way.

Keywords: nitrogen oxides, atmosphere, traffic, diesel,

Abstract

NO- and NO2-concentrations at 15 monitoring network stations throughout Hamburg decreased during the last years. But still NO2-concentrations surmounted the legal limit at 4 traffic sites. Therefore two street lines in Hamburg were blocked for old diesel vehicles since 1 June 2018 after a thorough scientific model evaluation of several options to reduce NO2-burden. NO- and NO2-concentrations monitored at two sites, where old diesel passage was blocked, decreased also, but much more than at the other thirteen network sites, namely by additional 47 % - 49% for NO and by additional 11% -14% for NO2. These additional decreases can be attributed to passage closing of old diesel vehicles. NO2 / (NO + NO2) reduction ratios in air concentrations at the two streets were quite similar (26% and 30%), although the measures taken differed because of different traffic quality and volume. The fact that NO- and NO2-concentrations decreased at the two blocked streets in a similar way indicates, that the different measures for old diesel vehicles taken were quite adequate. NO2-immission values in 2020 got under the legal limit. During blocking, NO- and NO2-concentrations decreased only very slightly on sundays, whereas on working days the concentrations decreased at the thirteen network stations and at the two blocked street stations by about 27% for NO and by about 14% for NO2 in quite a similar way.
PM10 concentrations did not react on the traffic restriction for old diesel vehicles. The uncertainties of the NO2-concentration measurements and of NO2-health effects give ample room for legal interpretation of the present NO2-immission limit.

1. Introduction

In recent years the concentration of air pollution in urban areas was of high concern in public and scientific discussions (e. g. Coghlan 2015, Lindrigan et al. 201, Sinharay et al. 2017, UmweltBundesamt 2018 a, WHO 2020). The concentrations of atmospheric short living air pollution trace substances like SO2, NO, NO2, PM10 decreased in most areas over time as in Hamburg, shown e.g. in fig.1. However, the annual ozone concentration in Hamburg increased since the beginning of O3-measurements. Despite the general emission decrease of NO and NO2 on the road (Carslaw et al. 2019), the legal immission concentration limit of 40µg/m3 for NO2 in the atmosphere was often surmounted at traffic sites in Hamburg (fig. 2). At other monitoring sites in Hamburg NO2-concentrations were quite lower (fig. 2).
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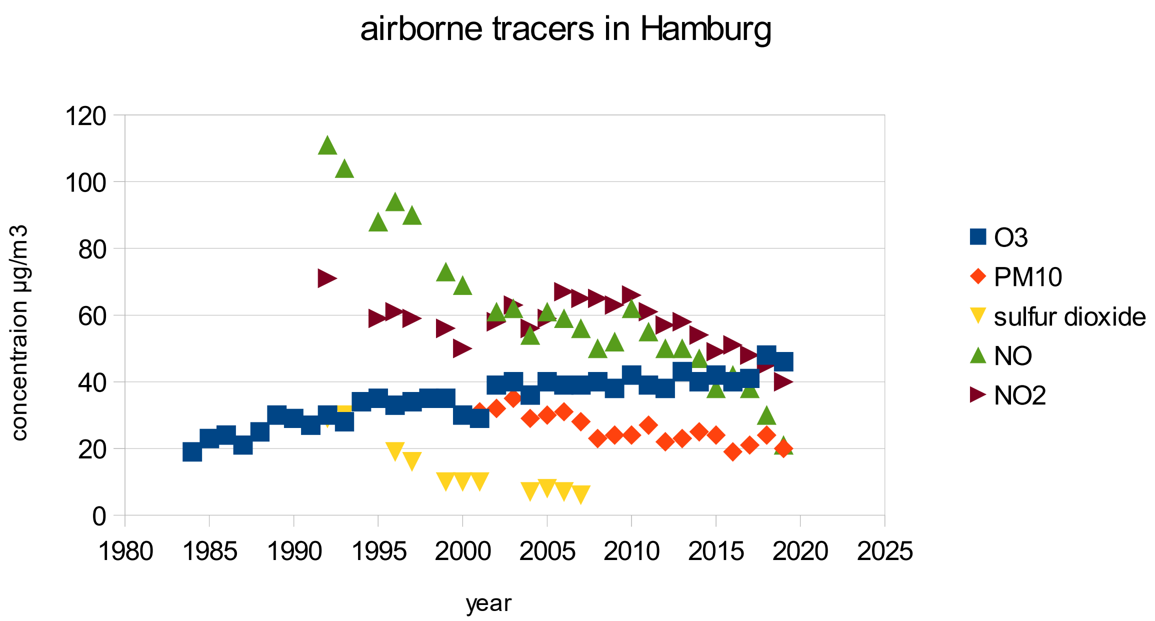

Fig. 1 trend of short living air constituents at 2 stations in Hamburg
O3: Sternschanze, all others: Stresemannstreet.

