Master's Thesis

Influence of engine speed and power change on emissions of PEMS measurements

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Graz, 28.08.2014

Vorwort

Zuallererst möchte ich mich herzlich bei meinem betreuenden Professor Stefan Hausberger sowie dem Institut für Verbrennungskraftmaschinen und Thermodynamik (IVT) und dessen Institutsvorstand Herrn Professor Eichlseder für die Möglichkeit bedanken meine Masterarbeit auf diesem renommierten Institut zu einem sehr zukunftsträchtigen und interessanten Thema zu verfassen. Insbesondere bedanke ich mich bei Professor Stefan Hausberger für das jederzeit offene Ohr - die Betreuung war hervorragend und die Zeit, die ich hier verbringen durfte, eine sehr lehrreiche.

Ein besonderer Dank gebührt meinen Eltern, meinem Bruder, meiner Oma sowie meiner Großtante, welche mir während meines Studiums immer mit einem guten Rat zur Seite gestanden sind und auch in teils schwierigen Situationen stets an mich geglaubt und mich unterstützt haben.

Ein großes Dankschön gilt auch den Mitarbeitern des Fachbereichs „Emissionsforschung“ des IVT, die mich während meiner Masterarbeit mit ihrem kollegialen Einsatz immer unterstützt haben und von welchen ich in fachlichen Diskussionen sehr viel lernen durfte. Insbesonders hierbei zu erwähnen sind: DI Werner Stadlhofer, DI Silke Lipp, DI Claus Matzer, Dr. Martin Rexeis, DI Antonius Kies, DI David Leitner sowie die Sekretärin Alexandra Stiermair.

Content

Formula, Index and Abbreviations

Latin formula symbol

a_{ref}	m/s²	Reference acceleration, suggested: 0.45 m/s²
m_{ref}	kg	Test mass of the vehicle in NEDC
M	Nm	Engine torque
n	1/min	Engine speed
n_{idle}	1/min	Idling engine speed
n_{rated}	1/min	Engine speed at rated engine power P_{rated}
P_e	kW	Effective engine power
P_{drive}	kW	Vehicle specific power demand for a_{ref} and v_{ref}
P_{rated}	kW	Rated engine power
P_d	kW	Dragging power of an engine
P_{wheel}	kW	Power measured at the wheels during a dynamometer test
t_{PB_i}	%	Timeshare of powerbin i
t_{Cell_i}	%	Timeshare of power and engine speed cell i
v_{ref}	m/s	Reference vehicle velocity, suggested: 19.4 m/s

Greek formula symbol

λ	–	Air/fuel ratio
π	–	Circle constant
ν	–	Velocity function
ω	s^{-1}	Angular velocity

Operators

$\sum$	Sum
Δ	Difference of two quantities

Further indices and abbreviations

CADC	Common Artemis Driving Cycle
CLEAR	Classification of Emissions from Automobiles in Real Driving
CO	Carbon Monoxide
CO_2	Carbon Dioxide
DOC	Diesel Oxidation Catalyst
DPF	Diesel Particle Filter
ECU	Engine Control Unit
EFM	Exhaust Flow Meter
EGR	Exhaust Gas Reduction
EU	Europoean Union
FID	Flame Ionization Detector
HGV	Heavy Goods Vehicle
ICE	Internal Combustion Engine
LDV	Light Duty Vehicle
NEDC	New European Driving Cycle
NO	Nitrogen Monoxide
NO_x	Nitrogen Oxides
NSC	NO_x Storage Catalyst
NDIR	Non-Dispersive Infra Red Sensor
NDUV	Non-Dispersive Ultra Violet Analyser
PAH	Polyaromatic Hydrocarbons
PB_{n_i}	Normalised Powerbins
PB_i	Vehicle Specific Powerbins
PEMS	Portable Emission Measurement System
PN	Particle Number
RDE	Real Drive Emissions
RPA	Relative Positive Acceleration
RPM	Rounds Per Minute
SULEV	Super Ultra Low Emission Vehicle
THC	Total Hydro Carbons
TPP	Target Power Pattern
WLTC	World Harmonized Light Duty Test Cycle
WLTP	World Harmonized Light Duty Test Procedures

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Graz, am 28.08.2014

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Zusammenfassung

Die allgemein wachsende Sensibilität hinsichtlich zahlreicher Umweltthemen und steigende Luftgüteziele veranlassen die EU unter anderem zu einer immer strengeren Emissionsgesetzgebung für Kraftfahrzeuge. Um realitätsnahe Fahrzeugemissionen zu identifizieren, plant die EU Kommission für das Jahr 2017 Onboard-Emissionsmessungen, sogenannte PEMS-Tests (Portable Emission Measurement System), als verpflichtenden Bestandteil der Abgasmessung der EURO 6c-Abgasgesetzgebung einzuführen. Dies stellt die Automobilhersteller vor große Herausforderungen, da in Zukunft zusätzlich zu den auf dem Rollenprüfstand während eines Typprüfzyklus (WLTC) gemessenen Emissionen auch die bei PEMS-Tests onboard gemessenen Emissionen bestimmte Grenzwerte (um einen CF-Faktor erweiterte EURO 6 – Grenzwerte, CF = Conformity Factor) einhalten sollen. Die große Beeinflussbarkeit der Emissionen bei PEMS-Tests durch den Fahrer, die Route und zahlreiche andere Randbedingungen machten es notwendig, Untersuchungen hinsichtlich einer möglichen Emissionsnormalisierung durchzuführen, um so verschiedene PEMS-Tests miteinander vergleichbar zu machen. Der erste Ansatz des Fachbereichs „Emissionsforschung“ am IVT der TU Graz hinsichtlich einer Emissionsnormalisierung basiert auf der Gewichtung der Emissionen mit einer standardisierten zeitbasierten Häufigkeitsverteilung für die am Rad abgegebene Leistung. Die Ergebnisse dieses Normalisierungsansatzes sind bisher sehr zufriedenstellend. Im Zuge dieser Masterarbeit wurde eine mögliche Verbesserung der Emissionsnormalisierung durch Berücksichtigung der Drehzahl untersucht. Hierfür erfolgte die Emissionsgewichtung mit Leistungs-Drehzahlhäufigkeitskennfeldern (P-rpm-maps). Die Berücksichtigung der Drehzahl hinsichtlich der Gewichtung der Emissionen zeigte jedoch nicht die gewünschte Wirkung, wodurch im Umkehrschluss die These aufgestellt wurde, dass der Einfluss der Drehzahl auf Emissionen bei PEMS-Messungen gering sein muss. Da eine weitere Emissionsnormalisierungsverbesserung durch die Drehzahl nicht möglich ist und der Fahrer- und Routeneinfluss auf die Emissionen sehr groß sind, wurden in dieser Masterarbeit zusätzlich fahrdynamische Bewertungsparameter hinsichtlich ihres Potenzials für eine PEMS-Test Validierung untersucht und bewertet. Hierbei handelt es sich um die Parameter ΔP (Leistungsgradient) und RPA (Realtive Positive Acceleration). Beide Parameter zeigten Korrelationen mit verschiedenen Emissionen und eigneten sich daher für die Ableitung möglicher Schwellwerte, innerhalb welcher ein normaler PEMS-Test stattfinden sollte. Mittels der vorgeschlagenen Schwellwerte war eine akzeptable Identifikation von aggressiv oder ökonomisch gefahrenen PEMS-Trips möglich.

Summary

Both the growing sensibility regarding environmental issues and increasing air quality targets lead the EU to define stricter emission legislations for vehicles. In order to identify emissions much closer to reality the EU commission plans to introduce onboard emission tests, so called PEMS-tests (Portable Emission Measurement System), for vehicles as an obligatory part of the 2017 EURO 6c exhaust legislation, which is a great challenge for all OEMs. The high persuasibility of the emission level of PEMS-test by the driver, route and other boundary conditions made investigations regarding the normalisation of PEMS-tests emissions necessary in order to make these tests comparable to each other. The first approach by TUG with the software tool CLEAR is based on the weighting of emissions by a standardized target frequency distribution for the power at the wheel hubs P_{wheel}. This approach showed an emission normalisation with a proven record of success. Tasks of this thesis were the investigation of a possible improvement regarding the emissions normalisation and the assessment of driving dynamic parameters for future normality validation of PEMS-tests by investigation of the influence of engine speed and power change on emissions of PEMS-tests.

Investigations of PEMS-tests on the Mazda CX5, BMW 320d and VW Bus T5 regarding the influence of the engine speed on the emissions showed that the engine speed seems to have a small influence on the emissions. This conclusion is based on the fact, that an additional normalisation of measured emissions by P-rpm-maps (frequency maps for the engine speed and power at the wheel hubs) does not bring an improvement respectively the weighting of emissions in order to get better normalised and more comparable results. Furthermore several normalisation attempts by many different P-rpm-maps showed that it would have been difficult to define a general P-rpm-map for each car representing a normal frequency map beccause of the high amount of variabilites even for just one car (gear ratio, vehicle weight, kind of engine and propulsion combination, etc.). For these reasons the engine speed seems to be no adequate quantitity to normalise emissions of future PEMS-tests in order to make them more comparable to each other.

If there is no improvement of emission normalisation visible, other possibilities in order to check the validity of a PEMS-test have to be investigated. Due to the great influence of the driver and the route on emissions of PEMS-tests, driving dynamic parameters were searched in order to define the normality of future PEMS-tests. As dynamic driving parameters the power change ΔP and RPA (Relative Positive Acceleration) have been investigated for many different trips of several vehicles. For both parameters normal PEMS-trips characterising thresholds have been suggested to identify too economic or too aggressive driven trips. In order to get more representative thresholds regarding ΔP and RPA more vehicles shall be investigated form the statisitical point of view. Also the possibility for vehicle class specific RPA may be investigated in the future.

Summerized all investigations showed that the vehicle, the driver and its driving style and the route have a big influence on the emissions which enlarges the complexity of the attempt to firstly make future PEMS-test emissions comparable to eachother and secondly find boundaries that represent a normal driving behaviour in order to check the validity of future PEMS-test. Nevertheless possible boundaries for ΔP and RPA in order to identify abnormal PEMS-test have been found and suggested in this thesis.

1 Introduction

Severe problems to meet air quality targets and ambitious targets for greenhaus gas emissions lead to new and stringenter emission regulations for passenger cars and light commercial vehicles. Until today all new cars have to pass a type approval test consisting of a specified driving cycle called NEDC at defined test comditions on a chassis dynamometer. Because of its lack of dynamic parts during the cycle and by OEM optimised vehicle emission performances it was not very difficult to pass the test. For this reason from 2017 on there will be a new type approval test procedure called WLTP, which shall depict real driving situations much better then the NEDC. In this procedure besides a driving cycle on a chassis dynamometer, called WLTC, all new cars shall also have to comply with emission boundaries on a real traffic ride - so called PEMS-tests. Emissions produced during these real traffic tests are measured and noted. Especially the new emission limits of NO_x emissions for diesel engine vehicles are a big concern for OEMs. Several studies have indicated that in particular on-road NO_x-emissions are much higher than on a NEDC dynamometer test which doesn’t represent the actual on-road emissions of light-duty vehicles at all. In order to comply with the required emission regulations adapted to on-road conditions special exhaust aftertreatment technologies would be necessary for many cars.

It’s commonly known that the influence of a driver, his driving style,, the route, the traffic and other environmental conditions have a big impact on emissions measured during PEMS-tests. In order to compare PEMS-tests of one and the same car to each other the validity of a PEMS-test has to be defined. E.g. an aggressive driving style will usually cause more emissionsin [g/km] than an economical one. For this reason limits concerning dynamics of a valid PEMS-test have to be found. The focus is on the dynamic of a trip represented by the change of engine speed and power, which seem to be good dynamic indicators. The aim is to identify the impact of those two indicators on on-road emissions. The investigations concentrate on NO_x emissions because of the new European Emission Regulation EURO 6 (09/2014) for vehicles with a diesel engine, where a NO_x reduction of almost 70% compared to EURO 5 was adopted by the European Commission. The analysis is made and supported by a software tool called CLEAR (henceforth just CLEAR), which was developed at the Emissions Research Departement of the Institute for Internal Combustion Engines and Thermodynamics at TU Graz. The investigated cars were solely cars with a compression ignition engine. Especially the influences on the NOx emissions have been considered.

Chapter 2 gives an overview on the theoretical basics, the current environmental situation, legal regulations and effects regarding the relevant emissions NO_x, CO_2, HC and CO. In addition the WLTP, with focus on the WLTC, the used measurement equipment for PEMS-tests and the evaluation method of CLEAR are explained. Above all analysing methods for PEMS-test normality respective the engine speed and power change are shown.

