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Impact analysis of changes in passenger vehicle fleet composition to reduce the NO_2 immissions

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Abstract

This paper presents a methodology to forecast the changes of NO_2 immissions due to changes in fleet composition of passenger vehicles and emission classes. Within this scope, possible changes in vehicle technologies (e.g. lower emission of diesel engines) are considered in different scenarios using the example of Munich. In line with this purpose, the traffic volumes and origin-destination data are obtained from a macroscopic traffic model, local registration statistics of vehicles are used to estimate fleet compositions. In addition, for immission modelling data on characteristic roadside structure as well as weather conditions of the investigation area are considered. For different scenarios with adapted passenger vehicle fleet compositions, the reductions of NO_2 immissions levels as well as the special distribution in the road network is calculated. Additionally, the remaining length of the road network, where the legal threshold of daily average of 40 $\mu g/m^3$ NO_2 in Germany is exceeded, is shown for each scenario. Moreover, the contribution of the sub-fleet of commercial cars to these changes in emission is calculated.

The results show that the higher share of low emission classes (e.g. Euro 6 RDE for diesel engines) lead to continues reductions of NO_2 immissions. The highest decrease of NO_2 immission in the main road network of Munich is calculated for use of petrol cars with emission class Euro 6 for all passenger vehicles. To achieve the goal that the predominant part of the road network is fulfilling the legal threshold for NO_2 immissions, a high share of electric vehicles is needed.

Keywords: fleet composition, emission class Euro 6, environmental imapct, NO_2 immission

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1. Introduction

The immission values of Nitrogen dioxide (NO_2) at the air quality measurement stations of The Bavarian Environmental Agency (Bayerisches Landesamt für Umwelt – LfU) at Landshuter Allee and Stachus in Munich exceed the maximum allowed annual mean value of 40 µg/m³ set by European Parliament (European Parliament; 2008) and German Federal Immission Control Act (BMJV; 2010) often. The motorised road traffic, especially diesel vehicles, is considered to be a main emitter of these NO_2 immissions. In order to decrease these immission values two general adequate approaches are suitable:

1. Improvement of fuel-driven vehicle fleet by using more environmentally friendly drive technologies (reduction of immission levels by substitution of vehicles with conventional engine by emission reduced vehicle types e.g. electric vehicles or vehicles with emission classes Euro 6/IV)
2. Reduction of traffic volumes on the roads using traffic management measures (reduction of traffic volume also decreases the total immission levels)

The second approach enables the reduction of NO_2 immissions in short term compared to the first approach. Within the 6th Update of Clean Air Plan for the City of Munich (Regional Government of Upper Bavaria, 2015) measure number one was stated as "the assessment of the investigation of traffic management related measures for reducing the traffic volume and their impact on reducing NO_2 immissions in highly polluted road segments and on air quality". The expert valuation of these measures will be conducted and should consider traffic control as well as traffic management measures in terms of their legal, spatial and traffic-related conditions. This study is finished, but the overall results are not shared with public yet.

This paper focuses on the first approach which aims at mid-term and long-term effects on NO_2 immissions. Following this approach, influences of changes in vehicle drive technologies can be assessed. Consequently, these results can help various stakeholders (e.g. automotive manufacturers or industry, trade and business associations) that are aiming to reduce NO_2 immissions by enhancing fleet compositions by setting new strategic goals and communicating between partners accordingly.

2. Methodology

2.1. Overview

The methodology of this study consists of three steps: in the first step, the traffic volume and, if needed, the change in traffic volume as a result of the investigated measures is modelled for each segment within the road traffic network of the investigation area on the basis of the macroscopic traffic model. Afterwards, the existing traffic volume and the traffic fleet composition for passenger vehicles, heavy-duty vehicles (HDV) and busses are used to calculate the traffic-related NO_2 emissions of each road segment. In the third step, a dispersion model for partially or completely closed roadside structures (i.e. street canyons) is used to calculate the traffic-related immission levels for the whole investigation area. These values are overlaid with the existing non-traffic-related pollution to get the overall NO_2 immission levels. An overview of the methodological approach is shown in Figure 1. In the following chapters these three steps are described in detail.

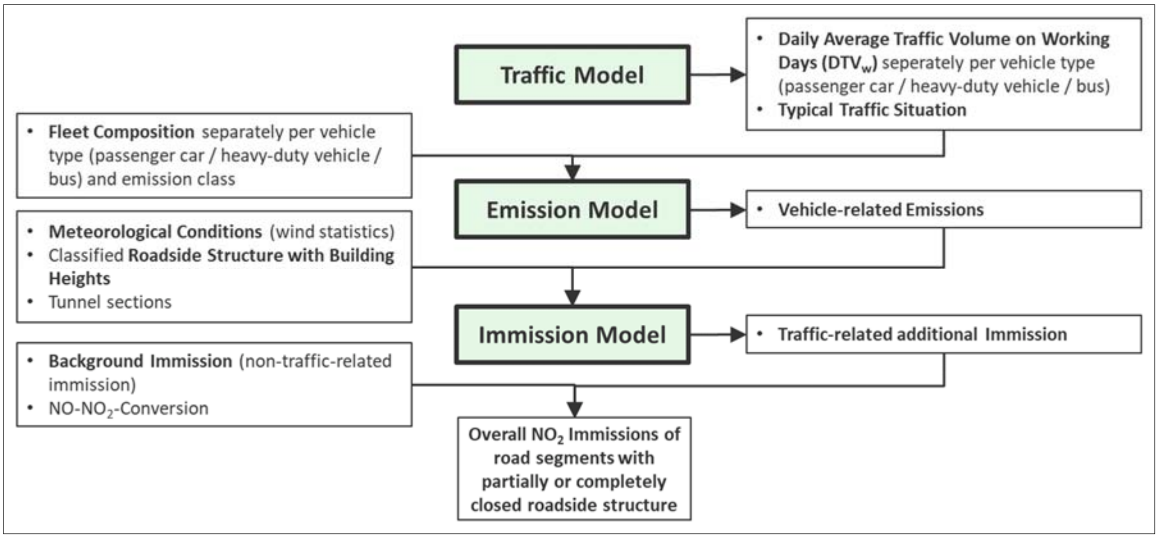

Fig. 1. Methodological approach.