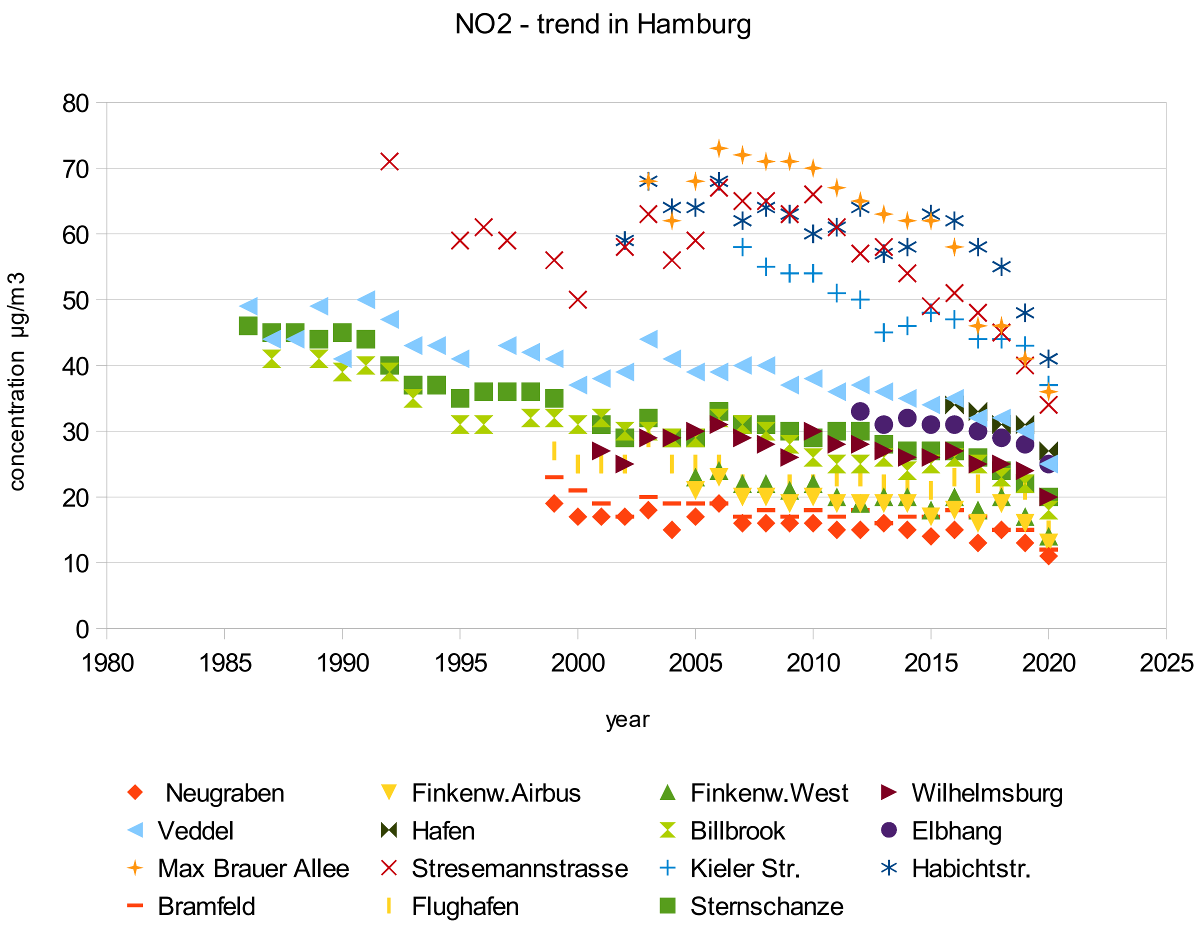

fig. 2 NO2-values at 15 monitoring stations in Hamburg. At the 4 traffic stations, Habichtstr. , Kieler Str., Max Brauer Allee, Stresemannstrasse, the legal limit 40 µg/m3 is just reached in 2020.

Health effects were claimed to be caused by atmospheric NO2 and, therefore, an engaged debate was led to reduce NO2-concentrations at urban sites (e.g. Fauastini et al. 2014, US EPA, 2016, Jonson et al. 2017, UmweltBundesamt 2018 b).The NO-concentrations decreased faster than the NO2-concentrations. In Hamburg the immission ratio NO2-N / (NO2-N+NO-N) increased from about 0.29 in the beginning of the nineties of last century to about 0.55 of today thirty years later. But for which reasons? NO2 can be emitted into the street atmosphere directly from vehicle motor exhausts or it can be formed within the street atmosphere from precursors. Furthermore it can be transported from the urban background and from the hinterland of the urban area to the street site. Based on atmospheric measurements of the broad field distribution of NO2, the direct source fraction within a street atmosphere was estimated to be about 14% to 18%, the secondary source of the fraction generated within a street atmosphere to be also about 14 % to 18% of the measured NO2-concentration at the street site (LUBW 2016, Hueglin 2016). Thus 28% to 36% of the NO2-immission is produced within the street atmosphere. Reducing the traffic frequency and the passage of diesel cars for a street line will mainly reduce this fraction.
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To quantify air pollution concentrations, especially of NO2 at heavy traffic sites in cities, reaction kinetic models were set up merging emission sources, atmospheric motions and chemical reactions (e.g. Diegmann and Mahlau 1999; Diegmann, 2008, Diegmann 2011, Wang and Zhang 2012, Kuik et al. 2018, Pfaefflin et al. 2019, Chan et al. 2019). With the help of such models, the effect of traffic changes on NO2-concentration can be estimated. It is, however, difficult or nearly impossible to quantify in a correct way necessary input data to model small scale situations in time and space.

