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SPECIFICATION OF ZERO-IMPACT VEHICLE EXHAUST EMISSIONS FROM THE AMBIENT AIR QUALITY PERSPECTIVE AND DEMONSTRATION OF ZERO IMPACT

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Abstract: In a novel approach, aspects of ambient air quality, atmospheric processes, road traffic and air quality guidelines have been combined to specify emission levels of vehicles that "do not affect" air quality at kerbside. Zero impact air quality targets were specified to 1.2 µg/m³ for NO_2, 0.5 µg/m³ for PM2.5 and 650 #/cm³ for particle number (PN 20-800 nm). Based on these targets zero impact vehicle exhaust emissions were inferred. A Lagrangian particle model was used to simulate the dispersion of NO_x, PM2.5 and particle number concentration (PN) in selected urban case studies for base cases (validation) and scenarios. For PM2.5 and NO_2 the base case validation was straightforward and it was demonstrated that a hypothetical 100% Zero-Impact Vehicles (ZIV) fleet fulfills above mentioned air quality targets at kerbside. For PN, the comparison of simulated versus monitored particles resulted in a large mismatch indicating an abundance of small so-called delayed aerosol particles. A correction of simulated PN vehicle emissions by a factor of ≈4 seems an appropriate correction for two base cases. For solid particles the specified limit of 650 #/cm³ can be already fulfilled with latest Euro-6 emission standards and even more with a hypothetical 100% ZIV fleet if solid particle emissions are of concern. Multiplying the ZIV scenario results by a factor of 4 would result in zero impact. However, this simple correction is difficult to justify for a future scenario.

Key words: Zero-Impact Vehicle Emissions, NO_2, PM2.5, Solid and Volatile Particle Number.

INTRODUCTION

The aim of the project was to analyse the requirements of road traffic "zero impact emission levels" from an air quality perspective. First, three possible definitions of “zero impact on air quality” were developed and thereafter analysed in detail:

1) The road traffic contribution to air quality concentration levels is smaller than monitored at clean rural background and untraceable related with state-of-the-art monitoring
2) The road traffic contribution at kerbside locations shall be irrelevant according to air quality directives, i.e. shall be < 3% of air quality limits (3% irrelevance criterion”)
3) Concentration at the vehicle’s tailpipe < the workplace limit (960 µg/m³ for NO_2)

Table 1 summarises the results for option 1) and 2). Option 3) leads to similar emission targets as option 2) but gives different thresholds for stoichiometric and lean combustion concepts and was thus not pursued further. In the end, our zero-impact definition was “the road traffic contribution to air pollutants near roads shall be irrelevant compared to the WHO 2006 air quality guidelines, i.e. lower than 3% of these ambitious air quality (AQ) limits”. For PN no air quality limit is defined or recommended in any regulations. Therefore, the ZIV PN 20-800 nm size range criteria of 650 #/cm³ was derived based on conclusion by analogy using the NO_2 zero impact target related to the NO_2 clean background target (1.2 µg/m³ : 3.6 µg/m³) and PN 20-800 nm of 2000 #cm^{-3} monitored at clean background sites.

Table 1. Comparison of the zero impact targets for the maximum traffic contribution to the ambient air concentrations near roads

Station	NO_2 (µg/m³)	PM10 (µg/m³)	PM2.5 (µg/m³)	PN 20-800 (#/cm³)	eBC (µg/m³)
Clean background ≥ 900m a.s.l.	3.6	8.4	6.5	2000	0.3
3-% criterion for WHO 2005 AQ limits	1.2	0.6	0.3	650	0.1

Current contributions of road transport exhaust gas emissions to the air quality near roads in Europe were analysed to identify the relation between road vehicles emissions and pollutant concentrations measured next to the road. From the worst-case situation, identified at “Stuttgart Neckartor” in the year 2016, we assessed the necessary traffic emission reduction rates to meet the zero impact pollutant concentrations next to the road. With these reduction rates and with the corresponding fleet average emissions, the maximum emissions per kilometre for “Zero Impact Vehicles, (ZIV)” for NO_x and PM were calculated as a first assessment. For PN, source specific i.e. traffic related contributions to air quality at kerbside in Europe is rarely available. Therefore, the PM target was used and average monitored particulate numbers per emission mass were used to assess PN targets. The resulting ZIV emission targets based on the driving situation at Stuttgart, Neckartor in 2016 are shown in **Table 2**.