Chapter 3 deals with the evaluation of the results. First of all an overview on the examined cars with its specifcations is given. Furthermore, the influence of engine speed and engine speed change and power change are examined and evaluated. The same analysis is executed with RPA (Relative Positve Acceleration) and the power normalisation. Subsequent to every detailed analysis suggestions respective boundary conditions for the different dynamic parameters are made.

Chapter 4 draws a conclusion and outlook regarding the prospective PEMS-tests, its dynamic parameter boundaries and possibilities to implement these limits in a legal text for the new test procedure WLTP.

2 Theoretical Basics

This chapter delivers the necessary basics and gives an insight into relevant areas of emissions formation, the effect of emissions and furthermore the function of exhaust aftertreatment systems. The current environmental situation and legal regulations regarding the relevant emissions NO_x, CO_2, HC and CO are explained, too. Additionally, the evaluation method applied by CLEAR and analysing methods for the normality of PEMS-tests are shown.

2.1 Emissions

The products of an ideal complete combustion of a combustion engine, whether a compression or spark ignition engine, are H_2O and CO_2. The precursors of these reactions are hydrocarbons depending on the type of engine (diesel, gasoline, gas). Equation 2-1 [1] shows the chemical reaction of an ideal combustion.

$$\mathrm{C}_x H_y O_z + \left(x + \frac{y}{4} - \frac{z}{2}\right) O_2 \rightarrow xCO_2 + \frac{y}{2} H_2O \qquad 2\text{-}1$$

In reality, there is no complete combustion, which is the reason for the formation of unburnt hydrocarbonates (HC), particulate matter (PM) and CO emissions. Additionally, NO and NO_2, together NO_x, are build of air nitrogen, which is oxidated during the combustion.

Following subchapters explain the formation, effect and reduction measures of emissions.

2.1.1 CO

Carbonmonoxide is the most relevant emission source of spark ignition engines operated without a catalytic converter and the typical product of an incomplete combustion with a lack of air. It’s a poisonous and colorless gas with a very high affinity to connect to hemoglobin and thus prevents oxygen saturation in the blood. In order to reduce the amount of CO the combustion should take place with air excess (diesel engine) or a catalytic post-combustion is needed. Today obligatory three-way catalysts for spark ignition engines bring the CO emissions to a non-polluting and for human beings harmless level.

2.1.2 HC

Hydrocarbons are cursory organic substances. Due to the fact that all diesel and gasoline fuels consist of HC and ideal combustions practically do not exist always unburnt HC remain in the exhaust gas. Together with NO_x and solar radiation they can cause musosal irritation and force the appearance of ozone-smog. Some of the hydrocarbon links are carcinogenic, e.g. Benzol (group of PAH). Low-NO_x-Combustion tends to lead to a high amount of HC especially in low load areas and should be avoided in order to hold the level of appearing HC emissions down. This leads to a HC-NO_x-Trade-off. Futhermore, humid exhaust gas with a big amount of HC can pollute fastly the EGR cooler, which is a very important part of the exhaust aftertreatment system of a diesesl engine car. The onboard measurement of HC is not innocuous. The reason is that the measuring principle is based on the FID (Flame Ionization Detector), which needs hydrogen for the measurement.

2.1.3 CO_2

CO_2 is a colorless and odorless gas. It is the desired product of an ideal complete combustion but also the most relevant greenhouse-gas. For this reason the CO_2-emissions caused by cars are limited. The average fleet emission is limited from 2015 on to 130g_{CO2}/km and from 2020 on to 95g_{CO2}/km. CO_2-emissions are directly connected to the fuel consumption, because during the combustion fuel carbon is converted almost completely to CO_2. For this reason, whether for a gasoline or diesel engine, 3,15kg CO_2 per kg fuel are generated. In order to reduce CO_2 emissions either the fuel consumption has to be reduced or the usage of regenerative energies or less C containing fuels have to be supported. The measuring principle is based on NDIR (Non-Dispersive Infrared Sensor).

It is widely known that CO_2 emissions have a nearly linear connection to the power demand at a constant engine speed described by so called Willans-Lines. For this reason CO_2 could be a good measure for the engine load in general. The Vehicle-Willans-Line tries to explain this connection (2.3.2.1). They will probably form the basis for future power demand calculations of PEMS-tests. Further investigations and calculations of this thesis are based on Vehicle-Willans-Lines calculated CO_2 emissions. Hence a good and reliable CO_2 emission signal during onboard measurements is required.

2.1.4 NO_x

New and much lower NO_x emission limits of the EURO 6 emission regulation are especially for diesel vehicles a big challenge to comply with (almost 70% lower than EURO 5). NO_x is a big concern, because latest emission results of PEMS-tests show, that “on-road NO_x emissions of diesel vehicles substantially exceed EURO 3-5 emission limits up to a factor of 4-7” [7]. Additionally, there is just a small decline from EURO 2 to EURO 5 real world NO_x emissions (Figure 2-1).

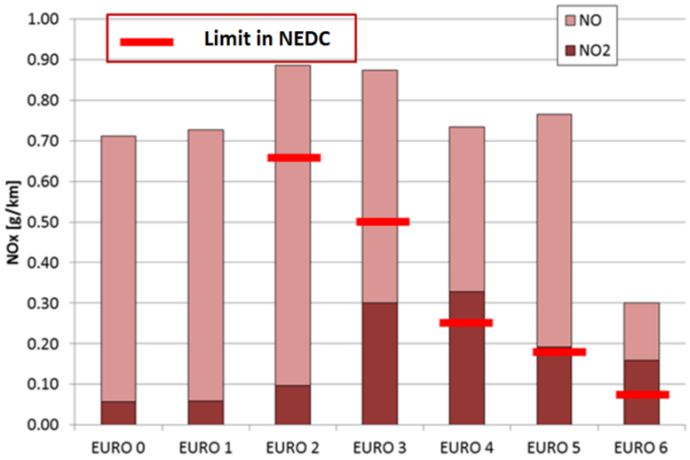


Figure 2-1: NO_x-emissions from diesel cars during real world chassis dyno cycle CADC (1/3-mix urban, road, motorway)

Nitrogen oxides result from high combustion temperatures and/or oxidation processes of nitrogen compounds due to air excess. Genereally there are three formation mechanisms for NO:

1. Thermical NO (Zeldovich-NO)
2. Sponteneous NO
3. Oxidation of fuel N to NO

NO is oxidated by UV light to NO2. Nitrogen dioxide is a very poisonous gas for human beings and the environment. Air quality legislation typically limits NO_2. New particle regulations by the European Union enforce the building of NO_2. This gas is the basis for the regeneration of particle filters and is the result from oxidation of NO by an oxidation catalyst. But this leads to a higher NO_2 concentration close to the streets. From vehicle legislation side there are just limits for the NO_x, which contains both the NO and the NO_2. This obvious CO_2-NO_x trade-off will be a research-dominating theme in the future (Figure 2-2). High combustion temperatures lead to a high efficiency factor of the ICE. On the other hand high amount of NO_x molecules are emitted.

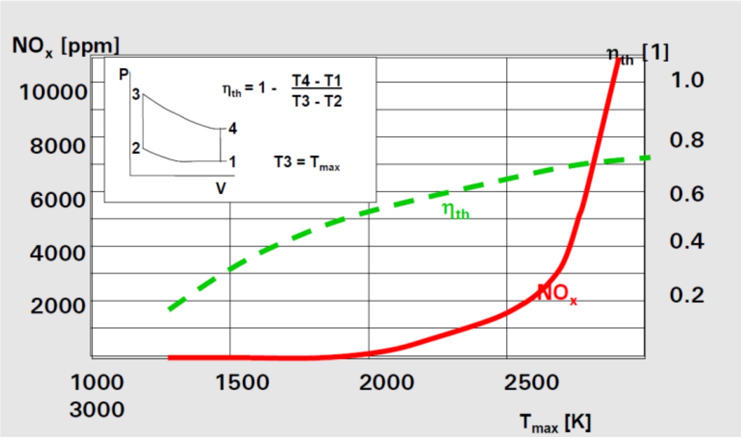


Figure 2-2: NO_x-efficiency factor trade-off

Following figure shows possibilities to reduce NO_x emissions of ICEs.

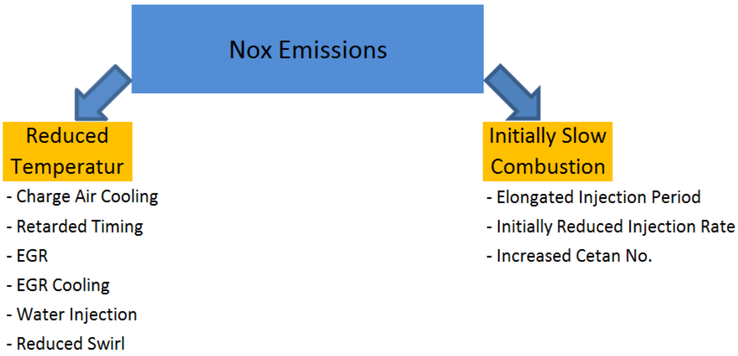


Figure 2-3: NO_x emission reduction possibilities [2]

The Nitrooxides (NO, NO_2) will be measured by a NDUV (Non Dispersive Ultra Violet) analyser installed at a PEMS measurement system.

In 2.1.6.2, 2.1.6.3 and 2.1.6.4 current exhaust aftertreatment systems e.g. EGR and the SCR systems are explained. Especially their influence on NO_x emissions and NO_x reduction possibilities for diesel engines are of great interest.

2.1.5 Particle/particulate matter and soot

Particle and/or soot built by internal combustion engines are assigned to particulate matter (PM) because of their small size (particle with a diameter smaller than 10µm are called

PM10). They occur at mid to high combustion temperatures (1700K-2500k) and at low local λ (lack of air). Spark-ignition engines with direct injection and λ>1 operation mode have problems with the amount of particles, too. Particles consist of solid carbon nucleus attached with solid or liquid materials (HC, sulphur or nitrogen connections, water or even heavy metals). Almost all particles emitted by ICEs possess a diameter smaller than 1µm. Due to their small size they are harmful and very toxic for humans. These small particles carry carcinogenic substances (PAH) and can get directly into the lung. In order to reduce the pollution by particulate matter different kinds of particle filters have been developed.

2.1.6 Emission control systems

In order to reduce exhaust emissions, especially NO_x emissions, and the amount of particles different exhaust aftertreatment systems are in use. Following chapters deal with systems whose purpose is the reduction of NO_x emissions during the operation of an internal combustion engine, in particular diesel engines.

2.1.6.1 DPF

Increasing stringent PN limits require an application of DPF especially in diesel passenger cars and heavy-duty vehicle. DPF have to bear up against high temperatures (up to 1000°C during regeneration), thermical tension and vehicle vibrations. Moreover good soot and ash storage capability, small thermical mass and a filter efficiency concerning particle mass and particle number greater 99% are required. Ceramical wall-flow monolithic filter consisting of silicium carbide meet these requirements. In a wall-flow filter particle and ash is stored at the filter material. On the other hand there are also open filter systems, which are rather used in retro-fitsystems. Continous regeneration of a wall-flow filter is based on NO_2. NO_2 is the product of an upstream DOC, which oxidizes engine out NO. Other possibilities to regenerate a filter are thermical regeneration e.g. by motor-driven heating with or without an additive compound.

2.1.6.2 EGR system

The EGR system is a very efficient and widely-used system at diesel engines in order to reduce nitrogen oxide emissions.

The formation of nidrogen oxides is reduced by supply of an inert gas into the combustion chamber. Such a gas could be the exhaust gas of the internal combustion engine. The fast oxidation of fuel molecules is prevented by the presence of exhaust gas molecules. Due to this fact high temperatures and NO_x emissions are reduced. Additionaly, this instance is supported by the fact that the exhaust components H_2O and CO_2 own high specific heat coefficients and additional mass has to be heated per mol O_2 used. For this reason the nascent energy of combustion heads to a lower combustion temperature and subsequent to lower NO_x emissions. On the other hand high EGR rates lead to high soot emissions, because of less oxygen concentration and due to and due to a lower combustion temperature which decelerates soot oxidation. Both emission parts are limited due to emission regulations whereby the already mentioned trade-off arises.