2.2. Traffic Model

All the equations and forecast calculations in the investigation area are done with the regional traffic model of the city of Munich (City of Munich; 2016). In this model, the traffic situation in Munich is modelled in detail for overall 1,066 traffic cells, whereas in the suburban region around Munich each municipality is represented by one traffic cell. For modelling the traffic, the traffic planning software VISUM 14 was used. The road network which is included in the study is defined as the main road network of the city of Munich. Therefore, the following criteria are used: (a) the street sections should have an average traffic volume per working day (DTV_W) of at least 5.000 vehicles/day and (b) the surveyed road network is complete and closed (i.e. all roads are connected, there are no dead ends of single roads). For this reason, some additional street sections had to be added to close the existing gaps. As a result, the main road network used has a length of 511 km. As shown in Figure 2 the highest average traffic volumes per working day (DTV_W) with partially more than 100.000 vehicles/day are determined on sections of the middle ring road (Mittlerer Ring). In addition to the middle ring road, it is recognizable that there are also other arterial roads with high traffic volumes (motorways A9, A94, A8, A995, A96, federal roads B11 - Wolfratshauser Str., B2 - Landsberger Str., B304 - Dachauer Str., B13 - Ingolstädter Str., B304 - Kreillerstr.). Within the middle ring road especially on roads leading to the city centre (e.g. Prinzregentenstr. and Ludwigstr.) high traffic volumes are noticed.

For this main road network, immission levels are subsequently calculated and results are shown. All calculations are based on traffic demand values of the status in the base year 2015. Following restrictions are the basis of model calculations for all scenarios of this study:

- no change of origin or destination districts of each journey
- no change of modal choice
- no change of traffic volumes

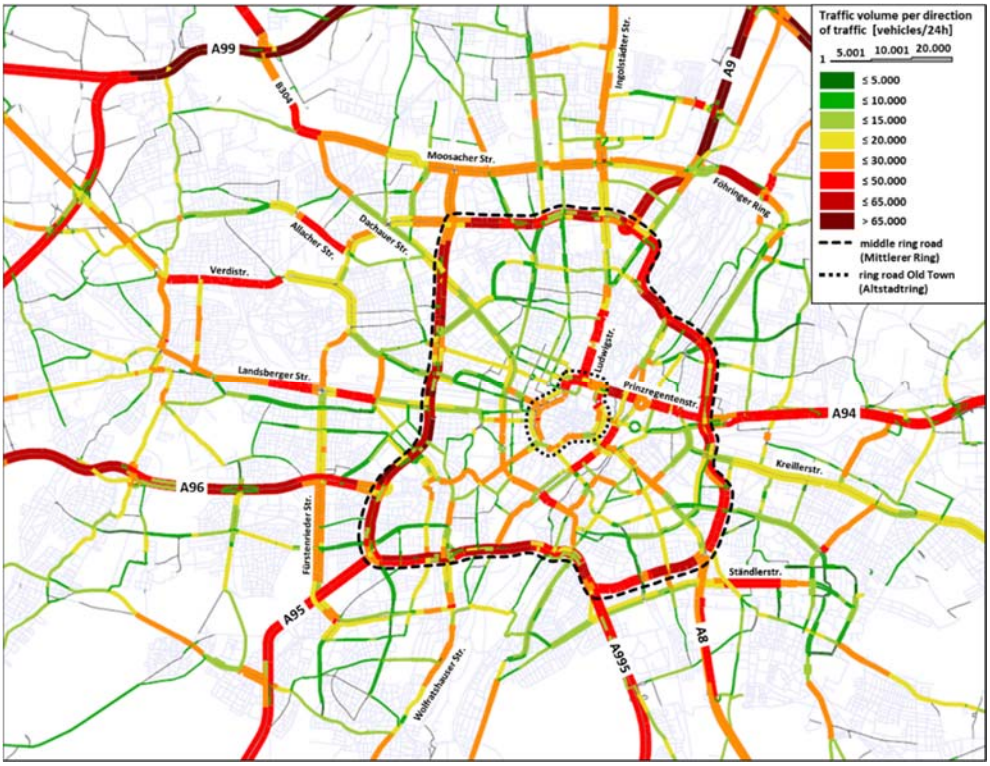

Fig. 2. Traffic volume (DTV_W) on the main road network of the city of Munich in baseline scenario 2015 (model values from traffic model).

2.3. Emission Model

The values of vehicle-related emissions are needed as a precondition for the calculation of immissions. These vehicle-related emissions are calculated by using the Handbook Emission Factors for Road Transport (HBEFA, Version 3.3, INFRAS; 2017). Therefore, in addition to the traffic volume (see chapter 2.3.1), the fleet composition (see chapter 2.3.2) and the typical traffic situation (see chapter 2.3.3) have to be defined for each road segment.