The ratio NO2 / (NO+NO2) in traffic exhausts depends on many factors, e.g. on engine type, driving conditions, outside temperature. This ratio can be as high as 30% and as low as 1 % (Lenner 1987, Carslaw 2005, Carslaw et al. 2018, LUBW 2014). To facilitate concrete measures a set of software packages was developed to guide and quantify emission - and immission- scenarios for clean air plans. This modular system IMMIS was used in many situations to investigate traffic problems in Germany (Diegmann and Mahlau 1999, Diegmann and Hartmann 2006, Diegmann 2008, Diegmann 2011, IVU Umwelt GmbH, 2021). This screening modular system was also applied for Hamburg and discussed here to estimate the effect of different measures to reduce NO2-air pollution problems caused especially by heavy traffic at several hot spots (Behoerde fuer Umwelt und Energie, 2017, IVU Umwelt GmbH, 2018).

The general difficulty in quantifying all the processes involved is especially enlarged by uncertainties in model input data. Emission factors on the road for NO and NO2 have often shown to be far beyond the ones encountered during tests for type approval (Mittermaier and Klemp, 2004, Carslaw et al., 2011, LUBW, 2014, O'Driscoll et al. 2016, Jonson et al. 2017). The motor techniques and their exhaust controls change with the traffic fleet on the roads. The contribution of different sources to airborne NO2 in a rather diversified agglomeration like Hamburg is quite complex, that means not really known just offhand at different sites and times.

The potentials of environmental zones subject to stickers or to traffic control measures were estimated for many cities in Germany with quantitative models. Calculations for measures to be taken resulted most often in modelled concentration decreases of up to some percent of airborne pollutants (Diegmann, 2013). However, it was not possible to verify these projections, because placebo comparison field tests could not be established. Nevertheless, intensive and ambitious efforts were undertaken to quantify air pollutant emission rates, transport flows, chemical reaction rates and resulting air concentrations with the modular model system IMMIS net/em/luft (Stern 1997, Diegmann 2008, Diegmann 2011). This experience led to the decison to evaluate different political options to change traffic in Hamburg by such a modelling approach. The results of these measures could be measured by the many air pollution monitoring stations throughout Hamburg (Behoerde fuer Umwelt, Klima, Energie und Agrarwirtschaft der Freien und Hansestadt Hamburg 2021).

Which traffic change is most effective in reducing NO2 and how large is the reduction? The City of Hamburg has stepped forward and has implemented a field experiment in blocking old diesel traffic at two street lines. The hope was to lower the immission of NO2 at these traffic sites in due time under the legal limit of 40 µg/m3.The results of this approach to reduce NO2-levels will be discussed here.

2. Basic traffic information for Hamburg

For the agglomeration of Hamburg the quantitative model system IMMIS with special reference to traffic sites were set up (Lorents et al. 2010; Behoerde fuer Umwelt und Energie, 2017) for 2014 and compared with measured concentrations to calibrate the model. The immission reduction of city wide general planning measures were calculated to reduce NO2-immission, by e.g. improvement of the public personal transportation system, the traffic management, the E-mobility or the ship emission rules. They together reduced the NO2-immission at the traffic sites Stresemannstreet only by about 3 µg/m3 in the year 2020 and by about 5 µg/m3 in the 2025, and Max Brauer Allee by 2µ/m3 and 3µg/m3 respectively (tab.1). These reduction rates were not large enough. Therefore additional reduction measures were considered and the effect of site specific traffic changes were calculated with the IMMIS model system (Behoerde fuer Umwelt und Energie 2017).

A status quo for the traffic at two street lines was elaborated. For Stresemannstreet a frequency of about 33 000 vehicles / 24 hours was estimated. Of the total NO2-sources for the NO2-concentration at Stresemannstreet about 30% were attributed to heavy utility vehicles and about 24% to passenger cars. For Max Brauer Allee a lower frequency of about 22 000 vehicles / 24 hours was estimated. There, about 8% of the total NO2-fraction emitted were attributed to heavy utility vehicles and about 20% to passenger cars. Therefore, at Stresemannstreet, a much higher fraction of heavy utility vehicles was responsible for the primary NO2-emission.

With the IMMIS package model (Behoerde fuer Umwelt und Energie, 2021) the NO2-situations for the years 2014 as the then present situation and for the year 2020 with different assumed measures were modelled (tab 1).