Diesel and gasoline engines with direct injection and satisfied-lean operation produce lean exhaust gases. These operation modes do not allow NO_x reductions in a three-way-catalyst, but are characterized by huge fuel consumption advantages. Both engine types however, have attractive fuel efficiencies. In order to comply with the regulations of EURO 6 these two drive concepts have to be operated with an additional exhaust aftertreatment system. There are two possible strategies:

1. NO_x storage catalyst
2. SCR (Selective Catalytic Reduction)

2.1.6.3 NO_x storage catalyst

This catalyst works e.g. at $\lambda=1$ like a three-way-catalyst. In addition to noble metal and oxygen storage components it possesses NO_x storage components. These storage components for NO_x are alkaline or alkaline earth components as e.g. Barium. NO raw emissions are oxidized to NO_2 and furtheron adsorbed as nitrate at the NO_x storage components. If the storage capacity is depleted the catalyst has to be regenerated by an engine operation mode with $\lambda<1$. During this short and rich engine operation the nitrates convert to NO_2 and desorb in the next step as NO. In addition to this operation the stored oxygen is set free. High CO, HC and H_2 concentration and a stoichiometric air ratio build the same initial point for the conversion reactions like in a three-way-catalyst. In the best case CO_2, N_2 and H_2O leave the catalyst during the regeneration. This kind of NO_x reduction is attractive from the economic point of view. The costs for the development, production and implantation of a NO_x catalyst are very low compared to full SCR system. Moreover there is almost no maintenance of new NO_x storage catalyst. Disadvantage is the increased fuel consumption during regeneration and a lower NO_x car version compared to SCR.

2.1.6.4 SCR

The SCR technology is a very effective but also expensive and compared to the NO_x storage catalyst complex way to reduce NO_x emissions. The basic concept of this technology is injecting urea (NH_3) in the tailpipe during engine operation. Mainly NO and NO_2 are reduced for the oxidation. For this reason this procedure is called selective catalytic reduction. Before the the SCR reaction can take place NO is oxidized to NO_2.

Equation 2-2 shows the chemical reaction of the SCR. By this reaction the NO and NO_2 is reduced to N_2 and H_2O.

$$NO + NO_2 + 2NH_3 + \ O_2 \rightarrow 2N_2 + 3H_2O + O_2 \tag{2-2}$$

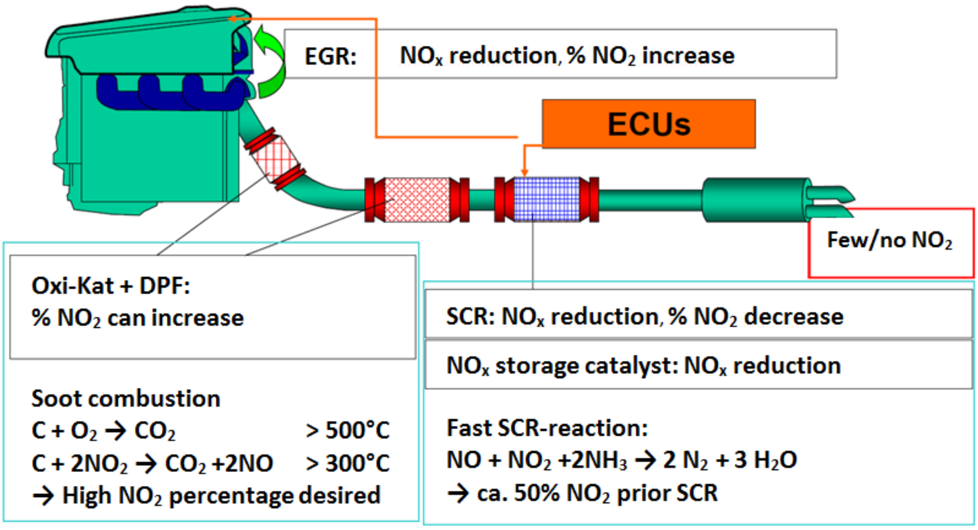


Figure 2-4: NO_x reduction technologies

Figure 2-4 gives an overview of actual exhaust aftertreatment systems and their influence on NO_x for future diesel engines. Ever stricter law regulations concerning the emissions force the OEM to equip new cars with one or both mentioned NO_x aftertreatment technologies depending on several conditions like e.g. vehicle mass and/or engine power.

Following chapter deals with the new and upcoming emission regulations.

2.2 Emission regulations and legislation for light-duty vehicles

A worldwide increasing travel demand and number of licensed cars plus the phenomenon of urbanisation led several governments to pass emission regulation laws. As a part of the type approval procedure emissions testing seems to be the biggest competition for OEM. Today EURO 5 thresholds have to be passed during a NEDC dynamometer test. From September 2014 on it will be compulsory to comply with the EURO 6 thresholds. From 2017 on it is planned to introducea WLTC dynamometer test combined with a PEMS-test that takes place in real traffic. These regulations will cover following vehicle categories:

i. M1 and M2 – passenger cars with maximum eight seats in addition to the driver’s seat and having a maximum mass not exceeding 5 tonnes

ii. N1 and N2 – vehicles used for the carriage of goods and having maximum mass not exceeding 12 tonnes. [7]

In this thesis just diesel vehicles of the categories M1 and M2 are under investigation.

2.2.1 Legislation Boundaries

Table 2-1 shows the development of the emissions treshold over the last 20 years compared to SULEV (California). Vehicles of the category M1 and M2 have to comply with these emission limits. Limited pollutants are: CO (carbon monoxide), HC (hydro carbons), NO_x (nitro oxides) and PM (particulate matter) in the case of diesel engines and gasoline direct injection engines. In case of the CO_2-emissions the European Commission introduced a fleet average CO_2 emissions target of new passenger cars of $130g_{CO2}$/km starting in 2015 and with $95g_{CO2}$/km target for 2021. Worth noticing is the step from EURO 5 to EURO 6 for diesel engines respective the decline of NO_x emission limits.

Table 2-1: Emission limits for passenger cars compared to American SULEV [3]

	CO [g/km]		HC [g/km]		NOx [g/km]		HC+NOx [g/km]		PM [g/km]	PN [1/km]
	Otto	Diesel	Otto	Diesel	Otto	Diesel	Otto	Diesel	Diesel & Otto DI	Diesel & Otto
EURO 1 (1992)	3.2	3.2					1.13	1.13	0.140	-
EURO 2 (1996)	2.2	1.0					0.50	0.70	0.080	-
EURO 3 (2000)	2.3	0.6	0.20		0.15	0.5	0.35	0.56	0.050	-
EURO 4 (2005)	1.0	0.5	0.10		0.08	0.25	0.18	0.30	0.025	-
EURO 5 (2009)	1.0	0.5	0.10		0.06	0.18		0.23	0.005	$6*10^{11}$
EURO 6 (2014)	1.0	0.5	0.10		0.06	0.08		0.17	0.005	$6*10^{11}$
SULEV (California)	1.0	1.0	0.01		0.02	0.02		0.03	0.010	-

2.2.2 WLTP

The fact that emission regulations get more stringent and the awareness of human beings regarding the environment and its pollution increases, type approval tests with a better reference to real driving have to be found. Today's standard type approval test is based on the NEDC which is nearly unchanged since 1996. In order to approve a new vehicle a test driver drives the NEDC on a chassis dynamometer, which simulates road load efficients R_0, R_1 and R_2. The measured exhaust gas emissions of this test have to comply with the actual threshold values. Due to the fact that the velocity profile of the NEDC isn't very dynamic measured exhaust gas emissions are often much lower than those in reality. Following Figure 2-5 shows the velocity profile of NEDC compared to a real world driving cycle.

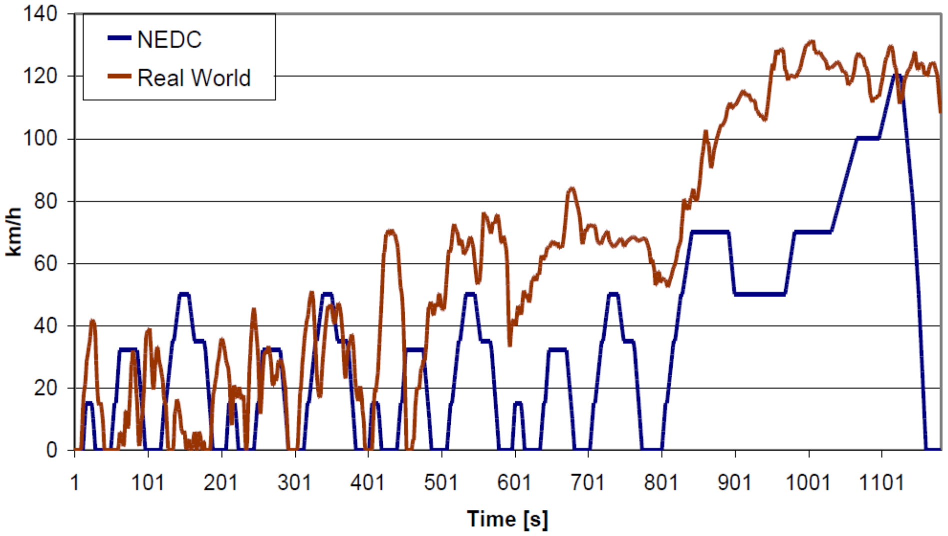


Figure 2-5: Speed profile of NEDC and Real World Driving [3]

2.2.2.1 WLTC

In order to represent the real driving conditions in a better way and deliver realistic exhaust gas emissions, including the fuel consumption, a new test cycle called WLTC was developed based on real world driving. Figure 2-6 and Figure 2-7 show the difference between NEDC and WLTC respective the velocity profile and the engine speed and power distribution.

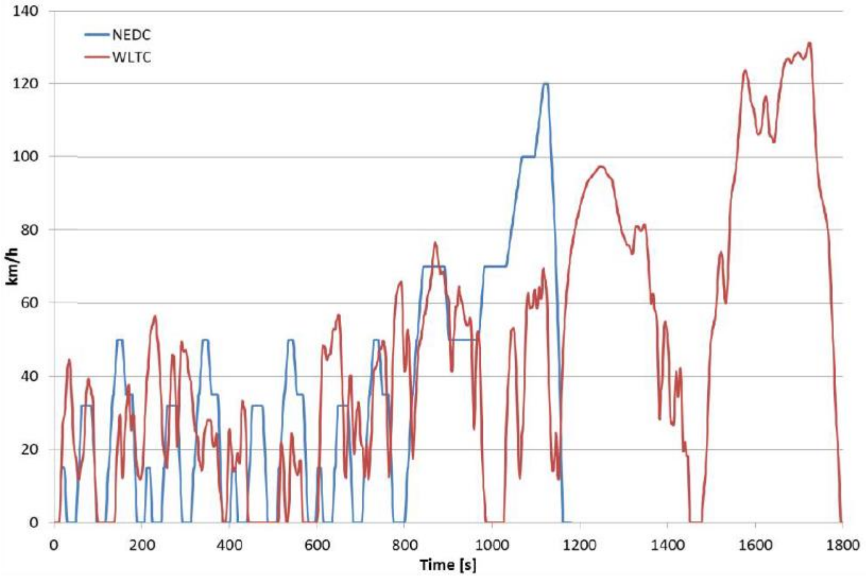


Figure 2-6: NEDC and WLTC velocity profile

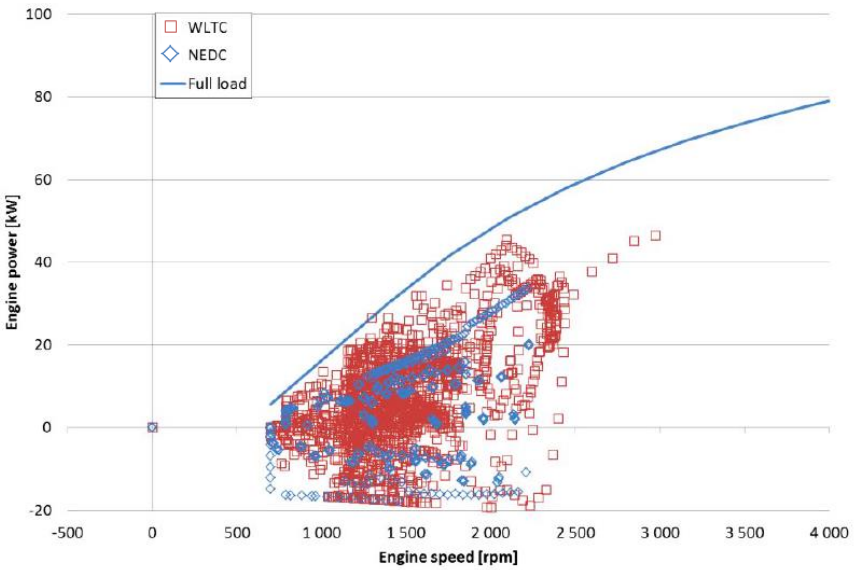


Figure 2-7: Engine speed and power distribution of NEDC and WLTC for a diesel engine vehicle

Obviously, the new driving cycle WLTC is more dynamic and therefore much closer to reality than the NEDC. The WLTC consists of an urban (0-60km/h), road (60-90km/h) and motorway (>90km/h) part and lasts for 30 minutes. However the WLTC doesn't cover higher engine speed areas, which are part of a realistic driving profile. Therefore in addition to the WLTC on a chassis dynamometer onroad emissions tests (PEMS-tests) are planned to be introduced in order to get more realistic emissions of a vehicle for future type approval tests starting in 2017.