2.3.1. Traffic volume

The most important factor influencing the calculation of traffic-related emissions is the traffic volume on each road segment. The traffic model which is used in this study includes the average traffic volume per working day (DTV_W) for passenger vehicles and heavy-duty vehicles. For the models used the average daily traffic volume (DTV) is needed in order to determine further equations of immissions. The average daily traffic volume (DTV) was obtained considering the differences of traffic conditions on working days (DTV_W), on Saturdays (DTV_{Sa}) and Sundays (DTV_{Su}) by applying reduction coefficients which were conducted in one of the previous studies (Nagel et al., 2012). The following reduction coefficients for passenger vehicle traffic and heavy-duty vehicle traffic are used for conversion between output values of the traffic model and input values for the emission model:

$$passenger\ vehicle\ traffic: \quad DTV_{Sa} = 0{,}827 \cdot DTV_w; \quad DTV_{Su} = 0{,}691 \cdot DTV_w \qquad \text{(Eq. 1)}$$

$$heavy - duty\ vehicle\ traffic: \quad DTV_{Sa} = 0{,}679 \cdot DTV_w; \quad DTV_{Su} = 0{,}200 \cdot DTV_w \qquad \text{(Eq. 2)}$$

$$average\ daily\ traffic\ volume: \quad DTV = \frac{5 \cdot DTV_w + DTV_{Sa} + DTV_{Su}}{7} \qquad \text{(Eq. 3)}$$

Next to these calculations of motorised transport and commercial transport, the routes and timetables of all bus lines are considered to define the average number of busses on each road segment.

2.3.2. Fleet composition

The passenger vehicle fleet composition separated by the vehicle types from 2015 was available for the city of Munich. These vehicle registration numbers represent the static fleet composition. They show, that 59 % of all private vehicles are petrol-driven, while only 41 % are diesel cars. Considering the different mileages of petrol and diesel vehicles, a local dynamic fleet composition for the city of Munich was created. For the emission class distribution (Euro 1/I to Euro 6/VI) the information from HBEFA were used. The dynamic fleet distribution is showing the expected distribution of different vehicle types in road traffic. Due to the fact that diesel cars generally have a higher mileage than petrol cars, the dynamic fleet composition, which is used for the calculation of emissions shows more diesel-driven cars (58 %) than petrol cars (42 %) (see left part of Table 1).

Table 1. Passenger vehicle fleet composition (static and dynamic) for city of Munich for the basic years of 2015 and 2022.

basic year	2015				2022			
fleet composition passengner vehicles	static fleet share		dynamic fleet share		static fleet share		dynamic fleet share	
fleet	passenger vehicles		passenger vehicles					
Petrol (Euro 0)	**0,6%**	**59%**	**0,2%**	**42%**	**0,2%**	**51%**	**0,1%**	**34%**
Petrol (Euro 1)	**2,7%**		**1,3%**		**2,0%**		**0,7%**	
Petrol (Euro 2)	**8,4%**		**4,6%**		**2,3%**		**0,9%**	
Petrol (Euro 3)	**6,3%**		**3,8%**		**1,5%**		**0,6%**	
Petrol (Euro 4)	**21,5%**		**15,5%**		**7,5%**		**4,1%**	
Petrol (Euro 5)	**16,2%**		**13,5%**		**9,2%**		**6,0%**	
Petrol (Euro 6)	**3,5%**		**3,0%**		**28,3%**		**21,6%**	
Diesel (Euro 0)	**0,4%**	**41%**	**0,2%**	**58%**	**0,0%**	**48%**	**0,0%**	**65%**
Diesel (Euro 1)	**0,3%**		**0,2%**		**0,2%**		**0,1%**	
Diesel (Euro 2)	**1,7%**		**1,6%**		**0,5%**		**0,3%**	
Diesel (Euro 3)	**4,7%**		**4,5%**		**1,1%**		**0,9%**	
Diesel (Euro 4)	**8,2%**		**9,8%**		**2,4%**		**2,1%**	
Diesel (Euro 5)	**21,7%**		**34,7%**		**7,7%**		**7,9%**	
Diesel (Euro 6)	**3,9%**		**7,1%**		**36,3%**		**24,7%**	
Diesel (Euro 6 RDE)							**29,0%**	
Electric (emission free)	**0,2%**		**0,2%**		**0,9%**		**1,0%**	

For the estimation of the impacts of future developments in emission class distribution, an extrapolation of the passenger vehicle fleet composition for the year 2022 was created. In this future fleet composition, emission classes with lower emissions (like Euro 6) have a higher share. Therefore, the real driving emissions (RDE)[1] which are the new regulations for emission tests, especially for diesel cars, are included. For the definition of the dynamic fleet composition also the procedures of HBEFA are used. The calculated estimation for the fleet composition in 2022 is shown on the right side of Table 1.

In addition to impacts of the entire passenger vehicle fleet on the immission load, the impact of the fleet share of commercially used passenger vehicles is evaluated in particular. The share of the commercial car fleet in each emission

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[1] The testing method Real Drive Emissions (RDE) is to provide better information about the real emission output of vehicles in use on roads and must be applied in the European Union since September 2017. Vehicles drive a journey in real traffic with defined conditions (a share each in the city, on trunk roads and on the motorway, speed ranges, driving duration, etc.) while measuring. A Portable Emission Measurement System (PEMS) detects particle number and the concentration of nitrogen oxides amongst others.

class for the base year 2015 and the scenarios 1 to 4 (see chapter 2.5) was determined based on the following statistical data:

- Statistical distribution of passenger car registrations – current figures of passenger vehicles in the city of Munich (Statistical office Munich, 2016):
  74 percent private car owner
  26 percent commercial car owner

- Statistical distribution of passenger car registrations – current figures of passenger vehicles by type of fuel and owner group in Germany (KBA, 2015):
  private car owner: petrol 72 percent diesel 28 percent
  commercial car owner: petrol 32 percent diesel 68 percent

- Statistical distribution of driving distance and frequency – driving distance per working day per owner group in Germany (WVI, 2010):
  private car owner: 33,1 km/vehicle*day
  commercial car owner: 72,2 km/vehicle*day

In order to define the share of commercial vehicles on reduction of NO_2 emissions, it is needed to calculate the share of commercial vehicles in the whole passenger vehicle fleet. Above mentioned statistical data was used to define the dynamic fleet distribution of two sub-fleets: private cars and commercial cars. It was considered that commercial vehicles have a higher average mileage and therefore, they have a higher share of the used dynamic vehicle fleet distribution than private cars. Moreover, diesel engines are proportionately used more often in commercial cars than as private cars. The resulting vehicle fleet composition of the sub fleets private cars and commercial cars is shown in Table 2.