Future concentrations of NO2 at the two passage restricted street lines were estimated taking into account additional measures in addition to the city wide ones, namely street specific realistic measures to reduce NO2-concentrations. General meteorological conditions were assumed for the future, so that annual averages of NO2-concentrations could be projected (tab.1).

At Max Brauer Allee the effect of two modelled measures, namely city wide measures and blocking all trucks for Max Brauer Allee seemed to be too small, so that an additional effect of passage blocking for all diesel vehicles was estimated. For Stresemannstreet the reduction measures seemed to be rather high and political not suitable. Thus based on these model results measures were finally taken, which seemed to be appropriate and to get the public to agree them. Detours for blocked vehicles resulted NO2-concentrations in these areas were calculated to increase, but to still fall under the legal limit. Therefore, a thorough basis for a political decision to optimise traffic conditions with respect to NO2-concentration at two street lines was developed. It was elaborated with all its uncertainties on the basis of scientific expert judgement and model information for Hamburg.

The measures finally taken were not modelled, but they are based on the different model results, which guided the measures to be taken. The following measures were finally taken from 1 June 2018 onwards: Max Brauer Allee: blocking the passage for all diesel vehicles with Euro norm less than 6 (passenger cars) and less than VI (trucks); Stresemannstreet: passage blocking for old diesel trucks with a permissible weight of more than 3.5 t with Euro norm V and smaller. Residential traffic and regular bus lines are allowed to enter these two streets. The finally implemented measures for Max Brauer Allee and for Stresemannstreet should be less effective in reducing NO2-concentrations than the strongest measure predicted. The imposed measure did not block all diesel vehicles as was calculated, but only those with Euro norms less than 6 and VI. A realistic decrease of 5µg/m3 may be expected with the implemented measures.

Street line	modelled measures	modelled NO2-change (µg/m3) 2020	2025
Max Brauer Allee	city wide traffic changes	- 2.1	-3.1
	In addition blocking all trucks	- 0.9	
	or blocking all diesel vehicles	- 7.2	
Stresemannstreet	city wide traffic changes	- 3.2	-3.1
	In addition blocking all trucks	- 3.2	
	or blocking all diesel vehicles	- 14.1	

tab. 1 modelled changes of NO2-concentrations at traffic sites for different measures; The changes for the final implemented measures were not modelled.

3. Measurements

In Hamburg, the air chemistry situation is surveyed by a particular administrative body, the Behoerde fuer Umwelt, Klima, Energie und Agrarwirtschaft, Institut fuer Hygiene und Umwelt (2021). Fifteen air monitoring stations are distributed over the entire Hamburg area, analysing NO, NO2, and sometimes also total particulate matter below 10 µm diameter (PM10) besides other components.
Two stations are situated at the two street lines chosen for blocking the passage of old diesel vehicles, the other thirteen stations quantify the concomitant development and change of NO- and NO2-concentrations. The measurements at these thirteen stations can serve as a placebo test for the measurements at the two stations blocked for old diesel vehicles.

Presently, the concentrations of NO are measured with the Horiba APNA 370 instrument via the intensity of chemiluminescence after reaction with prescribed O3. The concentration of NO2 was derived from two NO-measurements. One NO instrument measured NO only, another measured NOy, that means the sum of NO and NO2 and in addition other possibly present nitrogen oxides like N2O5, N2O4, HNO2, HNO3, NO3, which could be reduced to NO by a metal catalyst within the intake line. Therefore, this instrument determines the total sum of all nitrogen oxides (NOy) possibly present in the atmosphere and possibly being reduced to NO. The concentration difference between NO and NOy is interpreted to be NO2 and most often named NO2 as in the monitoring network of Hamburg. The mass of the particles with diameter less than 10µm (PM10) is measured with an oscillating TEOM micro balance (Thermo Scientific).

The instruments for air monitoring concentrations of NO, NO2, and PM10 are placed in containers on the north east side walk at Stresemannsstreet Nr. 95 and at Max Brauer Allee II, in front of house Nr. 92/94 on the middle stripe, which is planted with trees. The air to be analysed was taken at two different heights: at 1.7 m and at 4 m above the ground for gases and at 3.5 m height for particles at Stresemannstreet. Gases were taken at 1.5 m and 4 m and particles at 4 m height at Max Brauer Allee II.
At the thirteen sites the same air components are measured with the same techniques, but at sites, where no old diesel vehicles were blocked in their vicinity (fig. 2). It can be

assumed that at these stations the effects of a changing vehicle fleet, and of changes of other sources and sinks of nitrogen oxides are effective in a similar way as at Stresemannstreet and at Max Brauer Allee. Especially a change in atmospheric transport conditions can influence the measured NO2-concentrations.The weather situations at the two blocked stations and at the thirteen network stations are rather similar. The relative results of these thirteen stations can be transferred to the two blocked sites as concomitant conditions.
How important it is to include atmospheric conditions in evaluating the cause of concentration changes with time is shown in the discussion of the effect of Corona epidemic on NO2-concentrations at traffic monitoring sites in Germany (Plass-Duelmer et al. 2020). Only if the atmospheric dispersion was included according to the average meteorological situation during 5 years before 2020 with a fit-function and not with the present special meteorological situation during the onset of corona epidemic, a decrease of about 23 +-6%% of NO2-concentration could be deduced for working days during the first 4 weeks of Corona epidemic in 2020. .