2.2.3 PEMS-tests

PEMS-test (Portable Emission Measurement System) will build a significant part of future type approval tests. "Such a system is suitable to measure mobile source development. For the purpose of complieance (emission classes), regulation or to a better identification of actual in-use performances of vehicles, real world emission behaviour seem to get increasingly important."[6] Originally "PEMS equipment and testing procedures have been developed for testing the in service conformity heavy-duty vehicles and non-road machinery."[7] Already in 2004 the EU started a "cooperation with heavy-duty engine manufacturers to study the feasibility of PEMS for veryfiying the in-operation conformity of heavy-duty engines" [4]. Recent studies conducted by JRC and other European Institutes show that diesel engine vehicles currently on the market "are far from complying with regulatory emission limits under real driving conditions."[5] Especially "real-driving NO_x emissions of light-duty diesel vehicles did not change much over the last decades, despite the increased stringency of the limit values."[5] (see Figure 2-1). For this reason real driving emissions have to be measured and lead to RDE procedure in order to ensure that vehicle emissions comply with the regulation and "control technologies are functional under real-driving conditions."[5]. PEMS-tests seem to be the most efficient way to identify real driving emissions outside standardized laboratory conditions. ´

Following two chapters deal with the measurement equipment of PEMS-tests and show the construction exemplarily on an examined car, in this case VW Bus T5.

2.2.3.1 Measurement Equipement

The portable emission measurement system used by TU Graz in order to identify real driving emissions is a SEMTECH DS (Figure 2-8). PEMS measures the exhaust gas concentrations of the regulated pollutants, the exhaust mass flow and the exhaust temperature.

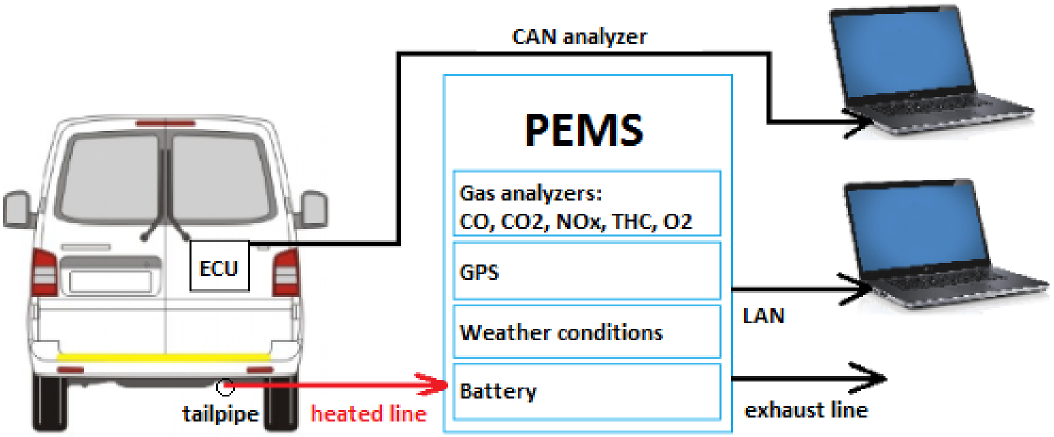


Figure 2-8: PEMS equipment

Figure 2-8: PEMS measuring equipment SEMTECH-DS

The system is capable of monitoring both the spark ignition and compression ignition engines. It consists of a Pitot tube for measuring the exhaust mass flow and temperature, exhaust gas analyzers for CO, CO_2, NO, NO_2 and THC, a tailpipe attachment and a heated exhaust line. Moreover a data logger, a GPS and sensors for ambient temperature and humidity are installed. The heated sample line minimizes the loss of hydrocarbons due to condensation prior entering the FID. The power supply is an external battery. Nitrooxides are measured by a NDUV analyser, CO and CO_2 are measured by a NDIR analyser. The data range of the system is 1Hz. [6]

The engine speed, velocity and acceleration are recorded by a separate laptop, which is connected to the ECU by a CAN analyser (VAG-Com).

The SEMTECH-DS unit isn’t weight optimized, because of its design for heavy-duty engines. But in case of a VW Bus T5 the additional weight of ca. 100kg for the whole PEMS installation seems to be negligable.

Some companies (e.g. AVL) are currently working on PEMS equipement with low weight in order not to falsify the measurement results (e.g. AVL M.O.V.E. PEMS iS).

Following pictures show the PEMS equipement installed at the test vehicle, a VW Bus T5.

(i) EFM (ii) Heated line and EFM (iii) PEMS unit and external battery

(iv) SEMTECH DS (v) SEMTECH operation interface (vi) CAN analyser interface

Figure 2-9: PEMS equipment installation and CAN analyser (VAG-Com)

2.2.3.2 CF-factor

Several investigations regarding emissions of on-road measurements (PEMS-tests) showed that some pollutants and especially NO_x emissions of light-duty diesel vehicle are higher than current legal limits. The hight of the emission level is influenced by the driver and its driving style, ambient, traffic and road conditions. This significant amount of dependencies leads in a high variance of emission levels of PEMS-test. For this reason the European Commission is discussing a conformity factor (CF) for EURO 6 emission limits concerning CO, HC and NO_x. The limit of each pollutant will be multiplied with this factor and thereby results in a higher threshold. Measured on-road emissions have to underlie these CF - limits in PEMS-tests. Currently a CF of 1.5 - 2 is discussed by the European Commission.

Following equation 2-3 shows the extended EURO 6 limits for PEMS-tests:

$$Limits_{EURO\ 6\_PEMS} = CF * Limits_{EURO\ 6} \qquad 2\text{-}3$$

2.3 CLEAR Evaluation Method

The main purpose of CLEAR (**CL**assification of **E**missions from **A**utomobiles in **R**eal Driving) is to minimize the influence of the driver and the route on test results by normalizing propulsion power distribution of PEMS-tests. This means that rather low energy consumption per km caused by a very economic driving style should be enhanced and specific energy consumption caused by a very aggressive driving style are lowered with consecutive effects on the result for exhaust emissions– summing up: emissions of different PEMS-test cycles are corrected to a comparable level that represents normal driving. This normalisation shall enable a fair assessment of emission behaviours of different vehicles.

2.3.1 General concept and method of CLEAR – Standard CLEAR method

The CLEAR method is based on weighting measured emissions according to a generalized target power pattern (power frequency distribution). This target power distribution represents the power demand of a normal driving behaviour and contains the information of time shares of different power bins (power classes) of a representative normal trip. Due to the fact that a typical power distribution in urban, road and motorway parts differs significantly, separate target power patterns for each driving area (urban, road, motorway, total) have been developed.

It is a fact that engine speed and power demanded during a trip depend very much on the vehicle mass and the vehicle specific road load coefficients R_0, R1 and R_2. For this reason each car has its own power bin classification that depends on the vehicle specific “P_{drive}” that de-normalises the target power pattern. “P_{drive} represents the power demand at the wheels at 70km/h speed and at 0.45 m/s² acceleration for the tested vehicle with the mass and road load applied as defined for the chassis dynamometer test in type approval. This approach considers the effect, that a vehicle is driven only in short acceleration phases near maximum power of the engine while most of the time the engine power demand is defined by the rolling and air resistance and by vehicle mass, which are independent of the engine rated power.”[8]

To create the “WLTP target power distributions” for Urban, Road, Motorway and Total trips the WLTP-Short-Trip-data-base was used containing different routes and different drivers. Figure 2-9 shows the frequency distribution for different trips of different vehicles over absolute engine power and over normalised power (normalised by P_{drive}).

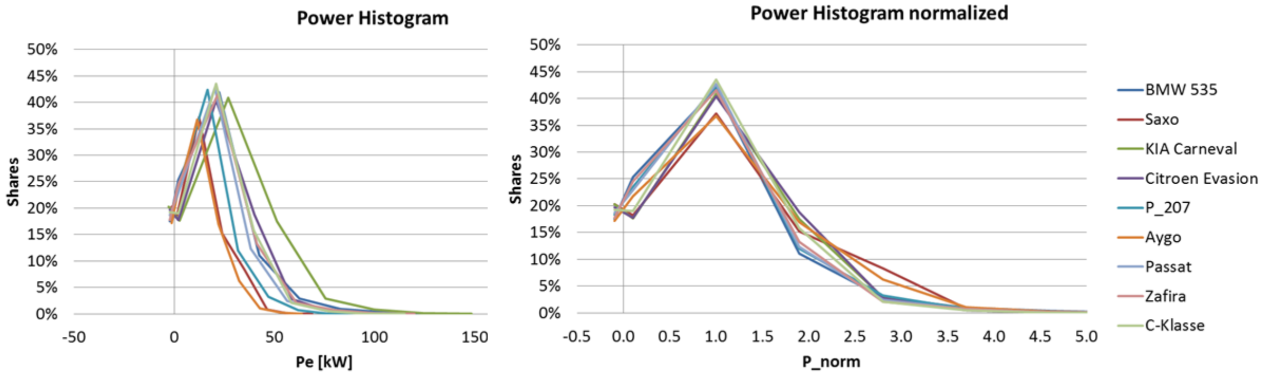
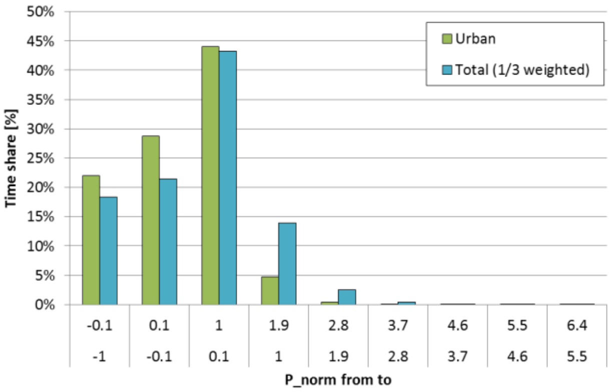


Figure 2-9: Power demand frequency of trips from different vehicles form WLTP-Short-Trip-Data-Base; left: plotted over absolute power, right: plotted over with P_{drive} normalised power

Several vehicle analyses showed so far that a division of the power demand of a normal trip by the vehicle specific power P_{drive} delivers over the whole trip very similar time shares of the power-bins idependent of a vehicle (see Figure 2-10). For this reason P_{drive} seems to be a good approach to weight the emissions of a trip as a function of the gathered time shares.



P_norm		Time share [%]	
from	to	Urban	Total
-1	-0.1	22.0%	18.3%
-0.1	0.1	28.8%	21.4%
0.1	1	44.0%	43.3%
1	1.9	4.74%	13.93%
1.9	2.8	0.45%	2.53%
2.8	3.7	0.045%	0.454%
3.7	4.6	0.004%	0.055%
4.6	5.5	0.0004%	0.0026%
5.5	6.4	0.00025%	0.00027%

Figure 2-10: Target power histogram (target power pattern) over P_{norm} with timeshares t_{PB_i} of each normalised power bin PB_{n_i}, total is a 1/3 mileage-mix of urban, road and motorway driving [8]

In order to de-normalize the generic target power pattern and to get a target power pattern with vehicle specific powerbins PB_i, P_{norm} of each power bin is multiplied with the vehicle specific P_{drive}. P_{drive} is calculated with the vehicle mass m_{ref}, the road load coefficients, a reference vehicle velocity v_{ref} and a reference vehicle acceleration a_{ref}:

$$P_{drive} = v_{ref} * \left(m_{ref} * a_{ref} + R_0 + R_1 * v_{ref} + R_2 * v_{ref}^2\right) \tag{2-4}$$

$$P_{norm} = \frac{P_e}{P_{drive}} \tag{2-5}$$

With R_0, R_1, R_2.....road load coefficients [N], [Ns/m], [Ns²/m²]

m_{ref}...........test mass of the vehicle in NEDC [kg]

a_{ref}.............reference acceleration, suggested 0,45m/s²

v_{ref}.............reference velocity, suggested 19,4m/s (70km/h)

Based in these theoretical facts and informations the CLEAR method of weighting emissions by the target power pattern is as follows:

1) De-normalisation of the target power pattern by multiplying with vehicle specific P_{drive}: normalised PB_{n_i} → vehicle specific PB_i
2) Averaging the instantaneous signals (1Hz) of PEMS-test over 3s (→ moving average)
3) Binning the measured emissions into the corresponding power bin PB_i (Figure 2-11)
4) Check amount of measuring points with each power bin (minimum 10)
5) Averaging emission values of each power bin (Figure 2-11)
6) Multiplying averaged emissions with corresponding time share of power bin t_{PB_i} → weighted emission values [g/h]
7) Summarizing weighted emission values [g/h]
8) Divide summarized weighted emissions by the weighted velocity of the test for the

selected driving situation → weighted emission values [g/km] to be compared with the type approval limits.