Table 2. Fleet composition (dynamic) of the sub-fleets of private cars and commercial cars for city of Munich in 2015.

basic year	**2015**					
fleet composition passengner vehicles	**dynamic fleet share**					
fleet	**passenger vehicles overall**		**sub-fleet private cars (57%)**		**sub-fleet commercial cars (43%)**	
Petrol (Euro 0)	**0,2%**	**42%**	**0,3%**	**59%**	**0,1%**	**19%**
Petrol (Euro 1)	**1,3%**		**1,8%**		**0,6%**	
Petrol (Euro 2)	**4,6%**		**6,6%**		**2,0%**	
Petrol (Euro 3)	**3,8%**		**5,4%**		**1,7%**	
Petrol (Euro 4)	**15,5%**		**21,9%**		**7,1%**	
Petrol (Euro 5)	**13,5%**		**19,1%**		**6,3%**	
Petrol (Euro 6)	**3,0%**		**4,3%**		**1,2%**	
Diesel (Euro 0)	**0,2%**	**58%**	**0,1%**	**41%**	**0,3%**	**81%**
Diesel (Euro 1)	**0,2%**		**0,1%**		**0,4%**	
Diesel (Euro 2)	**1,6%**		**0,5%**		**2,9%**	
Diesel (Euro 3)	**4,5%**		**2,3%**		**7,3%**	
Diesel (Euro 4)	**9,8%**		**6,0%**		**14,7%**	
Diesel (Euro 5)	**34,7%**		**25,8%**		**46,4%**	
Diesel (Euro 6)	**7,1%**		**5,8%**		**8,8%**	
Diesel (Euro 6 RDE)						
Electric (emission free)	**0,2%**		**0,1%**		**0,1%**	

2.3.3. Traffic situation

For the definition of typical traffic situations on each road segment (in line with HBEFA), the following influencing factors were considered: speed limits respectively desired mean speeds, number of lanes (synonymously road capacity), type of area (motorway, urban, rural) and level of service (LOS). The attributes of desired mean speeds, number of lanes and type of area were available in the traffic model. For determination of the level of service, all road segments were grouped according to road types (linkage function, see Table 3). For these groups, an indicator for the level of service value is calculated. This indicator is defined as the percentage of current travel speed to the desired speed on the road segment. Finally, the threshold values for these indicators are set in order to assign them to LOS categories based on the Highway Capacity Manual (HCM) (Transportation Research Board; 2010). Due to the different linkage functions of roads, the range of the indicator values for each LOS category is different. An overview of these thresholds is shown in Table 3. For example, due to lower desired speeds on collector roads (mostly 50 km/h) a stable traffic condition (LOS 2) is assigned if the current speed on the road segment reaches 25 km/h (50 % of the desired speed). For roads with higher relevance for the road network and higher traffic volumes (e.g. motorways and ring roads) a stable traffic condition can be assigned if the current speed is more than 67 % of desired speed on the road segment (more than 80 km/h for motorways or more than 50 km/h for ring roads).

Table 3. Thresholds for assigning level of service (LOS) for road segments (travel speed as a percentage of the desired mean speed on street segments).

Level of service (LOS)	**Road types (Linkage function) / example for mean speed on road segments**				
	Motorway	**Ring road (grade separated sections)**	**Main roads (incl. single level sections of ring roads)**	**Collector roads**	**Minor roads**
	desired speed of e.g. 120 km/h	**desired speed of e.g. 60 km/h**	**desired speed of e.g. 50 km/h**	**desired speed of e.g. 50 km/h**	**desired speed of e.g. 30 km/h**
LOS 1 (free-flow operation)	**> 85 % (> 100 km/h)**	**> 85 % (> 50 km/h)**	**> 67 %(> 35 km/h)**	**> 85 % (> 40 km/h)**	**> 85 % (> 25 km/h)**
LOS 2 (stable operation)	**> 67 % (> 80 km/h)**	**> 67 % (> 40 km/h)**	**> 50 % (> 25 km/h)**	**> 50 % (> 25 km/h)**	**> 50 % (> 15 km/h)**
LOS 3 (less stable condition)	**> 40 % (> 50 km/h)**	**> 40 % (>25 km/h)**	**> 40 % (> 20 km/h)**	**> 40 % (> 20 km/h)**	**> 40 % (> 10 km/h)**
LOS 4 (stop & go)	**≤ 40 % (≤ 50 km/h)**	**≤ 40 % (≤ 25 km/h)**	**≤ 40 % (≤ 20 km/h)**	**≤ 40 % (≤ 20 km/h)**	**≤ 40 % (≤ 10 km/h)**

Using the information of the traffic model (street characteristics like: street category, number of lanes and desired mean speed) and the LOS-definition above, a representative traffic situation is defined for each road segment. The HBEFA-Tool includes emission factors for different pollutants (e.g. Nitrogen dioxide NO_2, Nitrogen monoxide NO, Carbon dioxide CO_2, particular matter PM_{10}, Hydrocarbons HC) for each traffic situation and each emission class per drive type (e.g. Euro 4 diesel, Euro 6 petrol) based on engine tests of real vehicles. These emission factors are used to calculate the overall traffic emissions on each road segment.