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It is reasonable to assume that the average concentrations, measured at these other network stations in Hamburg, but without traffic blocking for old diesel vehicles in their vicinity, could serve as a placebo reference for the year with old diesel blocking at the two streets.

For this study the concentration trends of NO, NO2, and PM10 with time were taken from values published online by Behoerde fuer Umwelt, Klima, Energie und Agrarwirtschaft (2021) for the two blocked stations Stresemannstreet and Max Brauer Allee II and for all other network stations in Hamburg.

3.1 Monitoring airborne nitrogen monoxide (NO) and nitrogen dioxide (NO2) in Hamburg

3.1.1 Annual averages of NO- and NO2-concentrations

Concentrations during four years before the passage blocking for old diesel vehicles (1 June 2014 to 30 May 2018) and during the first year with blocking at the two traffic sites (1 June 2018 to 30 May 2019) are given in tab.2 and for the other thirteen network stations in tab. 3.

	NO2			NO			PM10		
	Cm	Cy	C	Cm	Cy	C	Cm	Cy	C
Stresemannstreet	41.2	49.9	0.8	24.1	39.9	0,6	22.8	22.6	1
Max Brauer Allee II	43.8	55.6	0.8	38.3	65.0	0.6	20.8	20.8	1

tab. 2 Average daily concentrations (µg/m3) of NO2, NO and PM10 at two streets in Hamburg during a year with old diesel restriction (Cm, 1 June 2018 to 30 May 2019) and during 4 years before old diesel restriction (Cv, 1 June 2014 to 30 May 2018) and the ratios C= Cm/Cy.

In the following air concentrations in Hamburg are compared for the time period with blocking at the street lines Stresemannstreet and Max Brauer Allee and without blocking. Also the concentration trends at the thirteen network stations are separated in these two periods, although blocking was not imposed there. NO2-concentrations of the thirteen network stations in Hamburg decreased from the four years before blocking to the one year with blocking at the two street sites to about 91% and to about 93% of the former NO- and NO2-values respectively (tab.3). These relative decreases with time are quite similar throughout Hamburg.

It can be assumed that this relative reduction in concentrations could also have occurred and would also have been observed at the two blocked sites, however without the traffic blocking in place. The measured concentrations during the four years without blocking at the two sites were extrapolated via the factors 0.91 and 0.93 resp. derived in tab.3 to the first year with blocking at the two traffic sites (tab.4)

Monitoring sites	NO2	NO	PM10
Finkenwerder Airbus	0,9	0,88	-
Elbhang	0,9	1	-
Veddel	0,9	0,9	1,1
Sternschanze	0,9	0,83	0,94
Habichtstraße	0,92	0,89	0,93
Bramfeld	0,92	0,96	-
Hafen	0,93	0,77	0,92
Billbrook	0,93	0,78	0,85
Kielerstrasse	0,94	0,85	0,92
Neugraben	0,97	0,91	-
Finkenwerder West	0,97	0,93	1,1
Wilhelmsburg	0,97	0,83	1,1
Flughafen	1,0	1,2	1,2
All monitoring sites of this tab. 3	0,93+-0,03	0,9+-0.1	1,0+-0,1

tab. 3 Ratio C=Cm/Cy of average concentrations (µg/m3) of NO, NO2 and PM10 at network stations in Hamburg. Cm: 1 June 2018 to 30 May 2019; Cy: 1 June 2014 to 30 May 2018. At these 13 network stations old diesel passage was not blocked. However, at Stresemannstreet and Max Brauer Allee II old diesel traffic was blocked during this one year period. .

	A	B	C	D	E %
NO (as NO2)					
Max Brauer Allee II	100	93	47	46	-49
Stresemannstreet	61	57	30	27	-47
NO2 (as NO2)					
Max Brauer Allee II	56	51	44	7	-14
Stresemannstreet	50	46	41	5	-11
NO + NO2 (as NO2)					
Max Brauer Allee II	156	144	91	53	-37
Stresemannstreet	111	103	71	32	-31

tab. 4 Average concentrations of NO and NO2 (given both as NO2 in µg/m3) at Stresemannstreet and at Max Brauer Allee; A: measured concentrations during 1 June 2014 - 30. May 2018 before old diesel restriction; B: calculated for 1 June 2018 - 30 May 2019 without old diesel restriction at these 2 streets, A x 0.93 for NO; A x 0.9 for NO2; C: measured concentrations during old diesel restriction; D absolute difference between B and C due to the restriction effect only; E: D as an additional decrease in % of B (- D*100/B).