Following equation 2-6 shows the calculation of weighted emissions:

$$Weighted\ Emissions\ \left[\frac{g}{km}\right] = \frac{Weighted\ Emissions\ [\frac{g}{h}]}{Weighted\ Speed\ [\frac{km}{h}]} = \frac{\sum \overline{Emissions_{PB_i}} * t_{PB_i}}{\sum \overline{Speed_{PB_i}} * t_{PB_i}} \qquad 2\text{-}6$$

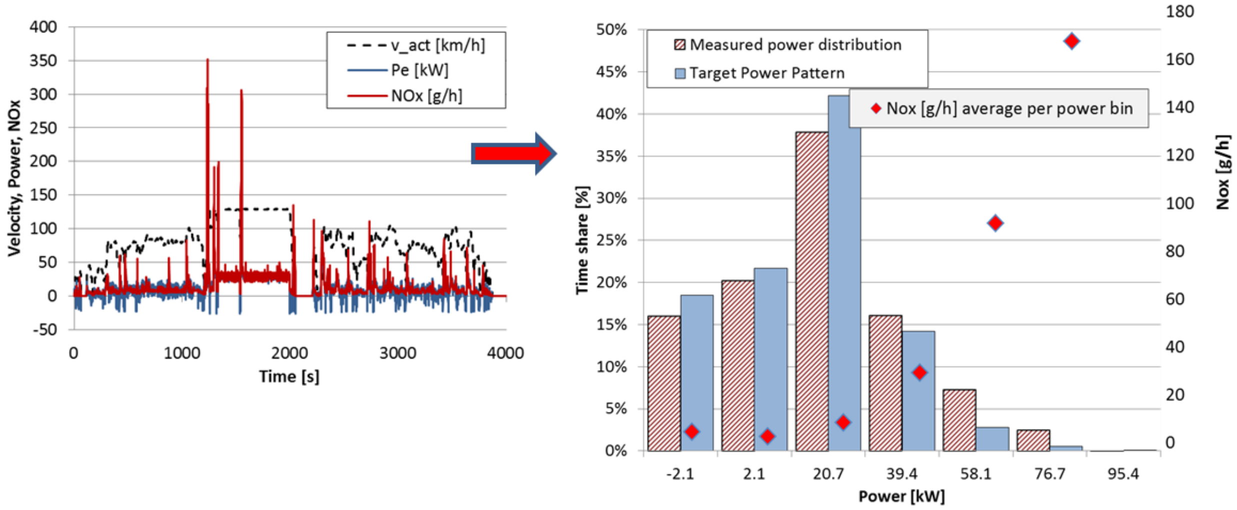


Figure 2-11: Results of step 3 done by CLEAR → power binned averaged emissions

Figure 2-12 shows examplarily the results of the normalisation by CLEAR in green compared to the measured NO_x emissions in blue. Emissions of an aggressive driving style (Route1_AGG) are lowered whereas emissions of a normal or economic driving style are enhanced. So the “Standard CLEAR method” shows the desired normalisation of the emissions.

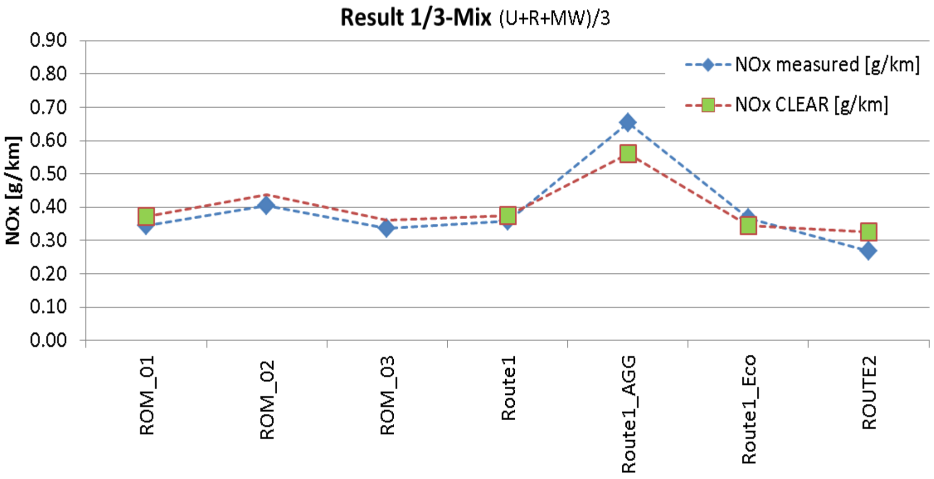
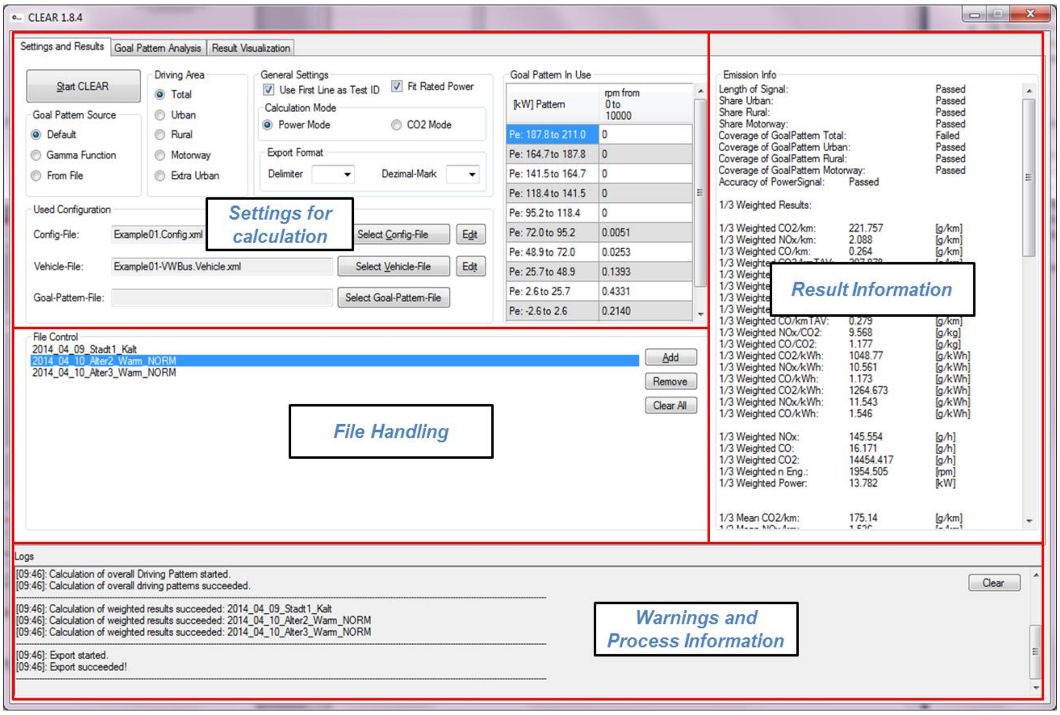


Figure 2-12: Measured NO_x emissions (blue) and weighted NO_x emission results by CLEAR (green) of a light-duty diesel vehicle in 1/3 mix of urban, road and motorway; power signal measured or calculated by the Vehicle-Willans-Lines approach (CLEAR results without green quadrat are invalid) [8]

Following chapter describes shortly the CLEAR tool version 1.8.4 and how to use it. Additionally its ability to weight emissions by different user defined goal patterns is shown.

2.3.2 CLEAR Tool 1.8.4

Following figure shows the CLEAR interface. Beyond the “Start CLEAR” – button the field “Goal Pattern Source” is located. In this field the user has to choose whether his PEMS-test emissions shall be weighted by the target power pattern (“Default”) or another pattern e.g. engine speed distribution (“From File”). In the field “User Configuration” the user has to upload a “Config-File” that contains all relevant data for CLEAR (which column of the uploaded PEMS-trip-file is e.g. the engine speed, the NO_x emissions etc.). Furthermore a “Vehicle-File” is required by CLEAR which contains the relevant vehicle data e.g. road load coefficients, m_{ref} etc. for the P_{drive} calculation.



Goal Pattern Source: ● Default ○ Gamma Function ○ From File

Driving Area: ● Total ○ Urban ○ Rural ○ Motorway ○ Extra Urban

General Settings: ☑ Use First Line as Test ID ☑ Fit Rated Power

Calculation Mode: ● Power Mode ○ CO2 Mode

Export Format: Delimiter, Dezimal-Mark

Used Configuration

Config-File: Example01.Config.xml

Vehicle-File: Example01-VWBus.Vehicle.xml

Goal-Pattern-File:

Goal Pattern In Use

[kW] Pattern	rpm from 0 to 10000
Pe: 187.8 to 211.0	0
Pe: 164.7 to 187.8	0
Pe: 141.5 to 164.7	0
Pe: 118.4 to 141.5	0
Pe: 95.2 to 118.4	0
Pe: 72.0 to 95.2	0.0051
Pe: 48.9 to 72.0	0.0253
Pe: 25.7 to 48.9	0.1393
Pe: 2.6 to 25.7	0.4331
Pe: -2.6 to 2.6	0.2140

File Control

2014_04_09_Stadt1_Kalt
2014_04_10_Alter2_Warm_NORM
2014_04_10_Alter3_Warm_NORM

Emission Info

```
Length of Signal:                                Passed
Share Urban:                                     Passed
Share Rural:                                     Passed
Share Motorway:                                  Passed
Coverage of GoalPattern Total:                   Failed
Coverage of GoalPattern Urban:                   Passed
Coverage of GoalPattern Rural:                   Passed
Coverage of GoalPattern Motorway:                Passed
Accuracy of PowerSignal:        Passed

1/3 Weighted Results:

1/3 Weighted CO2/km:            221.757          [g/km]
1/3 Weighted NOx/km:            2.088            [g/km]
1/3 Weighted CO/km:             0.264            [g/km]
1/3 Weighted CO/kmTAV:          0.279            [g/km]
1/3 Weighted NOx/CO2:           9.568            [g/kg]
1/3 Weighted CO/CO2:            1.177            [g/kg]
1/3 Weighted CO2/kWh:           1048.77          [g/kWh]
1/3 Weighted NOx/kWh:           10.561           [g/kWh]
1/3 Weighted CO/kWh:            1.173            [g/kWh]
1/3 Weighted CO2/kWh:           1264.673         [g/kWh]
1/3 Weighted NOx/kWh:           11.543           [g/kWh]
1/3 Weighted CO/kWh:            1.546            [g/kWh]

1/3 Weighted NOx:               145.554          [g/h]
1/3 Weighted CO:                16.171           [g/h]
1/3 Weighted CO2:               14454.417        [g/h]
1/3 Weighted n Eng.:            1954.505         [rpm]
1/3 Weighted Power:             13.782           [kW]


1/3 Mean CO2/km:                175.14           [g/km]
```

Logs

```
[09:46]: Calculation of overall Driving Pattern started.
[09:46]: Calculation of overall driving patterns succeeded.
------------------------------------------------------------------------
[09:46]: Calculation of weighted results succeeded: 2014_04_09_Stadt1_Kalt
[09:46]: Calculation of weighted results succeeded: 2014_04_10_Alter2_Warm_NORM
[09:46]: Calculation of weighted results succeeded: 2014_04_10_Alter3_Warm_NORM
------------------------------------------------------------------------
[09:46]: Export started.
[09:46]: Export succeeded!
------------------------------------------------------------------------
```

Figure 2-13: CLEAR 1.8.4 interface

2.3.2.1 Vehicle-Willans-Lines

The CLEAR analysis is based on a high-quality power signal in order to sort the emission values into the corresponding power bins. To diminish the problem with the powersignal the Vehicle-Willans-Lines method was developed to calculate the power at the wheel hubs P_{wheel} from the instantenuous measured CO_2 emissions. The basic idea of the method is connected to the well-known Willans-Lines of an engine, which show the fuel consumption as function of the engine load at a constant engine speed. The Vehicle-Willans-Lines try to create a link between the CO_2 emissions and the power of the wheel independent of the engine speed.

