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Zero-Impact Fahrzeug-Emissionen (Konzeptionelle Studie)

FVV Nr. 1407 | Abschlussbericht (AB)

1 | Forschungsgesellschaft für Verbrennungskraftmaschinen und Thermodynamik mbH (FVT), Graz
Univ.-Prof. Dipl.-Ing. Dr.-techn. Helmut Eichlseder

2 | Institut für Thermodynamik und nachhaltige Antriebssysteme (ITNA), Technische Universität Graz
Univ.-Prof. Dipl.-Ing. Dr.-techn. Helmut Eichlseder

3 | AVISO GmbH (AVISO), Aachen
Dr.-Ing. Christiane Schneider

Thema:	Definition und Anforderungen von "Zero Impact Emissionsniveaus" aus der Perspektive der Luftgüte
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Bearbeiter und Verfasser:	Univ.-Prof. Dipl.-Ing. Dr. Stefan Hausberger (FVT) Dipl.-Met. Dr. rer. nat. Ulrich Uhrner (ITNA) Dipl.-Ing. Werner Stadlhofer (ITNA) Dr. rer. nat. Nicola Toenges-Schuller (AVISO) Dr.-Ing. Christiane Schneider (AVISO)
Vortragende(r):	Univ.-Prof. Dipl.-Ing. Dr. Stefan Hausberger (FVT)
Projektkoordination/projektbegleitender Ausschuss:	Prof. Dr.-Ing. Kurt Kirsten (APL Automobil-Prüftechnik Landau GmbH)

Danksagung

Dieser Bericht ist das wissenschaftliche Ergebnis einer Forschungsaufgabe, die von der Forschungsvereinigung Verbrennungskraftmaschinen (FVV) e.V. gestellt und von der Forschungsgesellschaft für Verbrennungskraftmaschinen und Thermodynamik mbH (FVT) in Graz unter der Leitung von Univ.-Prof. Dipl.-Ing. Dr.-techn. Helmut Eichlseder, am Institut für Thermodynamik und nachhaltige Antriebssysteme (ITNA) der Technischen Universität Graz unter der Leitung von Univ.-Prof. Dipl.-Ing. Dr.-techn. Helmut Eichlseder und von der AVISO GmbH (AVISO) in Aachen unter der Leitung Dr.-Ing. Christiane Schneider durchgeführt wurde.

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Kurzfassung

Ziel des Projekts war es, die Anforderungen an "Zero-Impact" Emissionsniveaus des Straßenverkehrs aus Sicht der Luftqualität zu beschreiben. Eine Fahrzeugflotte, die diese "Zero-Impact" Vorgabe erfüllt, soll mit ihren Abgasemissionen keine negativen Auswirkungen auf Gesundheit und Umwelt verursachen. Treibhausgase und Non-Exhaust Emissionen werden in dieser Studie nicht betrachtet.

Eine exakte Grenze, ab welchen Konzentrationen mit Sicherheit keine negativen Auswirkungen von Schadstoffen auftreten können, ist derzeit nicht mit Sicherheit festzulegen. Daher haben wir mehrere Optionen für die Definition von "Zero-Impact" untersucht und die anspruchsvollste davon als Basis für die Studie ausgewählt: "Der Beitrag des Straßenverkehrs zu Luftschadstoffen in Straßennähe muss im Vergleich zu den Luftqualitätsrichtlinien der WHO-2005 irrelevant sein, d.h. weniger als 3 % dieser Luftqualitätszielwerte betragen".

Ausgehend von einer Literaturrecherche über die derzeitigen Beiträge der Abgasemissionen des Straßenverkehrs zur Luftqualität, die an verschiedenen Straßen am Straßenrand gemessen wurden, haben wir den ungünstigsten Fall ausgesucht (Situation Stuttgart Neckartor 2016). Damit haben wir die Reduktionsraten berechnet, die im Vergleich zu den heutigen Emissionen der Fahrzeugflotte erforderlich sind, um die Zero-Impact Zielwerte für NO_2, PM (Partikelmasse) und PN (Partikelanzahl) zu erreichen. Mit diesen Reduktionraten wurden die maximal zulässigen Emissionen pro Kilometer für "Zero Impact Vehicles (ZIV)" für eine erste Bewertung berechnet.

Für eine Sensitivitätsanalyse haben wir ZIV Fahrzeug-Emissionsmodelle für PKW und schwere Nutzfahrzeuge erstellt, die die ZIV-Ziele in der Verkehrssituation für Stuttgart, Neckartor 2016, als Worst-Case Situation erfüllen. Hierfür wurde die Software PHEM verwendet, die auch Grundlage des Handbuchs Emissionsfaktoren (HBEFA) ist. Die Sensitivitätsstudie umfasste verschiedene Verkehrssituationen vom dichten Stadtverkehr mit hohen Kaltstartanteilen bis hin zu Alpenstraßen mit hohen Steigungen und dynamischer Fahrweise. Die Schwellenwerte für die Gesamtemissionen zur Einhaltung der Luftqualitätsziele von "Zero-Impact" wurden für mögliche Worst-Case-Situationen mit niedrigen Windgeschwindigkeiten und Verdünnungssituationen für stündliche, tägliche und jährliche Durchschnittsbedingungen berechnet. Um die Luftqualitätsziele zu erreichen, sollten die spezifischen NOx-Emissionen von ca. 7 mg/km für PKW und 30 mg/kWh für schwere Nutzfahrzeuge in dichten städtischen Fahrsituationen nicht überschritten werden. Für PN erfüllt die derzeitige EURO-6-Flotte bereits die ZIV-Ziele im Stadtverkehr in der Größenordnung von 5E+11 #/km. In anspruchsvolleren Fahrsituationen, wie z. B. auf Alpenstraßen mit großen Steigungen, sind wesentlich höhere Emissionen pro Fahrzeugkilometer möglich, ohne dass die Zero-Impact Immissionsziele überschritten werden, da viel weniger Fahrzeuge pro Stunde die Straße passieren. Im Gegensatz dazu sind auf dicht befahrenen Autobahnen aufgrund des höheren Fahrzeugaufkommens niedrigere Emissionen je Kfz-km erforderlich, um die Zero-Impact Ziele zu erreichen. Die Sensitivitätsanalyse wurde schließlich durch detaillierte Luftqualitätssimulationen für verschiedene Gebiete validiert. Luftgütemessungen in verschiedenen Abständen von 1 bis 5 Meter vom Straßenrand dienten zur Überprüfung der Modelle.