The thusly extrapolated but not measured concentrations include, therefore, all changes of air concentrations except traffic restrictions (tab 4, column B). However the measured concentrations in the one year at the two traffic sites with blocking (tab.4 column C) were still lower than the extrapolated virtual ones (tab. 4 column B). This additional decrease can be interpreted to be an effect of the blocking of old diesel vehicles. The amount of the NO-reduction (tab. 4, column D) is larger by about a factor of 5 to 7 than the NO2-reduction.The amount of old diesel passage blocking (column D in tab.4) contributes a rather large amount (column A minus column C) in reducing the concentration sum of NO and NO2. At Max Brauer Allee II it amounts to about 82 % and at Stresemannstreet to about 80% in addition to the small general trend in time (columns A minus B, tab.4).

The two blocked streets show rather similar relative reductions in NO -, NO2 - and PM10 - concentrations after blocking the passage of old diesel vehicles, although the restriction measures were different at both street lines (tab 2). At Stresemannstreet and at Max Brauer Allee trucks with less than Euro norm VI were blocked. But at Max Brauer Allee in addition to trucks old diesel passenger cars with less than Euro norm 6 were blocked, too. (see paragraph 2). This means that at Max Brauer Allee and at Stresemannsteeet different measures were taken resulting however in a similar effect at both streets. These two measures resulted in a similar decrease at both streets in NO2- concentrations. Blocking of old diesel vehicles decreased the NO2-concentrations during the one year 2918/2019 by about 5µg/m3 and 7µg/m3 (tab.4). These values point into the same direction as the IMMIS package model projections with 7µg/m3 to 14µg/m3, but with stronger reduction measures taken as modelled (tab.4). Therefore it can be assumed, that the underlying assumptions choosing these measures to block passage for old diesel vehicles and choosing the extent of these measures for both street lines were quite targeted. The differences still present are acceptable taking into account the uncertainty in model structure, in the input data and in their resolution in time and space. The results are encouraging to consider expert traffic modelling in guiding measures to plan traffic management.
For the above evaluation of blocking old diesel vehicles the time span from 1 June 2018 to 30 May 2019 was stipulated as the very first year after the blocking onset. Any other annual time span could have resulted in different numerical values, since the measured concentrations would differ somehow. The Behoerde fuer Umwelt, Klima, Energie und Agrarwirtschaft der Freien und Hansestadt Hamburg (2021) publishes daily average concentrations for all its air chemistry stations. For the entire year 2019 the same passage restriction for old diesel vehicles was still in action at the two streets blocked since 1 June 2018. The annual measured NO2-concentrations at Stresemannstreet and at Max Brauer Allee II, 41.2 µg/m3 and 43.8 µg/m3 for the annual year 2019, fall close to the legal limit of 40µg/m3 aimed at. In 2020 the NO2 - concentrations already fell to 35µg/m3 and 36µg/m3 respectively well below the legal limit of 40 µg/m3. However, the additional private and economic shut down due to the Corona epidemic probably helped to lower the concentrations (Plass-Duelmer 2020).

3.2 Influence of Corona epidemic on NO2-concentrations during passage restriction for old diesel vehicles

Corona epidemic reduced economic and private activity worldwide and also in Hamburg. Therefore airborne concentrations of NO2, especially in cities, should decrease. At the same time the weather could change thus influencing the dispersion of exhaust plumes and the vehicle fleet may have changed having new emission factors for NO and NO2. Eliminating the weather influence by a fit-function it could be shown that NO - and NO2 - concentrations decreased considerably on working days and sundays and holidays with the onset of Corona epidemic in Germany (Plass – Duelmer, 2020).
In Hamburg the measured NO2-concentrations decreased from the one year before Corona epidemic (March 2019 to February 2020) to the one year with Corona epidemic (March 2020 to February 2021) at the thirteen network stations and at the two sites with blocking of old diesel vehicles. The network sites decreased to 91%+-8% in a quite similar

way as the two blocked sites to 91%+-7%. This is a correlation with time, not necessarily a causal relation with the epidemic. How much of these quite similar decreases to 91 % is caused due to changes of weather, of the vehicle fleet or of other emission sources or of the overall one year effect of the corona epidemic?
In Europe NO2-concentrations analysed with remote sensed sentinal - 5P-images indicate a significant correlation, not necessarily a causal relation, between the population's activity level, industrial production and traffic volume and the reduction of NO2-values (Mesas-Casrrascosa et al. 2020, Virghilenau et al. 2020).

3.3 NO- and NO2-concentrations on sundays and on working days

The immission concentration values for NO and NO2 for individual days are published online (Behoerde fuer Umwelt, Klima, Energie und Agrarwirtschaft, 2021), so that concentrations on sundays and on working days can be separated. To evaluate the effect of different weekdays for old diesel passage restriction at Stresemannstreet and Max Bauer Allee two separate time spans were chosen to compare daily annual concentration averages: one time span covers the entire years 2013 to 2017 without blocking passage of old diesel vehicles. During the four year time span the blocking of old diesel vehicles was not in place throughout Hamburg, whereas during the entire year 2019 Stresemannstreet and Max Brauer Allee were closed for passage of old diesel vehicles. In general, the concentrations decreased with time between these two periods (tab. 3, tab. 5).