2.4. Immission Model

The traffic-related immissions were estimated applying the dispersion model PROKAS B Version 6.8.7 (Lohmeyer, 2017). As a basis for these equations the network layout of the traffic model is used. The immission calculations are determined for the existing road cross-sections. At first, all lanes running parallel to each other are aggregated to one single road segment. These segments are divided into several sub-segments with approx. 100 m length. With the provided data from the city of Munich (digital city basic map, digital terrain model and building model with corresponding heights) all sub-segments are designated to defined canyon types. These canyon types are differentiated according to their roadside structure (buildings on one or on both sides of the road), the relation between building heights and canyon width and the proportion of gaps in the existing roadside structure.

Moreover, the meteorological conditions (specifically the wind statistics for the city of Munich) are considered. Using the wind data of a period from 2005 till 2014 a representative year (2009) was defined and included in the calculation of traffic-related additional immissions.

As a last step, PROKAS B includes the general background immissions as well as the chemical NO-NO_2-conversion. The background immission represents the sum of all non-traffic-related immissions. Based on measurement values of the urban environmental monitoring stations in Munich, a background immission value of 20 µg/m³ is estimated and included in the calculations. The NO-NO_2-conversion considers that NO is converted to NO_2 on its dispersion path.

By processing data as described, the NO_2 concentrations (average annual value) for all street segments of the whole investigation area is calculated. For this, the software tool PROKAS is able to consider the simultaneous emission of all street segments. The overall immission levels for each sub-segment is calculated in about 1.5 meter above ground at the facade of the building that is closest to the road.

2.5. Scenario description

This study identifies the impact of varying amendments of the passenger vehicle fleet on the overall NO_2 immission loads of the main road network in the city of Munich on the basis of 6 different scenarios. In addition to that, the status quo of the immission in the baseline year 2015 is determined. In the scenarios 1 to 4, only the composition of passenger vehicle fleet has been changed. The pollution classes of the heavy-duty vehicles and the bus fleet remained unchanged.

- Baseline scenario:
  All passenger vehicle trips are done with the existing fleet composition (see Table 1)

- Scenario 1:
  All passenger vehicle trips are done with vehicles of the emission classes Euro 6 (petrol engine Euro 6 and diesel engine Euro 6, percentage distribution between petrol and diesel according to German registrations statistics in the baseline year 2015)

- Scenario 2:
  All passenger vehicle trips are done with vehicles of the emission classes Euro 6 (petrol engine Euro 6 and diesel engine Euro 6 RDE with conformity factor[2] 2.1, percentage distribution between petrol and diesel according to German registrations statistics in the base year 2015)

- Scenario 3:
  All passenger vehicle trips are done with vehicles of the emission classes Euro 6 (petrol engine Euro 6 and diesel engine Euro 6 RDE with conformity factor 1.5, percentage distribution between petrol and diesel according to German registrations statistics in the base year 2015)

- Scenario 4:
  All passenger vehicle trips with vehicles with petrol engines of the emission class Euro 6

Furthermore, the effects of extrapolated vehicle fleet composition of two future scenarios (F1 and F2) for the year 2022 were surveyed considering an increased use of electric vehicles. In these scenarios, the bus fleet of public

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[2] The actual valid thresholds for NO_2 emissions of emission class Euro 6 has to be met in operation on the road according with the new emission standards and the conformity factor. During a transition period conformity factors has been set that define how NO_2 real driving emissions can be exceeded. Two stages of the implementation have been set:
Conformity factor 2.1 for the registration of new vehicle types form 1st Sept. 2017 and for the registration of new vehicles from 1st Sept. 2019
Conformity factor 1.5 for the registration of new vehicle types form 1st Jan. 2020 and for the registration of new vehicles from 1st Jan. 2021

transport is operating electrically and therefore, causes no pollution. However, the emission classes of the heavy-duty vehicle fleet remain unchanged. The future scenarios are characterised as followed:

- Scenario F1:
  All passenger vehicle trips are done with vehicles of emission classes according to the extrapolated vehicle fleet composition for the year 2022 (car fleet with more low emission classes compared to the base year 2015, with petrol engine, diesel engine vehicles and a higher percentage of electric vehicles)

- Scenario F2:
  All passenger vehicle trips are done with vehicles of emission classes according to the extrapolated vehicle fleet composition for the year 2022 and additionally a higher share of electric vehicles is considered which would result in complying with the threshold value of NO_2 on 99 percent of the main road network.

3. Results

All calculations and presented results are done within a project for the Chamber of Industry and Commerce of Munich and Upper Bavaria (IHK für München und Oberbayern, 2018).

3.1. Baseline Scenario

With the approach as described in chapter 2.4 the NO_2 concentration rates of the road sections with roadside structures are calculated and assigned to the road section in the road network map with colours. Figure 3 shows the NO_2 pollution in the year 2015 assessed with PROKAS. The pollution level of each section in the main road network is determined. Sections with NO_2 immission levels that comply with the legal threshold of 40 $\mu g/m^3$ of the 39th BImSchV (BMJV 2010) has been marked green. Road sections with NO_2 pollution rates exceeding this threshold were marked in differing shades of red. For sections shown in black the immission was not calculated due to not existing roadside structures, but these road sections have been considered as emission sources in the emission calculation.