Die Methoden und Ergebnisse für NOx, PM und PN werden in dieser Veröffentlichung vorgestellt.

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Zero Impact Vehicle Emissions (Conceptual Study)
FVV Nr. 1407 | Final report (AB)

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1 | Forschungsgesellschaft für Verbrennungskraftmaschinen und Thermodynamik mbH (FVT), Graz
Univ.-Prof. Dipl.-Ing. Dr.-techn. Helmut Eichlseder

2 | Institute of Thermodynamics and sustainable Propulsion Systems (ITNA), Graz University of Technology
Univ.-Prof. Dipl.-Ing. Dr.-techn. Helmut Eichlseder

3 | AVISO GmbH (AVISO), Aachen
Dr.-Ing. Christiane Schneider

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Research associate(s) / author(s):	Univ.-Prof. Dr. Dipl.-Ing. Stefan Hausberger (FVT) Dipl.-Met. Dr.rer.nat. Uhrner (TUG) Dipl.-Ing. Werner Stadlhofer (ITNA) Dr. rer. nat. Nicola Toenges-Schuller (AVISO) Dr.-Ing. Christiane Schneider (AVISO)
Lecturer(s):	Univ.-Prof. Dr. Dipl.-Ing. Stefan Hausberger (FVT)
Project coordination / user committee:	Prof. Dr.-Ing. Kurt Kirsten (APL Automobil-Prüftechnik Landau GmbH)

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Abstract

The aim of the project was to analyse the requirements for "zero-impact" emission levels of road transport from an air quality perspective. A vehicle fleet that meets this "zero-impact" requirement should not cause any negative impacts on health and the environment with its exhaust emissions. Greenhouse gases and non-exhaust emissions are not considered in this study.

At present, it is not possible to define a precise limit below which concentrations of pollutants cannot cause negative impacts. Therefore, we have examined several options for the definition of zero-impact and selected the most ambitious of these as the basis for the study: "The contribution of road transport to air pollutants near roads must be irrelevant compared to the WHO-2005 air quality guidelines, i.e. less than 3 % of these air quality target values".

From a literature review on the current contributions of road transport exhaust gas emissions to the air quality measured at kerbside different roads we used the worst case situation to calculate the reduction rates needed compared to the todays vehicle fleet emissions to meet the zero impact targets for NO2, particulate mass (PM) and particle number (PN). With the reduction rates identified the maximum emissions per kilometer for “Zero Impact Vehicles (ZIV)” were calculated as a first assessment.

For a sensitivity analysis, we set up vehicle emission models for passenger cars and HDVs applying technologies fulfilling the ZIV targets in the traffic situation for Stuttgart, Neckartor 2016 as worst-case. For this exercise, we used the software PHEM, which is also basis of the Handbook Emission Factors (HBEFA). The sensitivity study covered different traffic situations from dense urban traffic with high cold start shares up to alpine roads with high gradients and dynamic driving styles. The thresholds for the total emissions to meet the zero impact air quality (AQ) targets were calculated for possible worst case situations of low wind speeds and dilution situations for hourly, daily and annual mean conditions. For “zero AQ impact”, specific NOx emissions of ca. 7mg/km for cars and 30 mg/kWh for HDVs should not be exceeded in dense urban driving situations. For PN, the current EURO 6 fleet already meets the ZIV targets in urban driving in the range of 5E+11 #/km. In demanding driving situations, such as alpine roads with high gradients, much higher emissions per veh.-km are possible without exceeding the zero impact targets, since much less vehicles per hour are passing the road. In contrary, dense motorways need lower emissions per veh.-km due to the higher number of vehicles to remain below the zero impact AQ targets. The sensitivity analysis was finally validated by detailed air quality simulations for different areas. Air quality measurements at various distances from 1 to 5 metres from the roadside were used to check the models.

An overview on the methods and results for NOx, PM and PN are presented in this paper.

1 Introduction

Vehicle emissions are still an important source of pollutant emissions although significant reductions were achieved in the last decades. Especially the introduction of EURO 6 d-TEMP, 6d for cars and LCVs and EURO VI for HDVs has led to significant reductions in pollutant emissions, e.g. [1]. In the past, the introduction of new air quality targets typically led to tighter emission limits and more comprehensive test procedures for vehicles and other sources of pollutant emissions to avoid exceeding air quality targets. Newest WHO guidelines from 2021 again suggest a drastic reduction for PM and NO_2 air quality targets, [2]. Due to time constraints, these values could not be considered in the study.

To assess a "final target" for vehicle emission levels avoiding any harmful environmental effects from pollutant emissions, this study analysed several options to define "zero-impact" from the air quality (AQ) perspective. We had to find a robust definition of zero-impact thresholds for the contribution of traffic to the ambient pollutant concentrations. Based on this definition, the corresponding vehicle emission levels are of interest. It is obvious, that a 100% zero impact vehicle (ZIVs) fleet should not exceed the zero impact AQ targets even in worst-case situations. Since the ambient concentrations caused by road emissions depend on manifold parameters, this study performed extensive research on the correlation of vehicle emissions and contributions to pollutant concentrations near streets.

For worst-case mixes of high traffic volumes with unfavourable driving conditions and worse dilution and chemical reaction boundaries, we calculated the maximum emissions per vehicle-km to meet the zero impact AQ targets. From this exercise we got a set of zero-impact targets for NOx, PM and PN emissions per veh.-km for cars and HDVs which cover urban and motorway, extra urban alpine roads and also possible RDE test cases. The results show which fleet average emissions in [g/km] and [g/kWh] are needed from AQ perspective for zero impact in various traffic conditions. A rough assessment of the feasibility of these ZIV emission targets using a rather simple vehicle model indicates that the emission limits discussed for the upcoming EURO 7 regulation are in the range of the ZIV demands. Thus, we hope that conclusion found here for correlations of traffic situations with driving cycles and ZIV emission targets are a helpful input for discussing details of the next emission regulation.