On sundays the average decreases were relatively small at thirteen network stations (8% for NO and 3% for NO2). This suggests that on sundays the net emission of nitrogen oxides seem to remain rather constant with time in Hamburg. In contrast on working days the concentrations at the network stations were lower in 2019 for NO by 26% and for NO2 by 12% compared to the period 2013 – 2017 (tab.5). This concentration difference for different weekdays indicates that throughout Hamburg the net emission of nitrogen oxides has changed from working days to sundays.

		Hamburg network	Stresemannstreet	Max Brauer Allee
On sundays	NO2	0.97+-0.09	0.77	0.75
	NO	0.92+-0.25	0.76	0.58
On working days	NO2	0.88+-0.05	0.75	0.70
	NO	0.74+-0.13	0.48	0.47

tab. 5 ratio C = Cm/Cy of concentrations at 13 network stations in Hamburg, where no old diesel restrictions were in place in their neighbourhood, and at two traffic stations (Stresemannstreet, Max Brauer Allee).Cy for the years 2013 – 2017 without any blocking of old diesel vehicles and Cm for the year 2019 with blocking of old diesel vehicles at the two traffic sites only.

At the two blocked stations the ratio values C on sundays for NO and NO2 were smaller than at the network stations (for NO by 0.16 and 0.34 and for NO2 by 0.20 and 0.22, tab.5). On working days the ratio values for concentrations at the network stations were lower than on Sundays. The overall net emission could have become smaller with time or the net destruction rate have become larger. At the blocked sites the concentration differences over time were larger than at the network site. This clearly is an effect of the blocking of old diesel vehicles during the year 2919. The relative decreases at blocked stations were higher for NO (0.26; 0.27) than for NO2 (0.13 ; 0.18).The differences on working days are quite similar to the average values for all weekdays at the blocked streets as discussed in chapter 3.1 for NO and NO2 (0.20; 0.32 and 0.5; 0.17). However then the time spans were slightly different from the 4 years from June1913 to May 2018 without blocking to the year with blocking from June 2018 to May 1919. The larger concentration differences at the two blocked traffic sites for sundays and working days compared to the network stations could indicate, that the traffic quality or the traffic volume or both changed during the two time periods. NO changed most from sundays to working days at the network sites and at the two traffic sites. This reflects the decreasing trend of NO in the entire Hamburg area (fig 1).

3.4 Uncertainty of measured NO2-concentrations

If, e.g., observed speed limits are subject to legal punishment a range of uncertainty is often granted before official and legal measures are taken. With respect to NO2-concentrations measured in outside air at monitoring sites two uncertainties could be taken into consideration:

A air intake position at the street can be chosen within a certain range, and
B NO2 - values are measured with a limited accuracy only.

3.4.1 Air intake position

The micro intake position and especially the intake height can vary within certain limits (EU-Europaeische Union, 2008). The directive states: “As far as possible this has to be followed: - In general the intake height has to be between 1.5 m (breathing zone) and 4 m above the ground. A higher position of the inlet (up to 8 m) could be indicated under certain conditions.” At the two street sites in Hamburg, discussed here, NO and NO2 were measured at two heights: at 1.5 m and at 4 m above the ground at Max Brauer Allee II and at 1.7 m and 4 m at Stresemannstreet. At 4 m the concentrations were lower by about 7 % to 11% than at the 1.5 m and 1.7 m height for NO2 at both streets, with and without traffic blocking (tab. 6).

Ratio of concentrations at two different heights

	Before blocking of old diesel		during old diesel blocking	
	NO2	NO	NO2	NO
Stresemannstreet	0.93	0.82	0.92	0.82
Max Brauer Allee II	0.89	0.73	0.9	0.69

tab. 6 Ratio of concentrations of NO2 and NO in 4 m and in 1.5 m height (Stresemannstreet) and in 4 m and in 1.7 m height (Max Brauer Allee II).
For NO the values were lower at 4 m height by 18 % at Stresemannstreet and by 27% to 31% at Max Brauer Allee II with only small relative differences for blocked and unblocked passage for old diesel traffic conditions (tab. 6).

The vertical difference of NO is more pronounced than for NO2 indicating a faster reaction and stronger dilution influence for NO on the atmospheric transport way from lower to higher intake positions. Thus, the NO2 / NO2+NO) ratio of the immission ratio is changing with position and should not be mistaken as an emission ratio at the tail pipe.
Measured NO2 - concentrations at 1.5 m height levels could, therefore, be reduced by about 7 % to 11% to be still accepted for legislative evaluation in Europe. The intake height could be positioned at a 4m height instead of 1.5 m. The height relations of NO2 concentrations reported here agree with data of Behoerde fuer Umwelt, Klima, Energie und Agrarwirtschaft der Freien und Hansestadt Hamburg (2021), giving a concentration difference between the air intake at 4 m and at 1.5 m of about -20 % for NO and of about -7 % for NO2 at Stresemannstreet. NO2-concentrations decrease in addition with distance from the street rim. In about 15m to 20m distance the concentration has already decreased to about 70% to 75 % of the value at the street rim, depending on street

configuration and wind conditions (Richard-Bryant et al. 2017, Behoerde fuer Umwelt und Energie 2017)).