The results of the calculations of NO_2 immission values in the baseline scenario (average annual value) were validated with available data of the 5 official measurement stations (Lufthygienisches Landesüberwachungssystem Bayern – LÜB) in the city of Munich. The calculation of NO_2 immission values by using immission models contains uncertainties due to a wide range of input data and several influencing factors. That's why there are often some deviations between the modelled values and the measured immission loads. The calculated NO_2 immission values show a tendency of underestimation of the immission levels by less than 10 %. So, the differences between the values of official measurement stations and calculated values are below the permissible error tolerance of 30 % for air quality assessment (for NO_2) set by 39th BImSchV (BMJV, 2010).

As a result, it is shown that in the baseline scenario 30 percent (153 km) of the main road network is affected with NO_2 immission levels by exceeding the threshold of 40 $\mu g/m^3$. For 19 percent (96 km) of the main road network in Munich a NO_2 immission in the range of 40 - 50 $\mu g/m^3$ is calculated. Even higher exceedance levels in the range of 50 - 60 $\mu g/m^3$ are calculated for 33 km (6 % of the main road network). The highest NO_2 immission loads with more than 60 $\mu g/m^3$ occur on 24 km (5 % of the main road network). The map in Figure 3 shows that most of the high polluted street segments are located within the middle ring road (Mittlerer Ring). A similar map of the immission situation in 2015 in Munich is published on the website of Regional government of Upper Bavaria (Regierung von Oberbayern, 2017). The results shown in this map are slightly different due to different input data and calculation methods.

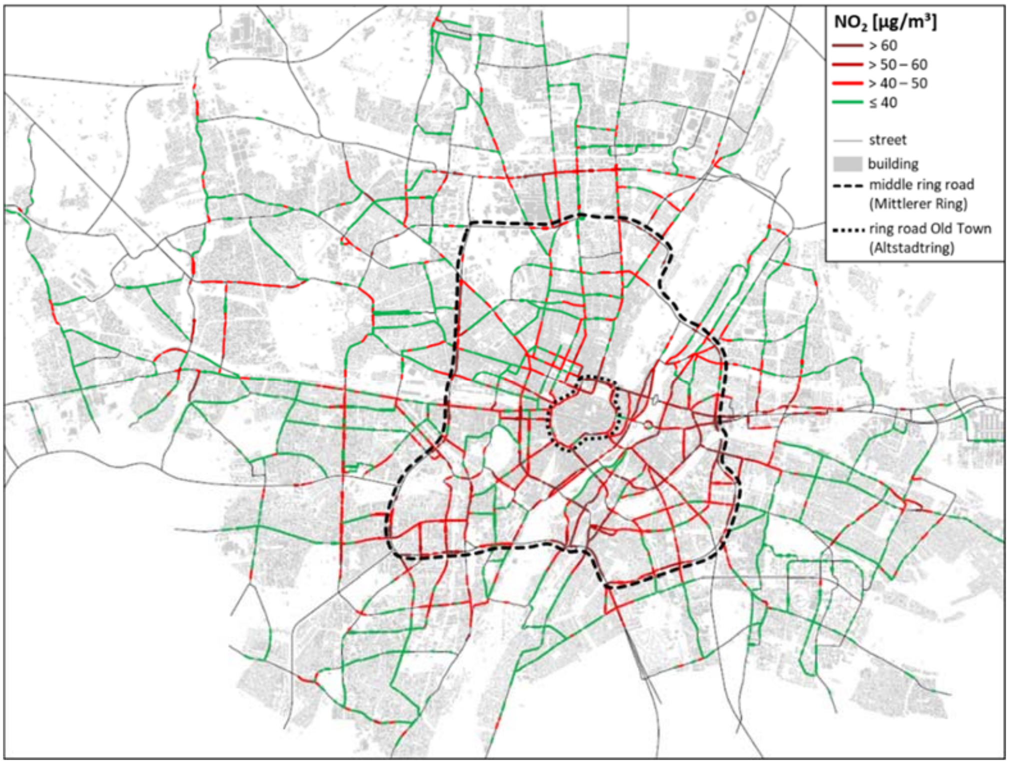

Fig. 3. NO_2 immission levels in baseline scenario 2015 (model values).

3.2. NO_2 immission levels in scenarios

For all scenarios NO_2 immission (average yearly values) for the main road network are calculated. The scenarios 1 to 4, which are based on the current situation in 2015 show a continuous improvement in the NO_2 immission situation. In Figure 4, the remaining length of the main road network (511 km) with NO_2 immission above the threshold is shown for each scenario. In scenario 1, a smaller percentage, only 18 percent (90 km), of the main road network is affected by NO_2 immissions above 40 µg/m³. This is a consequence of keeping the composition of passenger vehicle fleet the same (percentage of diesel and petrol cars) and replacing all vehicles with the emission class Euro 6. Assuming a passenger vehicle fleet with petrol engines meeting the Euro 6 standard and diesel engines meeting the Euro 6 RDE standard with conformity factor 2.1 (scenario 2) only 10 percent (50 km) of the street segments of the main road network exceed the officially defined threshold values. In case of diesel engines with the Euro 6 RDE with even conformity factor 1.5 (scenario 3) the NO_2 immission loads decrease more: only 8 percent (41 km) of the main road network is polluted with an annual mean value above 40 µg/m³. A further decrease in length of streets affected by high NO_2 pollution down to 37 km (7 percent of the main road network in the area of the city of Munich) results from replacing the passenger vehicle fleet completely by petrol engines with Euro 6 (scenario 4).