2 Possible zero-impact definitions

To analyse the requirements of "zero impact emission levels" from road traffic from an air quality perspective, we first developed three possible definitions of "zero impact on air quality" which we analysed in detail:

1) The road traffic contribution to air quality concentration levels (i.e. to the immissions[1]) is smaller than measured at a clean rural background above 900m see level and/or untraceable related with state-of-the-art monitoring techniques.

[1] We use also the word "immissions" in this paper for the pollutant concentrations resulting from the emissions.

2) The road traffic contribution to immissions shall be irrelevant according to air quality directives[2], i.e. shall be lower than 3% of air quality limits (3% irrelevance criterion”). We used the proposal of the WHO 2005 guidelines as AQ limits, since they are more ambitious than the EU AQ limits.

3) The concentrations at the vehicle’s tailpipe shall be lower than the workplace AQ limit, i.e., 960 µg/m³ for NO_2.

Each of these possible definitions was analysed in detail and related “zero impact” pollutant concentrations as target levels have been elaborated. Table 1 summarises the results for option 1) and 2). Option 3) leads to comparable emission targets as option 2) but gives different thresholds for stoichiometric and lean combustion concepts and was not pursued further. This paper presents main steps of the work and some results. Details of the methods and more results can be found in the final report, [4].

	NO_2 AM [µg/m³]	**PM_{10} AM [µg/m³]**	**$PM_{2.5}$ AM [µg/m³]**	***PN 20-800 [#/m³]***	***PN 30-200 [#/m³]***	***eBC [µg/m³]***
Clean background ≥ 900m a.s.l.	3.6	8.4	6.5	*2000*	*1500*	*0.3*
3-% irrelevance criterion [3]	**1.2**	**0.6**	**0.3**	***650***	***500***	***0.1***

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

3 Target emission levels for zero impact vehicles (ZIVs)

For a first assessment of tolerable vehicle emissions for zero AQ impact, we analysed current contributions of road transport exhaust gas emissions to the air quality measured at kerbside. We performed a European wide literature review to identify studies providing vehicle emission levels and related immissions to identify a representative relation between road vehicles emissions and pollutant concentrations measured next to the road.

3.1 Targets for dense urban traffic

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 the known reduction rates and fleet average emissions, the maximum emissions per kilometre for “Zero Impact Vehicles, (ZIV)” for NOx and PM were calculated as a first assessment. We have not identified source appointments for PN emissions at kerbside. Thus, we cannot compute a PN reduction rate for zero impact from AQ data. To assess the target PN emission levels for the ZIV we used the PM target and an average particle mass per particle to convert the PM target into PN targets. Later, this approach was validated with air quality simulations.

From the zero-impact air quality targets and the corresponding emission reduction rates, we derived the zero impact definition for fleet average emissions per vehicle kilometre for cars and HDVs for the driving situation mix at Stuttgart, Neckartor (Table 2).

[2] e.g., BImSchG 5 Abs. 1 Nr. 1.

[3] Definition of „zero impact“ used for this study.

Vehicle type	unit (activity)	NO_X [mg/unit]	$PM_{2.5}$ [4] [mg/unit]	PN_{20} [5] [10^{11} #/unit]
PC	km	6.7	0.4	1.2
LCV	km	7.9	0.5	1.5
HDV	kWh[6]	28.1	1.6	4.8

Table 2: Emission targets for the ZIV fleet in traffic situation according to Stuttgart, Neckartor in 2016.

3.2 Targets for various traffic situations

While the Neckartor-2016 situation was identified as a worst-case situation for the contribution of road traffic to pollutant concentrations measured kerb side in the literature review, other situations may demand quite different vehicle emission levels to meet the zero impact AQ levels.

In a sensitivity analysis we calculated thresholds for the total emissions on a road section per time unit to meet the zero impact air quality targets for several generic combinations of wind speeds and dilution situations for hourly, daily and annual mean worst-case conditions. The selection of possible worst-case scenarios was elaborated in close cooperation with TME from RWTH Aachen and the the parallel FVV project PG06 (“Zero Impact Tailpipe Emissions”). These worst-case “ambient scenarios” were then combined with worst-case traffic scenarios, which define the total vehicles per hour on the road together with worse driving conditions. The analysis covered dense urban traffic with high cold start shares up to alpine roads with high gradients and dynamic driving styles. In this exercise, only driving conditions possible for the defined traffic volumes are considered. For example, fast and aggressive driving is not possible in dense traffic and stop&go driving increases towards saturation level of a road. The thresholds for the total emissions on a road section divided by the total vehicles passing gives the ZIV-target in [g/km] and [#/km] for the fleet average ZIV emission level. Figure 1 shows examples for the traffic situations analysed.

In parallel, we set up vehicle emission models for cars and HDVs applying technologies fulfilling the ZIV targets in the traffic situation for Stuttgart, Neckartor 2016. For this exercise, we used the simulation tool PHEM, which is also basis of the Handbook Emission Factors (HBEFA). We simulated ZIV emissions in all various traffic conditions for which also the ZIV-targets were established. By comparing simulated ZIV emissions with the ZIV-targets, the critical driving conditions are visible, i.e. those where the simulated ZIV emissions are close to or above the ZIV-target emissions.

[4] PM2.5 is particle mass below 2.5 □m from the air quality data. Exhaust emissions from combustion engines are to almost 100% PM2.5, so we used this threshold later as PM ZIV target.

[5] PN20 means particle number with a cut-off above 20 nm as a result from the air quality data used. For vehicle emission tests a 50% cut off point of 23nm is currently used. PN23 values should be slightly lower than PN20.

[6] Emissions per km depend on the HDV size class and loading. Note: PC and LCV have the same emission targets per kWh as HDVs.