Table 2. Emission targets for the ZIV fleet, traffic situation according to Stuttgart Neckartor (2016) for the 3% irrelevance criterion.

Vehicle type	unit (activity)	EF NO_x (mg/unit)	EF PM2.5 (mg/unit)	EF PN20-800 (10^{11} #/unit)
PC	km	6.7	0.4	1.2
LCV	km	7.9	0.5	1.5
HDV	kWh	28.1	1.6	4.8

DISPERSION MODELLING APPROACH

The worst-case monitoring location may not coincide with the location of poorest air quality and uncertainties and assumptions in the data analysis may lead to an underestimation of ZIV emission factors. Therefore, a detailed validation of the EFs presented in **Table 2** was performed. A sensitivity analysis for different emission and traffic conditions, air quality simulations with a Box model (chemistry/aerosols) and a Lagrangian dispersion model for different hot spots and for entire municipal areas were performed. Subsequently, some results of the dispersion modelling efforts and related challenges with focus on PN will be presented here. In addition, the air quality impact of a 100 % Euro-6d/VI fleet was evaluated as well.
The GRAMM/GRAL modelling system (Uhrner et al., 2014, Öttl 2015, Öttl 2019) was used to model detailed flow and air pollutant dispersion. Highly resolved source specific emission data have been processed for the simulations, the main set-up features are shown in **Table 3**. The flow around buildings impacting upon dispersion was accounted, except in the Vienna study. After validation of the base cases, the traffic exhaust related NO_2, PM and PN concentrations was assessed for the base case, Euro-6 scenario and ZIV emission scenario (see **Table 2**). NO_x to NO_2 conversion was computed using a simple Romberg type empirical conversion formula (Romberg et al., 1996) for the Stuttgart, Vienna and Augsburg case studies. For the Graz study, a pseudo-steady state approximation approach (Seinfeld and Pandis, 1998) was used.

Table 3. Main set-up features of the the case studies, Δx,y is the counting grid resolution

Case study	Domain size	Δx,y	Air pollutant focus	# Monitoring
Stuttgart-Neckartor	1.4 km x 1.7 km	2 m	NO_x/NO_2	2 AQ stations hotspot & bg
Vienna	30 km x 24 km	10 m	NO_x/NO_2, PM2.5	17 AQ stations
Augsburg CAZ	4 km x 6.2 km	4 m	NO_x/NO_2, PM10, PN	4 AQ stations, 2 SMPS
Graz Plüddemanngasse	1.1 km x 0.8 km	2 m	NO_x/NO_2, PN	NO_x, PN4nm, PN23nm, CO_2

In Augsburg, the focus was laid on the central activity zone (CAZ). There, SMPS measurements from the GUAN network (Sun et al., 2019) were used to monitor the urban background; SMPS measurements were undertaken by TUG in the city centre at Königsplatz (KP) next to a busy road from 16.10.2020 till 12.01.2021. PN deposition was accounted, however the impact was negligible. Coagulation was neglected as a sink process. In Graz, NO, NO_2, PN and CO_2 were measured at 1 m, 3 m and 5 m distance at a busy road. The monitoring interval was 10 minutes each location and the measurements were undertaken over 7 hours, on 20.10.2021. PN measurements were switched all 10 minutes to distinguish between total particle number (TPN) and solid particle number (SPN). However, the SPN measurement results are highly questionable and were not used. Detailed accompanying traffic monitoring was performed as well. Emissions were computed using the software PHEM (Passenger car and Heavy-duty Emission Model) from TU Graz. Meteorological data for the flow field model forcing and air quality data were only available at

30-min resolution, therefore the accompanying NO_x and PN simulations were performed as 30-min means around the Plüddemanngasse street. NO_x urban background measurements were used from the air quality station "Graz-Ost" as well as O_3 and radiation measurements from Graz-Nord, all operated by the provincial government of Styria. Due to the sampling strategy, available NO_x and CO_2 is a factor of two higher than PN. The CO_2 measurements were performed in order to monitor dilution for box model studies. Here, these measurements were used together with the NO_x measurements to evaluate the plausibility of the (10 min) PN measurements. Therefore, at first, NO_x simulations were performed and compared with 10 minutes NO_x monitored values. Thereafter, PN simulations were performed and compared with selected PN monitoring. The GRAL model was run in transient mode.