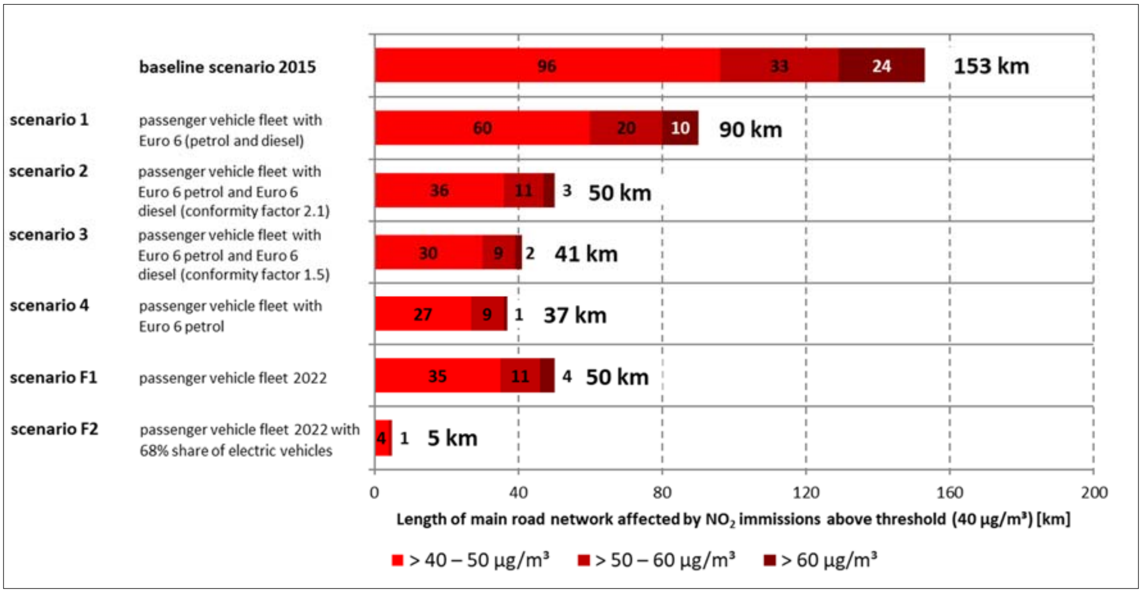

Fig. 4. Remaining length of the main road network with NO_2 immission above the threshold of 40 µg/m³ in all scenarios (model values).

Extrapolating the trend of the passenger vehicle fleet composition to the year 2022 (scenario F1), results show that 10 percent of the main road network (50 km) of the city of Munich is affected by exceeded NO_2 thresholds. So, the effects are comparable with the substitution of all passenger vehicles with emission class Euro 6 in scenario 2.

In order to achieve the goal in scenario F2 which is only 1 percent of the main road network of the city is polluted with more than 40 µg/m³ of NO_2, it is necessarily required that 68 percent of the passenger car trips based on the extrapolated passenger vehicle fleet has to be done with electric vehicles (or other emission-free drives).

The special distribution of the NO_2 immission levels below the threshold in the main road network of the city of Munich are shown in Figure 5 for all scenarios. It can be seen that the remaining road sections with high NO_2 immission loads are mostly located at middle ring road (Mittlerer Ring), the ring road Old Town (Altstadtring), the arterial roads heading towards city centre and streets alongside the river Isar.