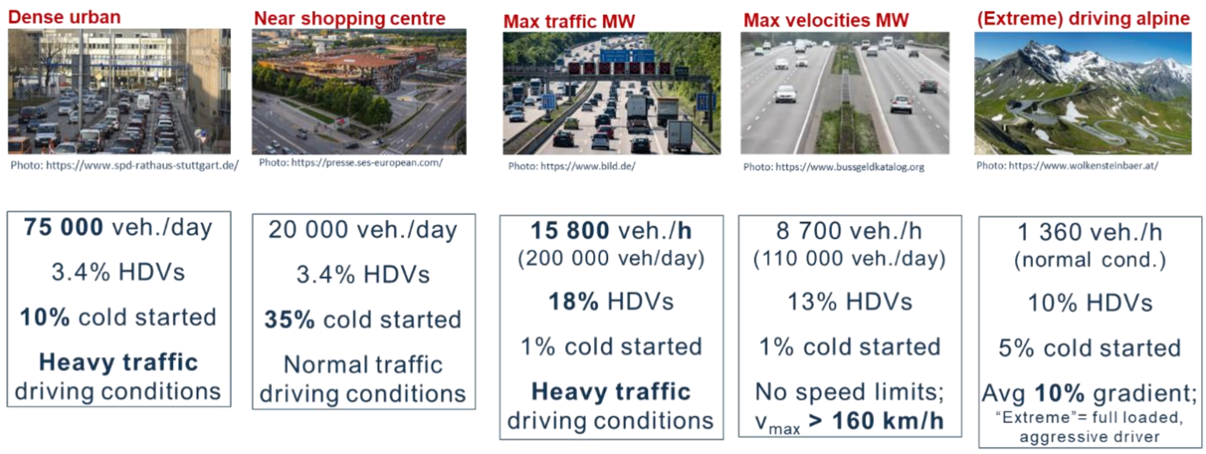

Figure 1: Examples for traffic situations analysed in the sensitivity analysis for the ZIV targets.

Figure 2 shows results from the analysis for passenger cars NOx emissions. For "zero AQ impact", specific NOx emissions of ca. 7 mg/km for cars and 30 mg/kWh for HDVs should not be exceeded in dense urban driving situations like Neckartor-2016, as already shown in chapter 3.2. For a worst-case dense urban traffic, we assumed 75 000 vehicles per day with 10% share of cold started cars and HDVs. With the advanced thermal management needed for ZIV vehicles, the catalysts are on full working temperature latest 1.5 km after start. Thus, the 10% share of cold started vehicles is a generic worst-case situation. Stuttgart Neckartor would have almost zero % share of cold started vehicles, [4]. Higher cold start shares may be possible in roads with lower traffic volumes, e.g. near a shopping centre. For such a situation with 20 000 vehicles per day and 35% cold start, the ZIV-target for cars is 26 mg/km.

In more demanding driving situations, such as alpine roads with high gradients, up to 26 mg NOx per veh.-km are possible without exceeding the zero impact targets, since much less vehicles per hour are passing the road. In contrary, motorways with very high traffic volumes ZIV cars need lower emissions per veh.-km. Since the ZIVs are in hot conditions on motorway and no aggressive driving is possible at such dense traffic, the simulation suggests, that such low NOx emissions seem to be possible at these driving conditions. In contrary, extreme RDE test cases – such as aggressive uphill driving on an alpine road with a full loaded car - show simulated NOx emissions up to 51 mg/km for the ZIV car. Even such emissions would still meet the related zero impact AQ level of 74 mg/km, since this extreme driving style is only possible with low traffic volumes.

A possible future real drive emission (RDE) test with cold start and 16 km distance would correspond to ca. 6.5 mg/km which is a similar level as needed to meet zero impact in the worst-case urban situation. It has to be noted, that the 6.5 mg/km are the fleet average emissions in the normal RDE driving situation and not a limit value for ZIVs. Since emission limits have to be met by all vehicles also under worst case test conditions, the limits are linked to the boundaries defined for valid test conditions and should furthermore be higher than the average vehicles emissions in such a worst-case test. If e.g., uphill driving with full loaded vehicle and aggressive driving style is a valid RDE test condition, the corresponding ZIV fleet target is 74 mg/km. For a conversion to a limit value, one could add a margin for serial spread in the production and for half of the emission deterioration expected over vehicles lifetime.

The discrepancy between urban ZIV targets and targets for such worst-case test cases indicates the necessity of reasonable definitions of the RDE test boundaries. E.g., demanding a similar altitude for start and end of a test leads already to much lower ZIV fleet targets (43 mg/km), since the traffic in both directions is considered where downhill driving produces much lower emissions per km. If e.g., in addition a combination of aggressive driving and full loaded vehicle gets separate limits, the target for normal “alpine road” is 25 mg NOx/km.

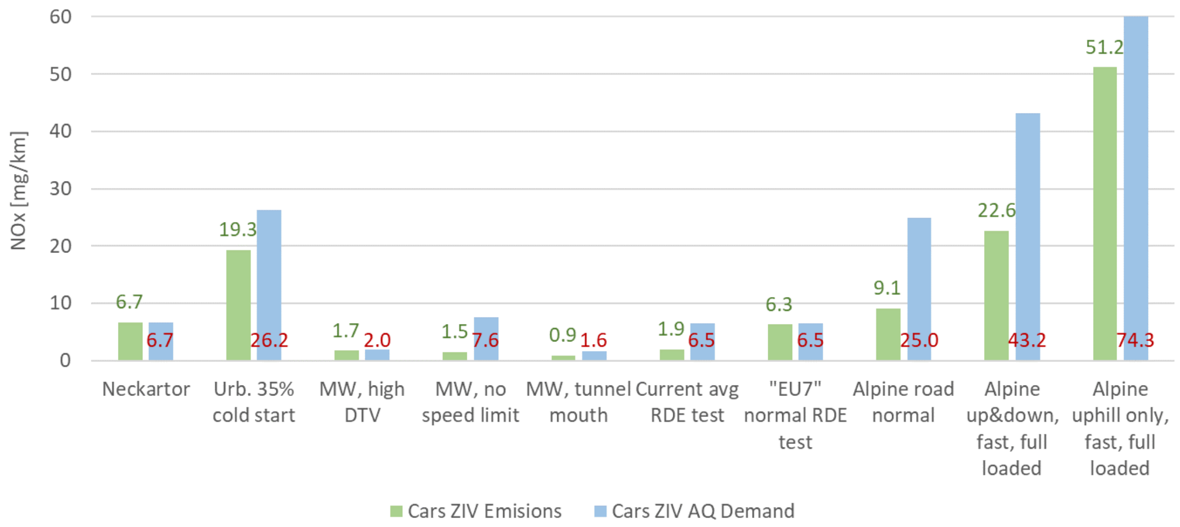

Figure 2: Distance specific NOx emissions for the ZIV passenger cars (target to meet zero impact AQ conditions compared with the ZIV car simulation).