RESULTS DISPERSION SIMULATIONS - DEMONSTRATION ZERO IMPACT

Augsburg CAZ Case Study

The focus in this paper will be laid on Augsburg and Graz NO_x and PN studies. In **Figure 1** the simulated annual mean (AM) NO_2 and validation of the base case is shown. High NO_2 concentrations were computed near the monitoing station Karlsstraße (KS) located in a street canyon and near the main arterial road B17 (ADTV 84 000 vehicles), located in the SW sector of **Figure 1**. In **Figure 2** the road traffic related NO_2 burden is shown for the base case (left) and the ZIV scenario (right). In the left figure, concentration values larger than the ZIV target of 1.2 µg/m³ for the AM NO_2 prevail, whereas with the ZIV scenario (right) the ZIV target of 1.2 µg/m³ is tightly fulfilled at kerbside.

In **Figure 3** total simulated mean PN concentrations are shown for base case (left). There, at "FH" monitored PN concentrations were used as urban background. The simulated increment is dominated by residential heating emissions from solid fuels. Simulated PN concentrations next to roads appear unrealistically low. Multiplying traffic related simulated exhaust particles by a factor of 3.8 yields a better match with the two monitoring stations and the resulting PN concentrations look more realistic, see **Figure 3** on the right. The target value of 650 #cm^{-3} is fulfilled at kerbside (**Figure 4**).

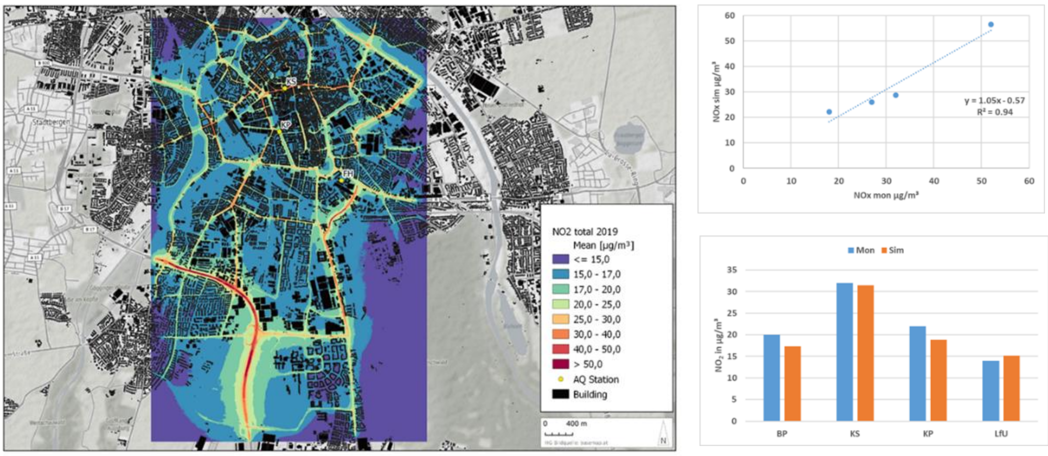

Figure 1. Augsburg CAZ simulated AM NO_2 2020/21, location of AQ stations and validation base case