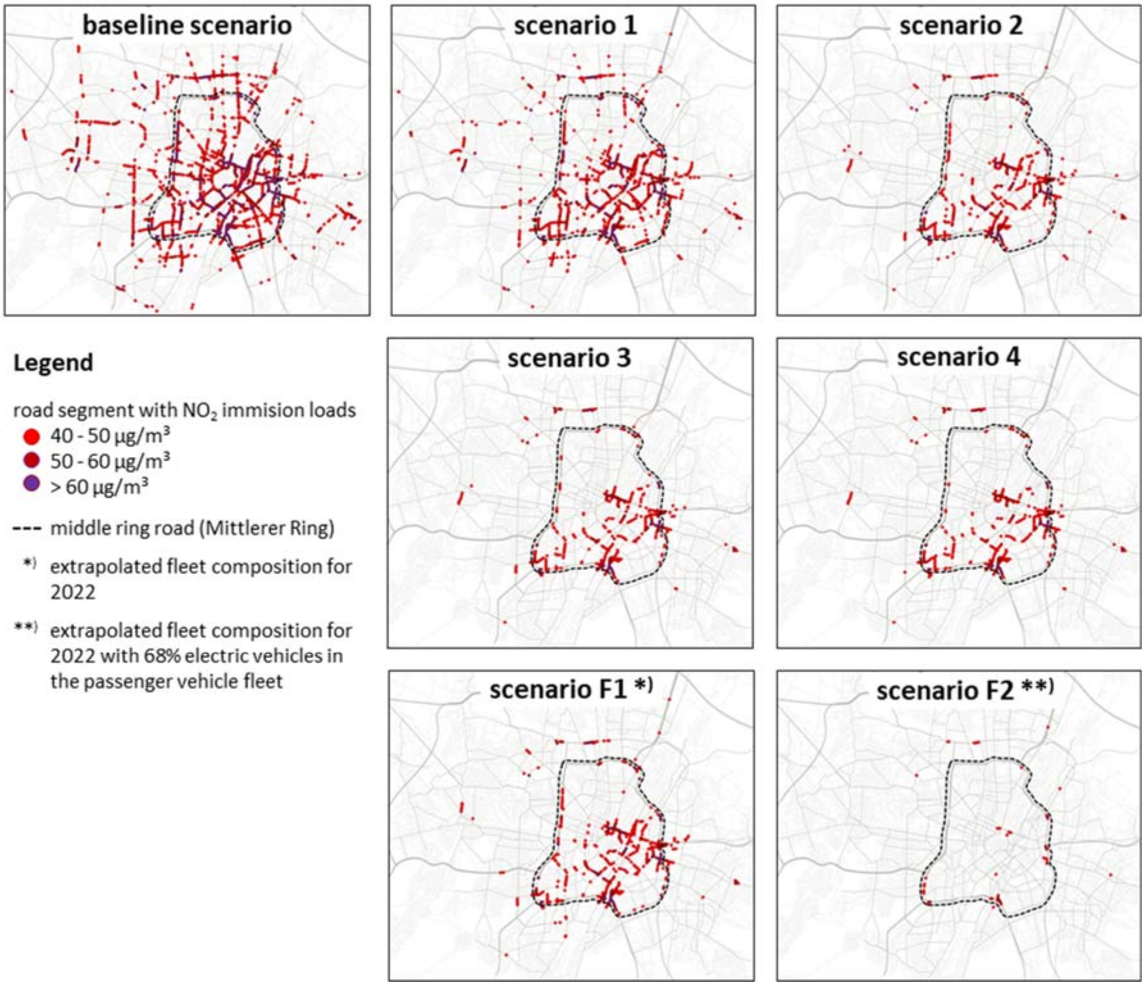

Fig. 5. Spatial distribution of NO_2 immission loads above the threshold of 40 µg/m³ (daily average value) for all scenarios (model values)

3.3. Contribution of commercial passenger vehicle fleet to total emission

Based on the vehicle fleet composition as described in chapter 2.3, the contribution of the commercial passenger vehicle fleet to the NO_2 emission rates is considered only within the area of the middle ring road (Mittlerer Ring). For all scenarios, the share of the sub-fleets "commercial cars" and "private cars and heavy-duty vehicles (HDV)" are calculated (see Figure 6). In the baseline scenario, the shares of the NO_2 emission of both sub-fleets are almost equal. In the scenarios 1 to 4, the NO_2 emission of the total traffic is strongly reduced due to amended fleet distributions. The settings of scenario 2 (passenger vehicles with petrol engine Euro 6 and diesel engine Euro 6 RDE with conformity factor 2.1) already lead to a reduction of the baseline NO_2 emission to 37 percent. Even higher reductions to 31 percent were achieved with scenario 3. Assuming all trips of passenger vehicles are done with petrol engine vehicles with emission class Euro 6 (scenario 4), less than a quarter (23 percent) of the baseline NO_2 emission are produced. In scenario 1 to 3, the reductions are mainly caused by amendments of the emissions in the sub-fleet "private cars and HDV". The reason for this is the higher share in the overall dynamic fleet composition and the lower share of diesel cars in this sub-fleet compared to the sub-fleet of "commercial cars". In scenario 4 the emission share of sub-fleet "commercial cars" can be reduced to 3 % of the baseline. Due to the fact that all diesel cars, which are the main part of this sub-fleet are (with a generally higher NO_2 emission), are substituted with low-emission petrol cars with Euro 6-Standard.

relative share of emission (reference baseline scenario) / scenarios	NO₂ emission				
	total fleet	commercial cars		private cars and HDV	
		share	change	share	change
baseline scenario 2015	**100%**	**47%**	0%	**53%**	0%
scenario 1	**61%**	**39%**	-8%	**22%**	-31%
scenario 2	**37%**	**25%**	-22%	**12%**	-41%
scenario 3	**31%**	**18%**	-29%	**13%**	-40%
scenario 4	**23%**	**3%**	-44%	**20%**	-33%

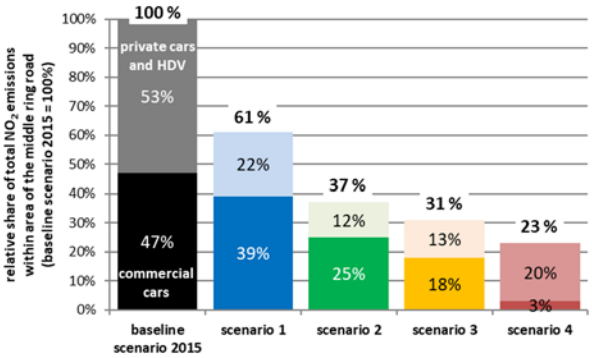

Fig. 6. Distribution of traffic-related NO₂ emission on main road network within the area of the middle ring road (Mittlerer Ring) among the sub-fleets “commercial cars” and “private cars and heavy-duty vehicles (HDV)“.

4. Summary

This paper describes a methodology of calculating the NO₂ immissions based on the example of the main road network of Munich. For these calculations, the existing traffic volume (based on the traffic model of the city of Munich), the roadside structures of each road section (based on the city’s digital model of buildings) as well as the passenger vehicle fleet composition (based on registration figures) are considered. The validations of the immission model have been applied by comparing the calculation results and measured immission values of the official air quality monitoring stations (LÜB-stations).

The share of the main road network exceeding the NO₂ threshold of 40 µg/m³ in the base year 2015 is determined as status quo. The impact of the passenger vehicle fleet modifications on the NO₂ immissions is described based on various scenarios including the future standard Euro 6 RDE of diesel engines. Reductions of immission levels within the main road network of Munich are shown at a glance by percentages as well as their spatial distribution on the road network.

Moreover, the required share of electric vehicles in the passenger vehicle fleet is determined in order to decrease the exceeding of the threshold of the NO₂ immission of 40 µg/m³ on at least 1 percent of the main road network. The contribution of sub-fleet of commercial cars is calculated separately and its share on the total emissions are shown. The approach described above allows the impact estimation of changes in fleet compositions on immissions using an integrated modelling of traffic, emission and immission.

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