We separated the target ZIV emission targets per veh.-km for cars and HDV by assuming the same g/kWh target for both vehicle categories. We expect this approach to lead to approximately comparable severity levels of the ZIV targets for all vehicle categories. We used the model PHEM to calculate the specific positive energy demand from the engines [kWh/km] needed for this approach for the ZIVs in all traffic situations.

Figure 3 compares the work specific targets for heavy duty (HD) ZIVs in [mg NOx/kWh] with the corresponding results from the ZIV HDV simulation. Since the distance specific emissions [g/km] depend very much on the HDV size class considered and since also exhaust emission limits are defined for HDVs in [mg/kWh], this unit seems to be more suited when looking at the HDVs. The figure shows also the specific positive engine work [kWh/km], which is calculated in these scenarios always for rigid trucks & buses and 40t tractor trailers in a mix appropriate for the scenario considered[7]. The emissions in [mg/km] can be calculated simply by multiplying the [kWh/km] and [mg/kWh].

Also, for the HD ZIV, the Neckartor-like traffic scenario is the most demanding situation where the simulation results are just slightly below the zero impact targets. As for the passenger cars, we see quite different demand for HD ZIVs emission levels as well as different emission levels expected from simulation from the ZIVs in the various traffic conditions. In normal, hot motorway driving conditions the HD

[7] The 40t HDVs have 75% share on Highways down to 10% in urban situations. The 10% share of 40t HDVs in urban driving considers articulated buses in cities.

ZIV targets is ca. 10 mg NOx/kWh while more extreme traffic situations, such as normal driving on alpine roads allow 74 mg/kWh to meet the zero impact AQ targets.

Due to the uncertainty related to worst case HDV shares as well as to the corresponding HDV mix between smaller and larger HDVs, we did not adjust the ZIV HD model to meet the targets at the Neckartor driving situation exactly. With the settings used in the simulation, more or heavier HDVs than assumed for the Neckartor-like scenario would also not lead to exceeding the zero impact targets since ca. 20% margin remain.

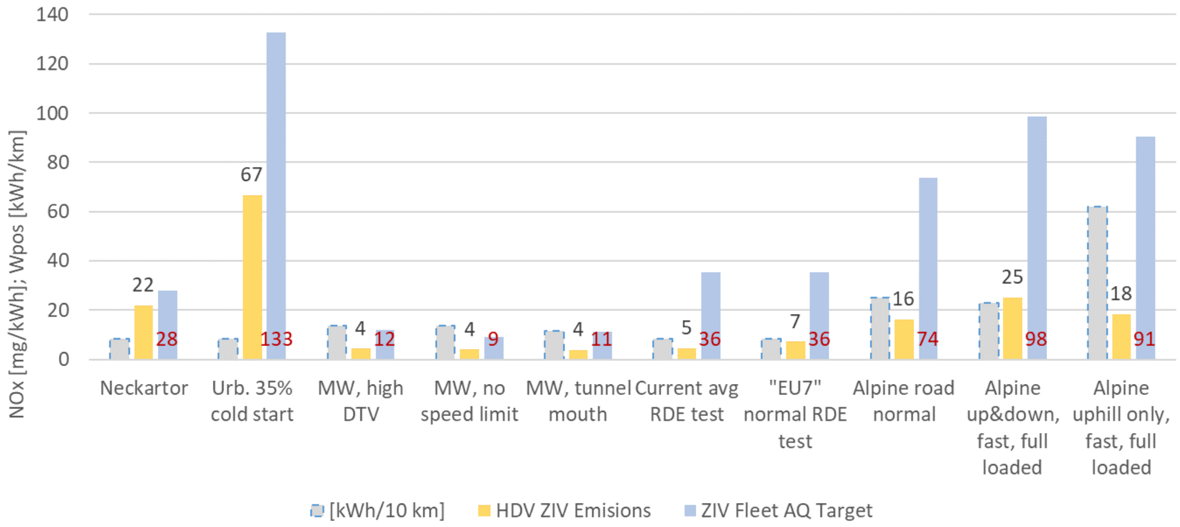

Figure 3: Engine work specific NOx emissions for the average ZIV HDV fleets (target to meet AQ zero impact conditions compared with the ZIV HDV simulation).

Figure 4 shows the PM results for the ZIV passenger cars with zero impact AQ targets of ca. 0.4 mg/km in dense traffic conditions. Comparing the work specific PM emission targets of the ZIV fleet with the emissions simulated with the ZIV models indicate, that also for PM the generic “Neckartor-like” road is the worst case for the ZIV vehicles. High traffic volumes in combination with rather high cold start shares create a demanding mix to meet the zero-impact PM AQ targets. In all other scenarios the simulated ZIV emissions have more margin to the target values.

As for NOx, the next critical scenarios are the motorway with highest traffic volumes and the tunnel mouth of a motorway. Also similar to NOx, in all scenarios with extreme driving conditions, the clearly lower number of vehicles allows higher emissions per vehicle to meet the zero impact AQ targets.