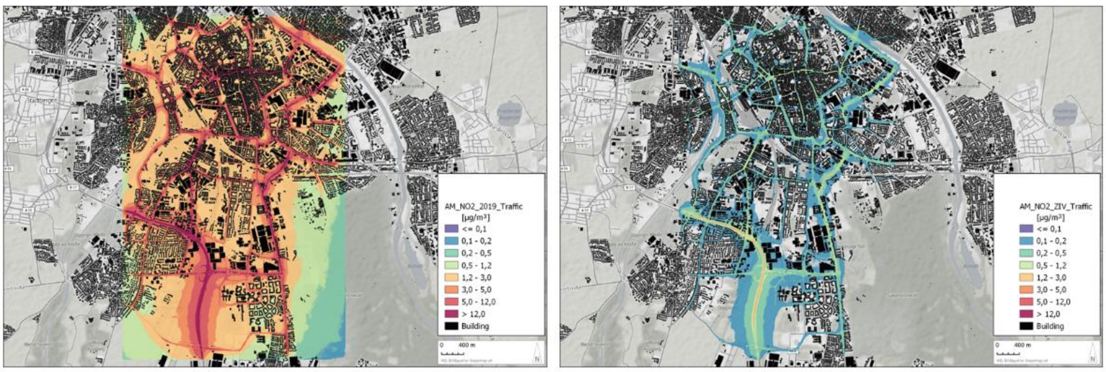

Figure 2. Augsburg CAZ simulated traffic related AM NO_2 for the base case (left) and the ZIV scenario (right)

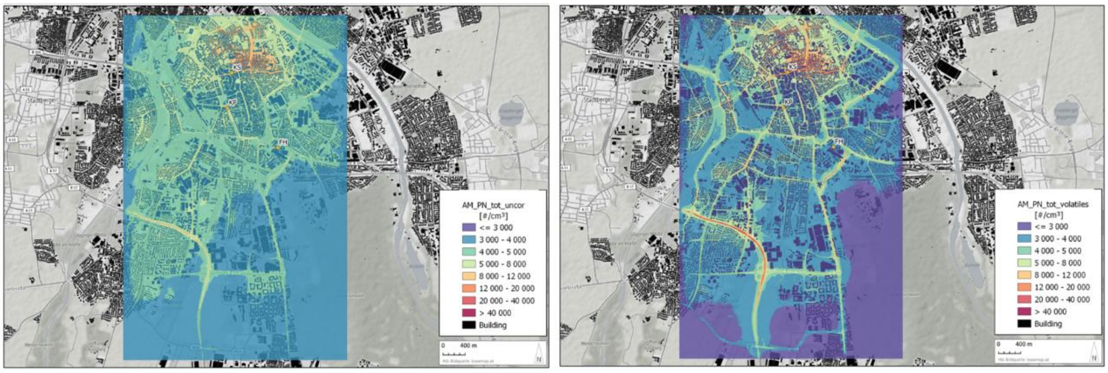

Figure 3. Augsburg CAZ simulated total mean PN (16.10.2020 till 12.01.2021) for the base case without correction for volatiles (left) and with correction for volatiles (right)

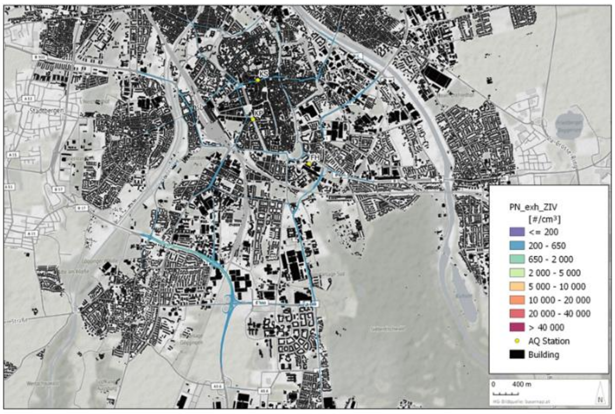

Figure 4. Augsburg CAZ simulated traffic related PN for the ZIV scenario

Graz Plüddemanngasse Case Study

In **Figure 5** simulated 30-min mean NO_x concentrations are compared versus monitored 10-min NO_x concentrations at 1 m, 3 m and 5 m distance from the road. At 1 m and 3 m a good relation is discernable. In **Figure 6** simulated 30-min mean traffic related solid PN > 23 nm (SPN23) is compared versus monitored 10 min mean total PN concentration (TPN23). The simulated spatial distribution is shown in **Figure 7**. The scatter plot of **Figure 6** indicates a good relation between these two different measures. The slope of 3.89 indicates that kerbside TPN may be composed of a large fraction of delayed aerosols mostlikely due to nucleating and rapidly growing (condensing) VOCs. Moreover, the intercept of approximately 4000 $\#cm^{-3}$ indicates the urban background and contributions from atmospheric new particle formation.