The WLTC test and its test results (CO_2, $P_{wheel,}$ etc.) build a common and standardized platform for Vehicle-Willans-Line coefficients determination.

$$CO_2 = k * P_{wheel} + D \tag{2-7}$$

The unit of the coefficient k is [g/kWh] and of D is [g/h]. The first step of the coefficient determination is to calculate averaged CO_2 emissions and the averaged wheel power of the 1st, 2nd, 3rd, 4th phase and of the total WLTC. This calculation delivers 5 points, each with a specific CO_2 and P_{wheel}- value. A linear regression based on these 5 calculated points shows the correlation between CO_2 and the wheel power and is called Vehicle-Willans-Line. In order to optimize the correlation the towing power P_d (intercept point of the line with the x (power) axis) based on the Vehicle-Willans-Line coeffients is calculated. Further all measured wheel power values smaller than P_d are replaced by P_d. Based on this new wheel power data set new averaged CO_2 and wheel power values of each phase are built and a new Vehilce-Willans-Line is calculated.

The fact that the CLEAR analysis is based on the wheel power emphazises the importance of the Vehicle-Willans-Lines. Ongoing investigations concentrate on P_d that has a significant influence on the pitch of the line and therefore on all new calculated power results of a PEMS trip. The latest approach relies on the rated power P_{rated} of an engine where P_d is a percentage of P_{rated}.

Nevertheless, if a measured power signal is available with sufficient accuracy, the measured power can be used directly for the CLEAR evaluation.

Figure 2-14 shows the Vehicle-Willans-Line of the examined VW Bus T5.

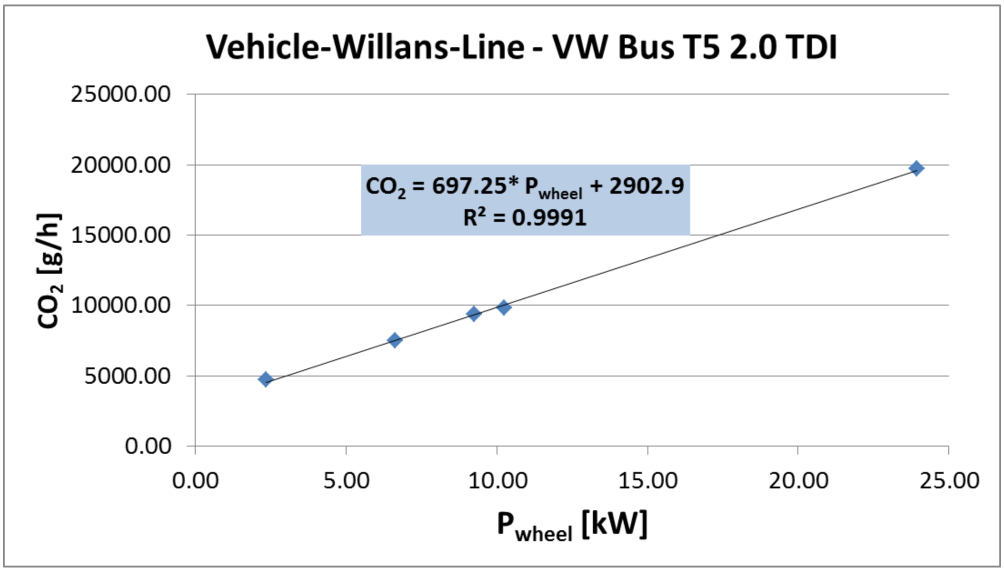


Figure 2-14: Vehicle-Willans-Line for VW Bus T5

2.4 Analysis of PEMS-test normality (validation)

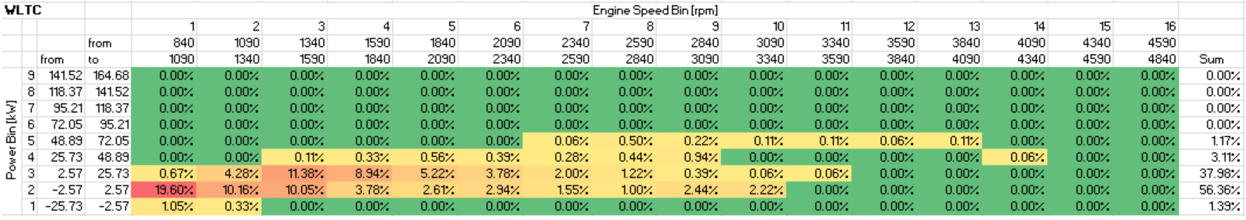
CLEAR normalises power and other variabilities not corrected like the engine speed from gearshift behaviour, dynamics of driving etc. PEMS trips driven too economically will not represent on road driving respectively the emitted pollutants in a good way and the other way around. For this reason boundary conditions have to be found for parameters with high effect on the exhaust emission level delimiting the space within a normal trip takes place.

Useful boundary conditions are based on driving dynamic factors and gear shift behaviour. Adequate characteristic factors to asses the trip are engine speed and engine speed change, the power change and a trip specific RPA value.

In order to define limits of these characteristic factors several trips of different vehicles driven by different drivers with different driving styles have been analysed in this thesis. The analysis is based on specific methods explained in following chapters.

2.4.1 Method to indentify the influence of engine speed – Extended CLEAR method

The “Default” setting of CLEAR implies the emissions weighting by the target power pattern time-shares as explained in 2.3.1, but further considerations were done towards an additional normalisation (weighting) by specific engine speed bin time shares. CLEAR contains the option to normalize the trip values by a defined target power and engine speed map (“From File”-setting) - a goal pattern with a frequency distribution in matrix form (3-dimensional). These three dimensional P-rpm-maps assign the time shares of every power and engine speed bin ceall and build the basis for further analysis of the influence of the engine speed change. Figure 2-15 shows exemplarily the time shares of a WLTC test and Figure 2-16 the general weighting methodology. Here the measured emissions in [g/h] are sorted by their power and engine speed value into the corresponding power and engine speed cell. Then the emission values of each cell are averaged and multiplied with the cell specific time share t_{Cell_i} of a P-rpm-map.



WLTC				Engine Speed Bin [rpm]																
				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	
			from	840	1090	1340	1590	1840	2090	2340	2590	2840	3090	3340	3590	3840	4090	4340	4590	
		from	to	1090	1340	1590	1840	2090	2340	2590	2840	3090	3340	3590	3840	4090	4340	4590	4840	Sum
Power Bin [kW]	9	141.52	164.68	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	8	118.37	141.52	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	7	95.21	118.37	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	6	72.05	95.21	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	5	48.89	72.05	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.06%	0.50%	0.22%	0.11%	0.11%	0.06%	0.11%	0.00%	0.00%	0.00%	1.17%
	4	25.73	48.89	0.00%	0.00%	0.11%	0.33%	0.56%	0.39%	0.28%	0.44%	0.94%	0.00%	0.00%	0.00%	0.00%	0.06%	0.00%	0.00%	3.11%
	3	2.57	25.73	0.67%	4.28%	11.38%	8.94%	5.22%	3.78%	2.00%	1.22%	0.39%	0.06%	0.06%	0.00%	0.00%	0.00%	0.00%	0.00%	37.98%
	2	-2.57	2.57	19.60%	10.16%	10.05%	3.78%	2.61%	2.94%	1.55%	1.00%	2.44%	2.22%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	56.36%
	1	-25.73	-2.57	1.05%	0.33%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	1.39%

Figure 2-15: Examplarily power and engine speed time shares t_{Cell_i} for a EURO 5 vehicle in the WLTC (red = high time share in [%], slightly red/yellow = mid to low time shares in [%], green = time share of 0%)

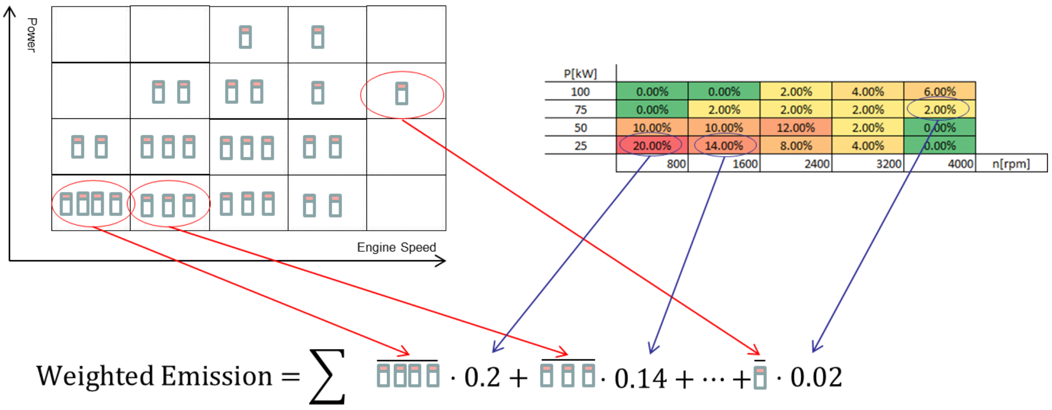


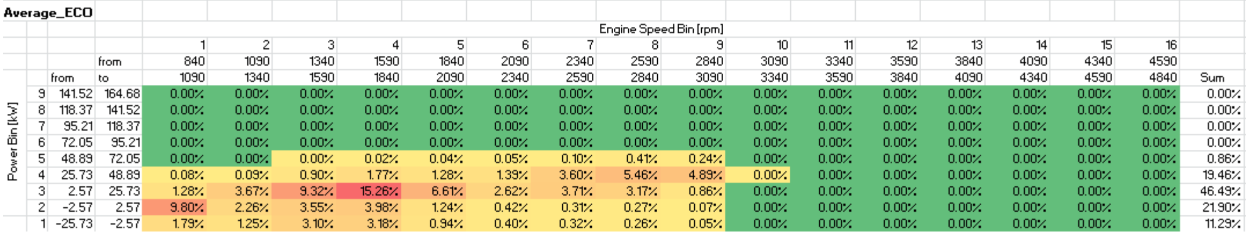
Figure 2-16: Concept of weighting emissions by power and engine speed bins

To obtain weighted emissions in [g/km], the average speed of each power and engine speed bin cell is calculated in the same way as the emissions. Further this averaged speed values are weighted like the emissions illustrated with t_{Cell_i} in Figure 2-16. Both weighted values are devided by each other and deliver weighted emissions in the desired unit [g/km]. Following equation 2-8 gives an overview of the calculation scheme:

$$Weighted\ Emissions\ \left[\frac{g}{km}\right] = \frac{Weighted\ Emissions\ [\frac{g}{h}]}{Weighted\ Speed\ [\frac{km}{h}]} = \frac{\sum \overline{Emissions_{Cell_i}} * t_{Cell_i}}{\sum \overline{Speed_{Cell_i}} * t_{Cell_i}} \qquad \text{2-8}$$

Different sizes of engine speed bins are possible. A standard CLEAR-Input map has to consist of 16 engine speed bins. The amount of 16 is a defined value in the CLEAR code. The engine speed bins start at idling speed n_{idle} and have to cover at least n_{rated}. For this thesis a step width of 250rpm was choosen and proofed to be sufficient for diesel vehicle engine examinations. To investigate gasoline cars the step width has to be enlarged due to the fact that rpm-range is wider.

In order to identify the influence of the engine speed on emissions several trips with different driving styles (economical, normal and aggressive) have been analysed by CLEAR. Generally in the "From-File"-mode CLEAR rasterizes the measured values of a trip by predefined vehicle specific power (2.3.1) and engine speed bins (based on a 3-dimensional P-rpm-map) and delivers new P-rpm-maps containing a trip specific frequency distribution.