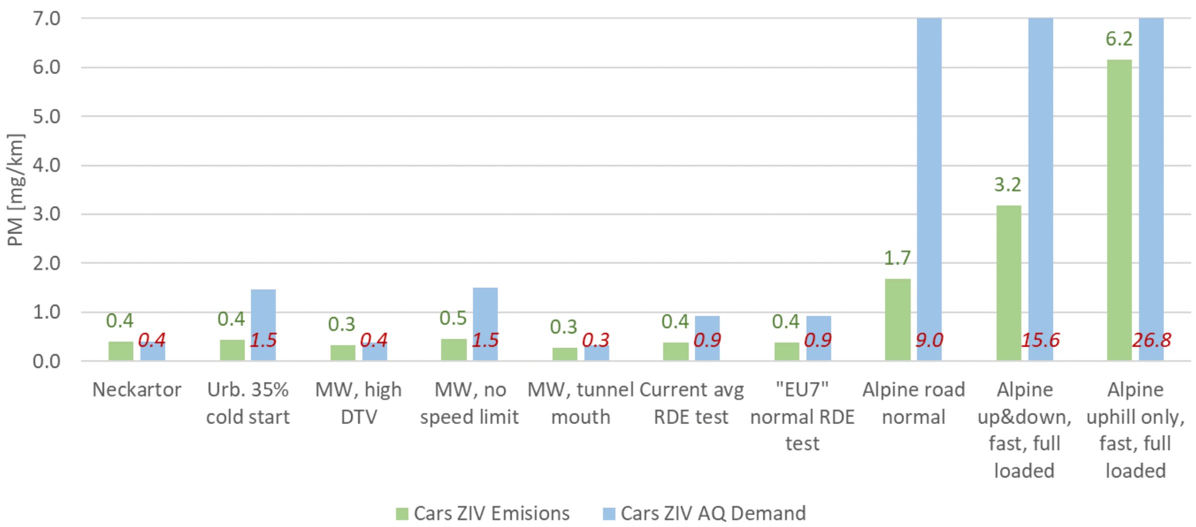

Figure 4: Distance specific PM emissions for the ***ZIV passenger cars*** *(target to meet AQ zero impact conditions compared with the ZIV car simulation).*

The HD ZIVs have to meet the ZIV targets of ca. 1.6 to 2.4 mg PM/kWh (Figure 5). This needs ca. 50% reduction compared to the average EURO VI D level shown in HBEFA 4.2. Due to the filter regeneration happening at high temperatures, which occur during long uphill driving, simulated PM emissions from the HD ZIVs increase in such extreme conditions up to almost 3 mg/kWh but are far below the zero impact AQ targets in such traffic situations.

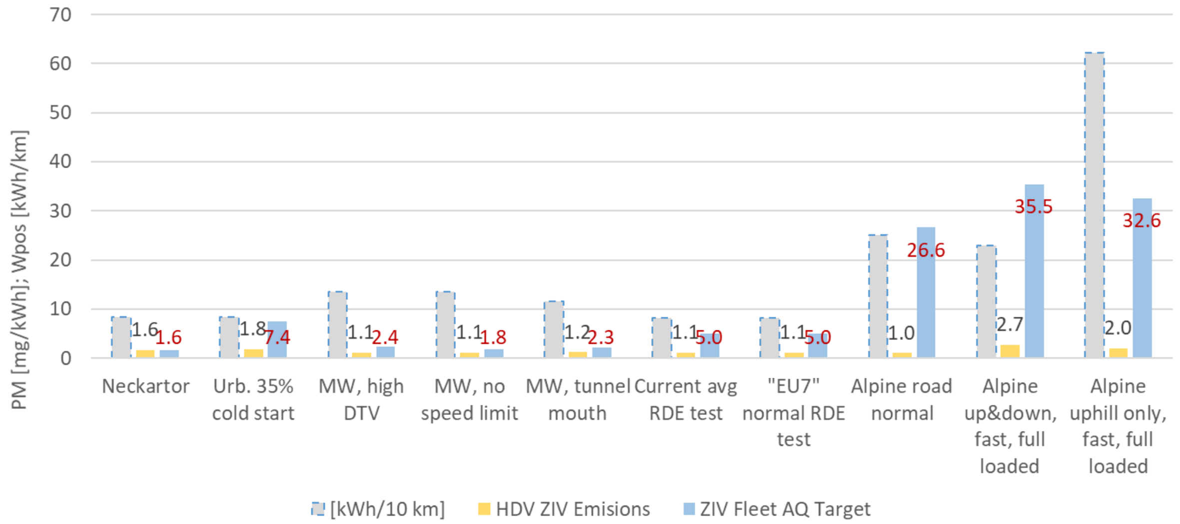

Figure 5: Engine work specific PM emissions for the average ZIV HDV fleets (target to meet AQ zero impact conditions compared with the ZIV HDV simulation).

Since the average specific emissions of the EURO 6d diesel cars and EURO VI D HDVs already are below the zero impact PN targets, the ZIV fleet – which in the simulation is slightly better performing in terms of PN than EURO 6d and EURO VI D from the HBEFA 4.2 data set - undercuts the targets in all scenarios. Figure 6 compares the distance specific PN emissions simulated for the ZIV car. Highest emissions per km occur again at the alpine uphill test with full loaded vehicle. As for NOx and PM, the emissions in the extreme test conditions are far below the zero impact targets since low traffic volumes allow higher emissions per vehicle-km.

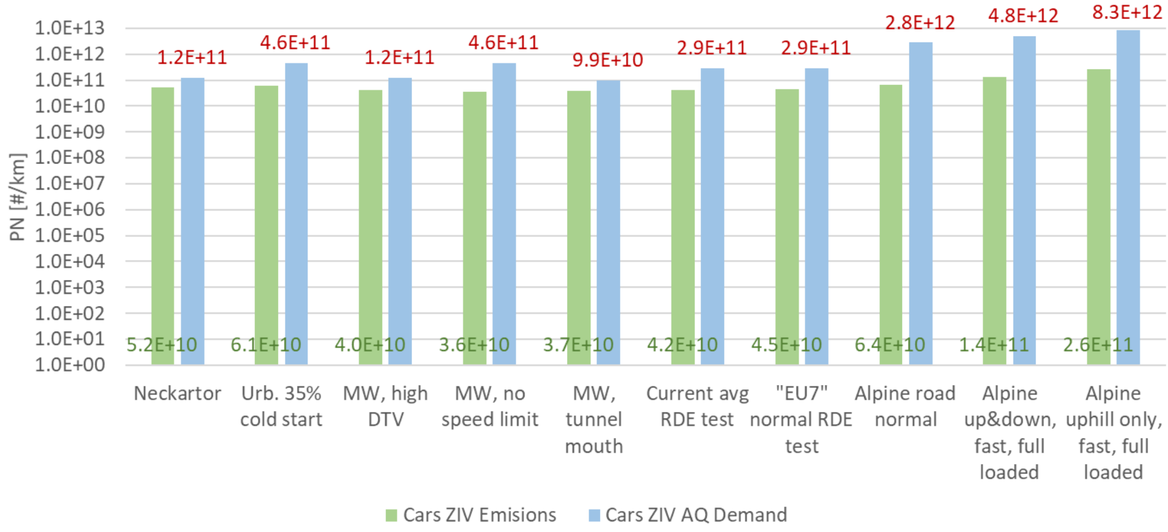

Figure 6: Distance specific PN23 emissions for the ZIV passenger cars (target to meet AQ zero impact conditions compared with the ZIV car simulation), log. scale.