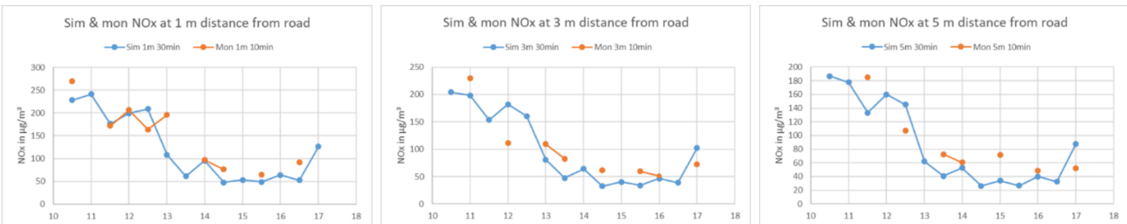

Figure 5. Base case, Graz Plüddemanngasse, simulated 30-min NOx versus monitored 10-min NOx at 1 m, 3 m and 5 m distance to road (x-axis show the hours of the day)

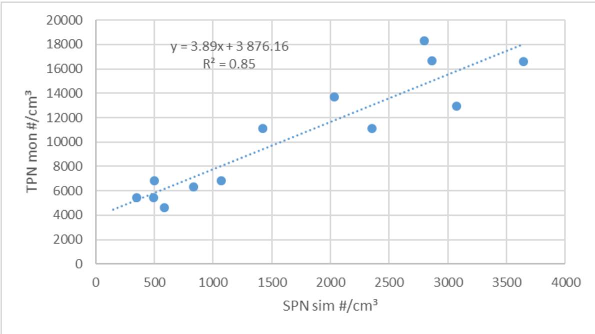

Figure 6. Simulated base case PN23 (30 min) vs monitored PN23 (10 min), questionable measurements were removed

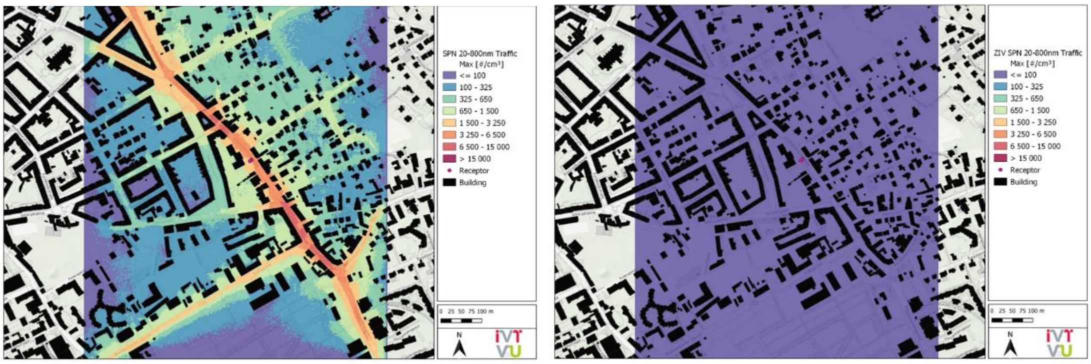

Figure 7. Graz Plüddemanngasse simulated max traffic related SPN23 base case (left), ZIV scenario (right)

CONCLUSIONS

Limits for future zero-impact vehicle exhaust emissions were analysed from the air quality perspective. Technically, to meet the 1.2 µg/m³ for NO_2 kerbside at hot spots with high traffic volumes or under extreme driving conditions seems to be most demanding. PM and PN limits for solid particles can be already fulfilled with latest Euro-6 exhaust technologies, however the use cases indicated a dominating role of delayed aerosol most likely of volatile origin. Accounting for the impact of volatiles in future scenarios bears large uncertainties.

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