Average_ECO																				
				Engine Speed Bin [rpm]																
				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	
			from	840	1090	1340	1590	1840	2090	2340	2590	2840	3090	3340	3590	3840	4090	4340	4590	
		from	to	1090	1340	1590	1840	2090	2340	2590	2840	3090	3340	3590	3840	4090	4340	4590	4840	Sum
Power Bin [kW]	9	141.52	164.68	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	8	118.37	141.52	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	7	95.21	118.37	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	6	72.05	95.21	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	5	48.89	72.05	0.00%	0.00%	0.00%	0.02%	0.04%	0.05%	0.10%	0.41%	0.24%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.86%
	4	25.73	48.89	0.08%	0.09%	0.90%	1.77%	1.28%	1.39%	3.60%	5.46%	4.89%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	19.46%
	3	2.57	25.73	1.28%	3.67%	9.32%	15.26%	6.61%	2.62%	3.71%	3.17%	0.86%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	46.49%
	2	-2.57	2.57	9.80%	2.26%	3.55%	3.98%	1.24%	0.42%	0.31%	0.27%	0.07%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	21.90%
	1	-25.73	-2.57	1.79%	1.25%	3.10%	3.18%	0.94%	0.40%	0.32%	0.26%	0.05%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	11.29%

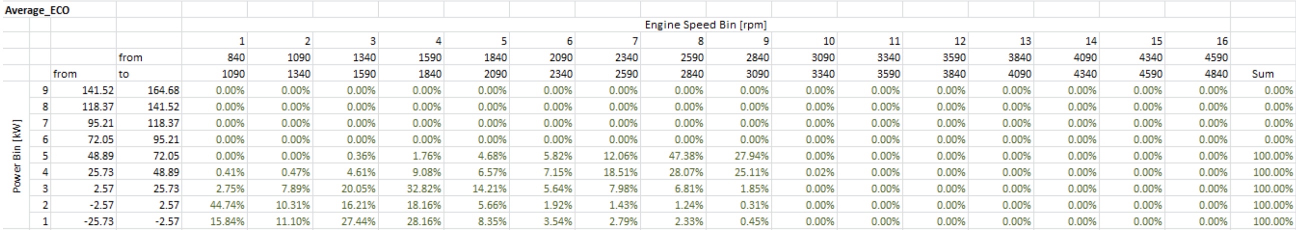
Figure 2-17: Averaged P-rpm-map of economic trips of investigated vehicles of this thesis compiled by CLEAR (red = high time share in [%], slightly red/yellow = mid to low time shares in [%], green = time share of 0%)

These P-rpm-maps are going to be modified by hand to a "CLEAR-Input map" by following steps referring to the shares of time of the WLTP target power pattern of a total trip (Figure 2-10). These shares of time serve as reference point and empower further comparisons of emission results of different trips.

Steps to create a CLEAR-Input map:

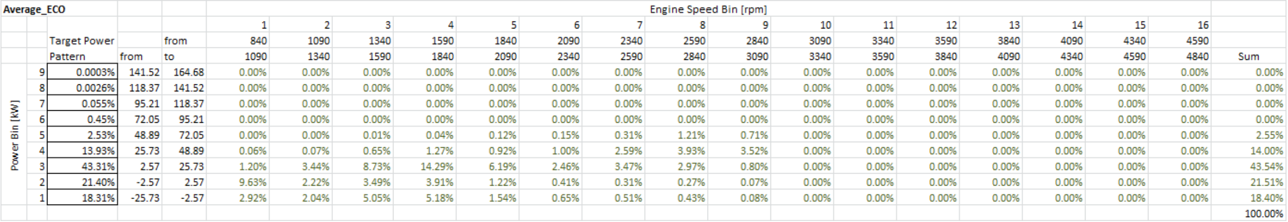
1. Compiling of frequence distribution maps (P-rpm-maps) of several trips with CLEAR
2. Averaging trips with the same driving styles → averaged driving style specific P-rpm-maps (e.g. Figure 2-17)
3. Enhancing engine speed bin time share values of each power bin up to 100% (Figure 2-18)
4. Taking reference to the CLEAR target power pattern (Figure 2-10) by multiplying enhanced engine speed bin time share values with the target power pattern time shares of each power bin

   → CLEAR-Input map with specific frequency distribution taking correct target power pattern time shares into account (Figure 2-19)



Average_ECO																				
				Engine Speed Bin [rpm]																
				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	
			from	840	1090	1340	1590	1840	2090	2340	2590	2840	3090	3340	3590	3840	4090	4340	4590	
		from	to	1090	1340	1590	1840	2090	2340	2590	2840	3090	3340	3590	3840	4090	4340	4590	4840	Sum
Power Bin [kW]	9	141.52	164.68	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	8	118.37	141.52	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	7	95.21	118.37	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	6	72.05	95.21	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	5	48.89	72.05	0.00%	0.00%	0.36%	1.76%	4.68%	5.82%	12.06%	47.38%	27.94%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	100.00%
	4	25.73	48.89	0.41%	0.47%	4.61%	9.08%	6.57%	7.15%	18.51%	28.07%	25.11%	0.02%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	100.00%
	3	2.57	25.73	2.75%	7.89%	20.05%	32.82%	14.21%	5.64%	7.98%	6.81%	1.85%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	100.00%
	2	-2.57	2.57	44.74%	10.31%	16.21%	18.16%	5.66%	1.92%	1.43%	1.24%	0.31%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	100.00%
	1	-25.73	-2.57	15.84%	11.10%	27.44%	28.16%	8.35%	3.54%	2.79%	2.33%	0.45%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	100.00%

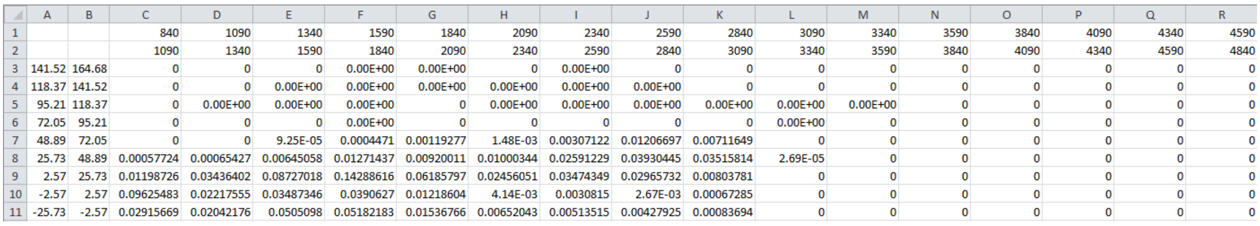
Figure 2-18: Engine speed bin time share values of each power bin



Average_ECO					Engine Speed Bin [rpm]																
					1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	
		Target Power		from	840	1090	1340	1590	1840	2090	2340	2590	2840	3090	3340	3590	3840	4090	4340	4590	
		Pattern	from	to	1090	1340	1590	1840	2090	2340	2590	2840	3090	3340	3590	3840	4090	4340	4590	4840	Sum
Power Bin [kW]	9	0.0003%	141.52	164.68	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	8	0.0026%	118.37	141.52	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	7	0.055%	95.21	118.37	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	6	0.45%	72.05	95.21	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	5	2.53%	48.89	72.05	0.00%	0.00%	0.01%	0.04%	0.12%	0.15%	0.31%	1.21%	0.71%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	2.55%
	4	13.93%	25.73	48.89	0.06%	0.07%	0.65%	1.27%	0.92%	1.00%	2.59%	3.93%	3.52%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	14.00%
	3	43.31%	2.57	25.73	1.20%	3.44%	8.73%	14.29%	6.19%	2.46%	3.47%	2.97%	0.80%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	43.54%
	2	21.40%	-2.57	2.57	9.63%	2.22%	3.49%	3.91%	1.22%	0.41%	0.31%	0.27%	0.07%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	21.51%
	1	18.31%	-25.73	-2.57	2.92%	2.04%	5.05%	5.18%	1.54%	0.65%	0.51%	0.43%	0.08%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	18.40%
																					100.00%

Figure 2-19: CLEAR-Input map

CLEAR-Input maps have been built for the “WLTC” of each car and different driving styles like “ECO”, “NORM” and “AGG”. Each “WLTC” and driving style specific compiled CLEAR-Input map is transformed by Excel into a CSV-file and serves as basis for further CLEAR weighting calculations of PEMS trips.



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
1			840	1090	1340	1590	1840	2090	2340	2590	2840	3090	3340	3590	3840	4090	4340	4590
2			1090	1340	1590	1840	2090	2340	2590	2840	3090	3340	3590	3840	4090	4340	4590	4840
3	141.52	164.68	0	0	0	0.00E+00	0.00E+00	0	0.00E+00	0	0	0	0	0	0	0	0	0
4	118.37	141.52	0	0	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0	0	0	0	0	0
5	95.21	118.37	0	0.00E+00	0.00E+00	0.00E+00	0	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0	0	0
6	72.05	95.21	0	0	0	0.00E+00	0	0	0	0	0	0.00E+00	0	0	0	0	0	0
7	48.89	72.05	0	0	9.25E-05	0.0004471	0.00119277	1.48E-03	0.00307122	0.01206697	0.00711649	0	0	0	0	0	0	0
8	25.73	48.89	0.00057724	0.00065427	0.00645058	0.01271437	0.00920011	0.01000344	0.02591229	0.03930445	0.03515814	2.69E-05	0	0	0	0	0	0
9	2.57	25.73	0.01198726	0.03436402	0.08727018	0.14288616	0.06185797	0.02456051	0.03474349	0.02965732	0.00803781	0	0	0	0	0	0	0
10	-2.57	2.57	0.09625483	0.02217555	0.03487346	0.0390627	0.01218604	4.14E-03	0.0030815	2.67E-03	0.00067285	0	0	0	0	0	0	0
11	-25.73	-2.57	0.02915669	0.02042176	0.0505098	0.05182183	0.01536766	0.00652043	0.00513515	0.00427925	0.00083694	0	0	0	0	0	0	0

Figure 2-20: CLEAR-Input CSV-file format of target power and engine speed map

The emissions are weighted by the frequency distribution of the CLEAR-Input maps (see equation 2-8) and the results of the evaluations are tested, whether an additional weighting by the engine speed gives less deviation of the emissions of different PEMS trips (if the Max/Min-ratio gets smaller, see chapter 3.4)

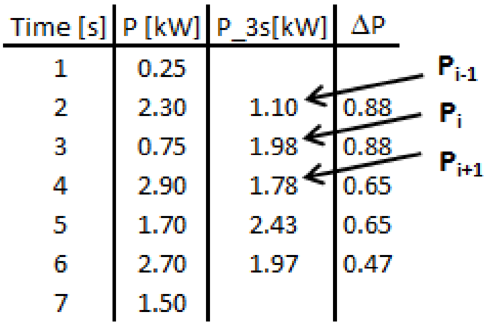
2.4.2 Method to identify the influence of power change ΔP

The absolute power change (henceforth ΔP) is a characteristic factor for the dynamic driving of a trip because of its direct connection to the acceleration of a vehicle. The assumption that a high ΔP is typical for an aggressive driving style and a low ΔP represents an economic driving style had to be demonstrated. If this assumption proves true ΔP will be a useful size to limit the dynamic of a trip and maybe possible thresholds concerning the limitation of normal driving can be derived.

To identify ΔP of a trip the power signal (either measured or calculated by the Vehicle-Willans-Line approach explained in 2.3.2.1) first is averaged by CLEAR over 3sec (see CLEAR Method in 2.3.1). Based on this new power signal ΔP is calculated by the difference of the maximum and minimum value of power values P_{i-1}, P_i and P_{i+1}. This calculation delivers for each over 3 sec averaged emission values one ΔP value built on the over 3sec averaged power values P_{i-1}, P_i and P_{i+1} (see equation 2-9).

$$\Delta \mathrm{P} = Max(P_{i-1}, P_i, P_{i+1}) - Min(P_{i-1}, P_i, P_{i+1}) \qquad \text{2-9}$$

Table 2-2: Table of calculated power P, averaged power P_3s and ΔP calculated by CLEAR



Time [s]	P [kW]	P_3s[kW]	ΔP
1	0.25		
2	2.30	1.10	0.88
3	0.75	1.98	0.88
4	2.90	1.78	0.65
5	1.70	2.43	0.65
6	2.70	1.97	0.47
7	1.50		

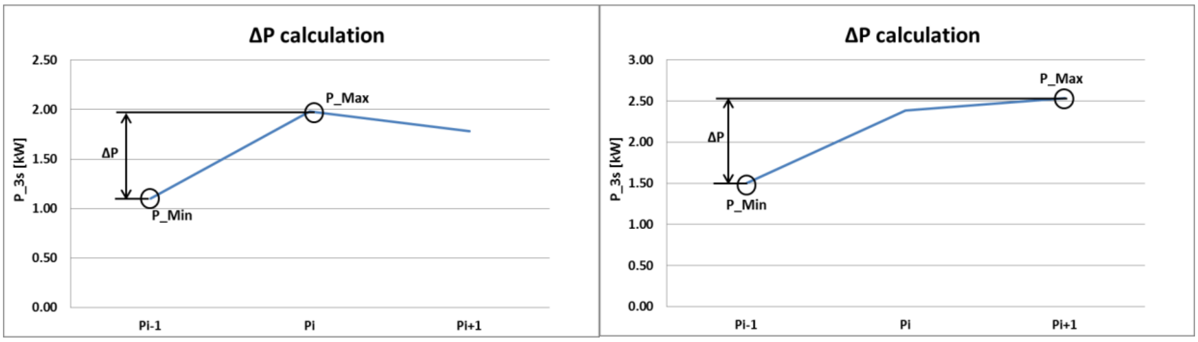


Figure 2-18: Schematic presentation of ΔP calculation

2.4.2.1 Power change normalisation

The basic idea of normalisation of power change is to eliminate vehicles influence on ΔP – to define a vehicle independent size in order to make different cars comparable to each other. Additionally, this normalisation could deliver driving style specific limits to categorize different trips by their driving style.