Details on the scenarios and more results can be found in the final report of the study [4].

4 Verification by detailed AQ simulation

In addition to the sensitivity analysis, we performed detailed air quality simulations for different areas to validate the zero impact definitions and to increase the understanding of the impact of traffic emissions contribution to pollutant concentrations next to roads. For all model domains base case simulations were carried out and validated with meteorological and air quality monitoring before the traffic related scenarios were computed. The GRAMM/GRAL modelling system, [6], was used to model detailed flow and air pollutant dispersions. Highly resolved source specific emission data were processed for the simulations shown below. The impact of buildings on flow was accounted and pollutant dispersion was resolved down to the street canyon level, [7], (4 m x 4 m x 4 m). NO to NO2 conversion was computed by a simple empirical approach. The 100% ZIV fleet meets the zero impact targets in all areas analysed also near roads with heavy traffic.

Figure 7 shows as example simulation results for the city of Augsburg for the current situation and for the ZIV scenario, assuming a 100% ZIV fleet with the current traffic volumes. The zero impact AQ target of “below 1.2 µg/m³” for NO2 is fulfilled in the ZIV scenario at curb side and at all AQ stations.

In the final report also results for the current and for a 100% EURO 6 d/VI D vehicle fleet are compared with ZIV results.

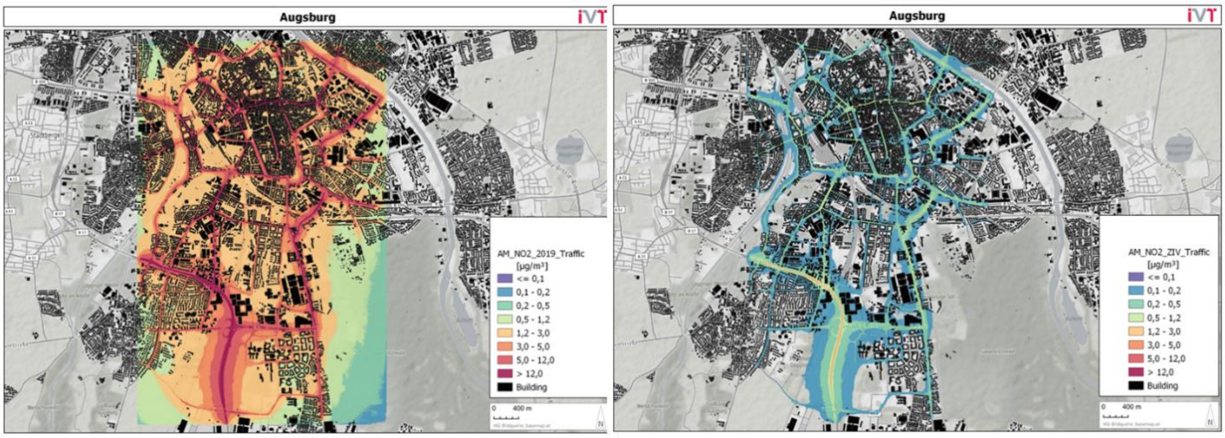

Figure 7: Contribution of road traffic to ambient NO2 concentrations from the AQ simulation using the models GRAMM/GRAL for the city of Augsburg (left = base case 2020/21 fleet, right = 100% ZIV fleet).

Figure 8 compares simulation results for Stuttgart, Neckartor using a chemistry box model described in [5]. Modelled daily average NO_2 concentrations at the hotspot are shown for the base case (top), for a 100% EURO 6 d/VI D vehicle fleet (middle), and for the ZIV fleet (bottom), each in comparison with the corresponding background concentrations. The background concentration includes contributions from the regional background and from urban sources as small combustion, industry, urban traffic etc. For the base case measurements from the urban background station Bad Cannstatt in Stuttgart are used in the model. The “total hotspot” concentration additionally includes the local traffic increment.

The scenario with 100% EURO 6d vehicles already shows a considerable reduction compared to the base case. However, for days with low ventilation, daily average NO_2 values in scenario 6 d still show some peaks that, while much lower than the corresponding peaks in the base case, are still higher than the background concentration. The scenario with 100% ZIV fleet leads to a further considerable NO_2 reduction. Here, daily NO_2 concentrations at the hotspot are only marginally higher than at the background.

Table 3 compares the local road traffic contributions and total road traffic contributions to the annual average NO_2 concentrations for two hot-spots simulated with the box chemistry model. Compared to the base case 2019

- The scenario “100% Euro 6 d vehicles” leads to reductions > 60% at Neckartor and > 70% at Taborstraße,
- The scenario “100% ZIVs lead to reductions of ca. 98% at both sites.

For both sites, the total road traffic contribution in the scenario 100% ZIV fleet is lower than the ZIV threshold of 1.2 µg/m^3 derived in WP 2.