3.4.2 Analytical uncertainty for NO2-concentrations

The analytic method to determine the NO2-concentration is a matter of uncertainty. NO2 at the blocked sites and at the network stations in Hamburg is not measured directly, but derived from two different types of measurement. In the one measurement NO is determined via reaction with prescribed O3 and the amount of its chemiluminescence as a measure for NO-concentration.
For the other measurement the sampled air is flowing over a heated metal catalyst, so that all nitrogen compounds (e.g. NO2, NO3, N2O4, N2O5, HNO2, HNO3, PAN) may eventually be reduced to NO, the concentration of which is again measured with chemiluminescence. The difference between these two types of NO-measurements is attributed to NO2. This procedure assumes that only NO and NO2 and no other nitrogen oxides are present in outside air. This uncertainty was estimated to be about 10 % (Schwarzenbach and Hueglin, 2011) and up to 50 % (Dunlea et al., 2007) and would always overestimate NO2-concentrations. A NO2-uncertainty is also related to the absolute concentrations of NO and H2O (Gerboler et al. 2003). Therefore it is reasonable that NO2-concentration values at traffic monitoring sites at a height of 1.5 m above ground could at least be lowered by about 15 % to take into account uncertainties in air intake height and in the analytical method.

4. Effect of blocking old diesel on mass concentration of airborne particles (PM10)

Besides NO and NO2 also airborne particle mass PM10 is measured at the two streets blocked for passage of old diesel vehicles. Sources of urban airborne particles could be caused by whirling up dust and tire abrasion, by emission of home heating, small and large industrial activities and car and ship exhaust.
In Hamburg, airborne particle mass and other air concentrations decreased over a long time (fig.1). But during last years the particle mass load remains rather similar at all network stations and the two blocked stations (tab1, tab 2), with and without traffic restriction. The old diesel traffic, therefore, does not contribute significantly to airborne PM10 burden at these sites in Hamburg.

5. Medical assessment of atmospheric NO2-concentrations

This field experiment was initiated to reduce the NO2-immissions in Hamburg under the legal limit of 40µg/m3. However the medical significance of a strict 40 µg/m3 NO2-concentration as a limit for health damages is a matter of discussion. Epidemiological investigations indicate a range of atmospheric NO2-concentration above 40 µgr NO2/m3 is responsible for respiratory and lung health effects. One cannot pinpoint an exact concentration value as starting point for a health damage only due to NO2. However in some public discussions clear causal relations between N02-concentrations in air and number of deaths were drawn (Umweltbundesamt 2018, WHO 2020). In some labour law measures vague relations are accepted between assumed or claimed medical damages and working conditions, although a 100 % scientific proof cannot be given. A medical online statement of the Forschungszentrum Muenchen from 20 March 1918 (Umweltbundesamt 2018) argues and concedes: "epidemiology will not be able to deliver a proof for a causal relation, because it is not a controlled experiment (…) Furthermore diagnostic possibilities are missing for relating deaths of humans to the irritant gas … until then the epidemiology is the best tool we have to describe the effect of NO2 " (translated by the author GG).

6. Conclusion

A thorough analysis of the traffic at two street lines in Hamburg led to official measures to try to reduce the NO2-immission concentrations to below the legal limit of 40 µg/m3. The traffic was blocked for passage of old diesel vehicles taking into account the different traffic structures of the two streets. The effect of the blocking of old diesel passage on concentration changes could be separated from other reasons. Therefore the pure effect of a certain passage restriction could be quantified. This blocking of the old diesel passage during the year June 2018 to May 2019 has contributed to the total decrease amount of the NO2-concentration by about 56% and 58% and to the total decrease amount of NO by about 87% to 89% before the onset of corona epidemic. The different traffic measures taken at the two street lines resulted in a similar NO2-reduction for both streets indicating a goal oriented success of the measures. Together with the general decreasing trend in time and with the blocking effect for old diesel vehicles the one year corona effect calculated from 1 March 2020 onto the end of February 2021 lowered the NO2-concentration at the two blocked sites, now undercutting the legal annual concentration limit of 40 µg/m3. The measurements of air constituents in Hamburg continue. Therefore such an analyses of the blocking effect could be repeated, but the effect will be smaller, since old diesel vehicles with the same and older Euro norms will get smaller. This field experiment indicates that an expert based assessment of the traffic situation and a thereon following scientifically deduced political decision to reduce NO2-concentrations will probably separate the community in Hamburg not any further.

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.
Declaration of interest: none.

Acknowledgment
I thank A.M. Fiedler, C. Frels, and D. Matzen, Institut fuer Hygiene und Umwelt, Hamburg, for analysing and publishing online the air chemistry data for Hamburg in a continuous and immediate way.

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