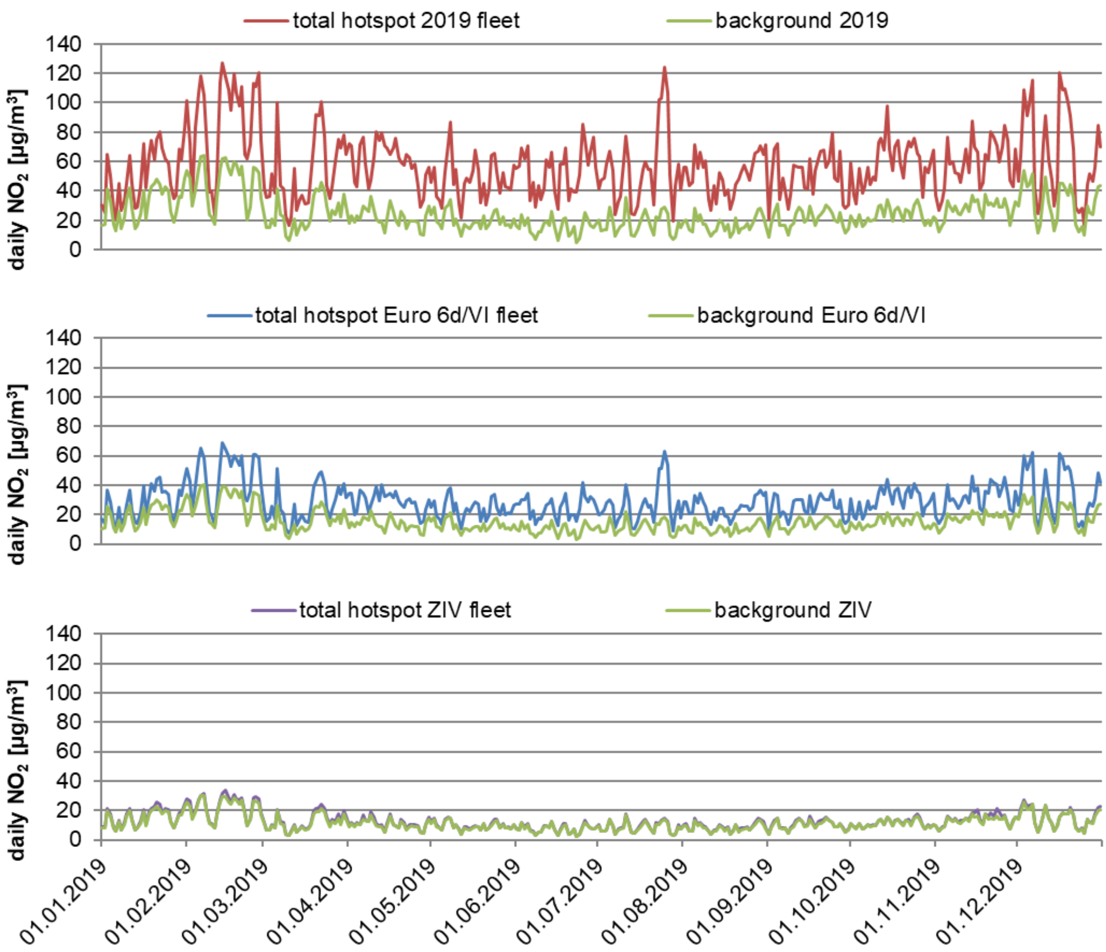

Figure 8: Daily average total hotspot NO_2 concentrations (top: 2019 fleet, middle: Euro 6 d/VI fleet, and bottom: ZIV fleet; each with corresponding background) for Neckartor simulated with the box model.

NO_2 [µg/m^3]		sc. 0 (base 2019)		sc. Euro 6 d		sc. ZIV	
		value	uncertainty	value	uncertainty	value	uncertainty
Stuttgart NT	local contribution	32.8	3.3	13.7	1.4	0.5	0.5
	road traffic background	13.1		3.8		0.3	
	total road traffic	45.8	3.3	17.5	1.4	**0.8**	**0.5**
Vienna Taborstr.	local contribution	18.1	1.8	5.2	0.5	0.4	0.5
	road traffic background	4.8		1.1		0.1	
	total road traffic	22.8	1.8	6.4	0.5	**0.5**	**0.5**

Table 3: Local and total road traffic contributions to annual average NO2 concentrations for all scenarios simulated with the box chemistry model for Stuttgart, Neckartor and Vienna, Taborstraße.

5 Summary and conclusions

From the study results, we conclude:

- The targets for vehicle emissions per km to meet the zero-impact air quality targets depend very much on the traffic situation, but also on site-specific environmental conditions that affect dispersion, such as basin or valley locations with low wind speeds and frequent inversions, e.g. Stuttgart.

- Situations with high traffic volumes need low emissions per veh.-km to meet the zero impact targets but do not have very demanding driving conditions,
- Extreme driving conditions are possible only at low traffic volumes and thus allow much higher emissions per veh.-km,
- Most critical for meeting zero impact seems to be dense urban and motorway traffic. Such situations should therefore be controlled properly in future RDE test regimes,
- The critical urban situation with maximum 10% of possible cold start shares is well represented by a ca. 15 km RDE test[8],
- A motorway situation with dense traffic of up to 200 000 vehicles per day cannot have significant shares of cold start and thus would be sufficiently represented in the hot parts of RDE tests,
- Extreme situations should certainly also be controlled in future emission regulations but may be aligned to a different set of limits since the zero impact targets for these traffic situations are much higher than for dense traffic.

Outlook:

The zero impact targets have been validated by detailed AQ simulation supported by AQ measurements. For PN emissions still model uncertainties concerning the complex chemistry and aerosol dynamics were identified. AQ measurements at different distances to roads for longer periods as well as background monitoring and further simulation work would be needed to improve the understanding particularly concerning volatile PN. Such an extended activity could include also non-exhaust particles for a complete picture of road traffic related PN and PM exposure (immissions).

6 Appendix

6.1 Bibliography

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[3] Handbook on Emission factors for Road Traffic (HBEFA); https://www.hbefa.net.

[4] Hausberger S., Tongues-Schulle N., Uhrner U., et.al: Zero-impact vehicle emissions (conceptual study); final report for FVV project; Graz 03/2022.

[5] Toenges-Schuller et al. (2019) NO2 Air Quality in German Cities: Trend Forecast and Scenarios, N. Toenges Schuller, Chr. Schneider, R. Vogt, St. Hausberger, TAP Conference, Thessaloniki, 16th May 2019.

[8] In the sensitivity analysis we defined the first 1.5 km after start as cold start distance with increased emissions. After this distance the simulated ZIV vehicles had in all cases “hot” emission level. With 10% cold start as worst case share for dense urban traffic, we get ca. 15 km as representative minimum test distance. Details of the simulation are described in the final report of the project.

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6.2 List of abbreviations

AQ	Air quality
DOC	Diesel oxidation catalyst
DTV	Daily traffic volume (vehicles/24 hours)
EC	European Commission
EU	European Union
HDV	Heavy duty vehicle
HEV	Hybrid electric vehicle
ICE	Internal Combustion Engine
LCV	Light commercial vehicle
LDV	Light duty vehicle
MW	Motorway
PC	Passenger car
PEMS	Portable emission measurement system
RDE	Real drive emissions
WHO	World Health Organisation
WLTP	Worldwide harmonised Light Vehicle Procedure
WP	Work Package
ZIV	Zero Impact Vehicle