Following normalisation suggestions are based on P_{rated} and P_{drive} to consider vehicle and engine specific attributes

2.4.2.1.1 Normalisation N_1

$$N_1 = \frac{\Delta\, P}{P_{rated}} \qquad \text{2-10}$$

The N_1 normalisation of ΔP uses the engine specific P_{rated}. This normalisation approach is independent of vehicle specifities like the road loads. Advantage is that P_{rated} is an accessible value. N_1 is calculated by the division of ΔP and P_{rated}.

2.4.2.1.2 Normalisation N_2

$$N_2 = \frac{\Delta\, P}{P_{drive}} \qquad \text{2-11}$$

This approach uses P_{drive} in order to normalise ΔP. P_{drive} depends on the vehicle mass and the road loads and doesn’t consider the engine at all. The N_2 normalisation is simple and eliminates the vehicles influence by devision of ΔP with the vehicle specific P_{drive}.

Follwing normalisations try to combine the quantities P_{rated} and P_{drive} in order to get maybe a better normalisation result.

2.4.2.1.3 Normalisation N_3

$$N_3 = \frac{\Delta\,\mathrm{P}}{P_{rated} * P_{drive}} \qquad 2\text{-}12$$

This normalisation takes P_{rated} and P_{drive} into account. It combines the vehicle and engine specific effects. N_3 is the quotient of ΔP and the product (P_{rated}*P_{drive}).

2.4.2.1.4 Normalisation N_4

$$N_4 = \frac{\Delta\,\mathrm{P}}{a * P_{rated} + b * P_{drive}} \qquad 2\text{-}13$$

The N_4 normalisation of ΔP is extended with weighting coefficients ‘a’ and ‘b’ for P_{rated} and P_{drive}. N_4 is the result of ΔP divided by (a*P_{rated}+b*P_{drive}). This normalisation is compared to N_2 quite complex because of the additional possibility of changing the weighting coefficients.

2.4.2.1.5 Normalisation N_5

$$N_5 = \frac{\Delta\,\mathrm{P} * P_{rated}}{a * P_{rated} + b * P_{drive}} \qquad 2\text{-}14$$

N_5 works like N_4 besides the fact that the whole quotient is multiplied with P_{rated}.

Investigations and results for possible limits regarding the power gradient normalisation are shown in chapter 3.5.2.1.1.

2.4.3 RPA

RPA [m/s²] stands for “Relative Positive Acceleration” and is known as a characteristic dynamic driving factor. It also can be seen as the specific acceleration work of a trip in (kW*s)/(kg*km). RPA characterizes the specific load of a trip and therefore may allow the graduation of trips into an economic, normal or aggressive driving style. It’is defined as the integral of the product of instantaneous speed and instantaneous positive acceleration over a defined length of a trip (integral of speed over time).

$$RPA = \frac{\int_{t_0}^{t_j} (v_i(t) * a_i^+(t))dt}{\int_{t_0}^{t_j} v_i(t)dt} \qquad 2\text{-}15$$

With $t_0\ and\ t_j$…..start and end time of trip [s]

v_i.....speed value at time step i [m/s]

a_i^+.....positive acceleration a at time step i [m/s²]

The RPA calculation steps compiled by CLEAR are:

1. Calclulation of positive acceleration a^+: $a_i(t) = \frac{v_i(t+i)-v_i(t)}{\Delta t}$, $if\ a < 0 \rightarrow\ a^+ = 0$
2. Multiplication of a^+ with corresponding v for each time step i
3. Calculation of the average numerator and denominator of RPA over 3 seconds:
   - Numerator: $\frac{v_{i-1}*a_{i-1}+v_i*a_i+v_{i+1}*a_{i+1}}{3}$, with a >= 0m/s²
   - Denominator: $\frac{v_{i-1}*t_{i-1}+v_i*t_i+v_{i+1}*t_{i+1}}{3}$
4. Building the RPA value by summing up all values of the numerator and denominator depending on the considered driving part (urban, road, motorway)

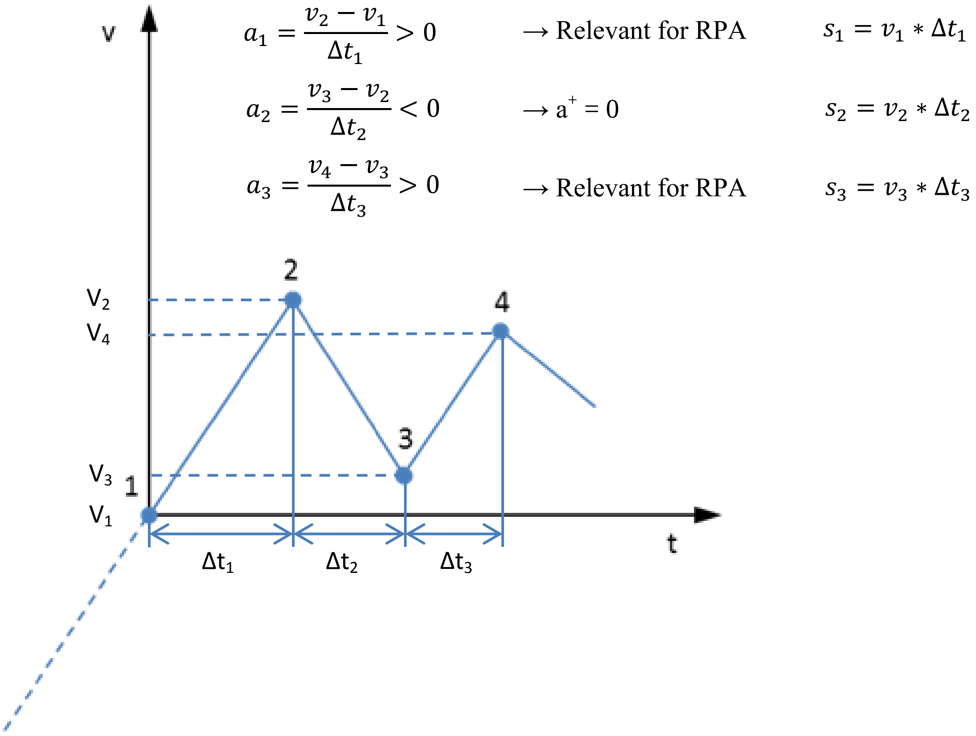


Figure 2-19: Example of a velocity profile and relevant factor for RPA calculation

3 Evaluation Results

Following chapters deal with the analysis perfomed within this thesis as a practical part of the work. First an overview of the examined cars and test routes is given. Then the influence of the engine speed especially on the NO_x-emissions is investigated by the comparison of the measured emission results of different trips with the weighted emission results of the "Standard CLEAR method" and "Extended CLEAR method". In the next step correlation investigations between the emissions and ΔP and the emissions and RPA of several trips are made. If the quantities correlate suggestions for normality boundary conditions for further trip validation are made for ΔP and RPA based on the measuring results. The ΔP threshold consideration requires a power change normalisation as mentioned in chapter 2.4.2.1. For this reason additionaly several normalisation variants N_1, N_2, N_3, N_4 and N_5 are discussed and a recommendation regarding the most suitable one is given.

3.1 Test Vehicles

Examined vehicles of this thesis have been a Mazda CX5 (data provided by JRC), BMW 320d (data provided by BMW), VW Bus T5 (measured in thesis at TUG) and belong all to categorie M1 of the European type approval classification for which currently applicable emission limits are provided in Table 2-1. Solely PEMS-trips with different driving styles of diesel cars with different exhaust aftertreatment systems are analysed. Following table shows relevant vehicle data for the analysis of the influence of engine speed and power change on emissions of PEMS-tests.

Table 3-1: Relevant vehilce data for further PEMS trip analysis

Data		**Mazda CX5**	**BMW 320d**	**VW Bus T5**
Datas from	**Unit**	**JRC**	**BMW**	**TUG**
General Information				
Model year	*[-]*	2013	2011	2013
Emission Standard	*[-]*	Euro 6	Euro 6	Euro 5
Emission Treatment Systems	*[-]*	DOC, DPF, EGR	NSC, DPF, EGR	DPF, EGR
Vehicle Type				
Vehicle Class	*[-]*	Uper Middle Class	Middle Class	Transporter
Engine				
Engine capacity	*[cm^3]*	2200	1995	1968
Propulsion type	*[-]*	Front	Rear	Front
Fuel	*[-]*	Diesel	Diesel	Diesel
P_{rated}	*[kW]*	109	135	84
Power-to-weight ratio	*[kW/kg]*	0.074	0.088	0.042
n_{rated}	*[rpm]*	4500	4000	3500
n_{idle}	*[rpm]*	750	780	840
Max torque	*[Nm]*	380 (1800-2600rpm)	380 (1750-2750rpm)	250 (1500rpm)
Test mass				
NEDC	*[kg]*	1470	1530	2001
Driving resistance factors				
NEDC				
R_0	*[N]*	-	-	152
R_1	*[N/(km/h)]*	-	-	0.37
R_2	*[N/(km/h)^2]*	-	-	0.05
Vehicle-Willans-Lines Coefficients				
CO2=k*P+D				
k	*[g/kWh]*	1591.06	800.25	697.56
D	*[g/h]*	791.17	2028.15	2899.29

3.2 PEMS-test routes

Concerning the RDE routes and their profiles driven by JRC and BMW no detailed information is available. For this reason just PEMS-test routes driven by TUG with a VW Bus T5 are explained in detail. The driving style of all trips of the three different cars is available, which is a basic requierement for further interpretation of the normalisation results compiled by CLEAR. PEMS-test routes should consist approximately of a 1/3 mix of urban, road and motorway based on distance. Two local routes nearby Graz called “Alternative” and “Ries” with a length of approximately 1.5 h seem to fulfil these requierements very well (Figure 3-1). In order to get a high variability 4 drivers with three different driving styles (economic, normal and aggressive) have been employed during the test compaign for this thesis.

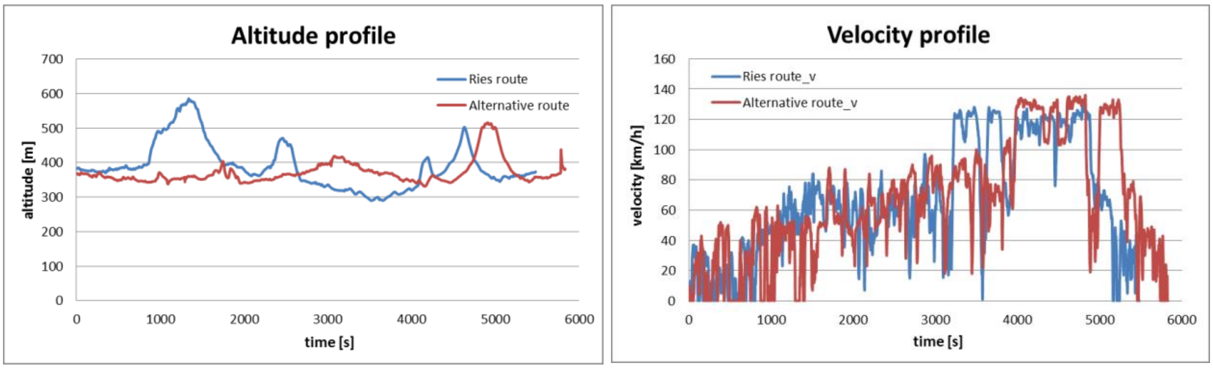


Figure 3-1: Height and velocity profiles of “Ries” and “Alternative”- route

Taking a closer look at the altitude profile of both routes the “Ries”-route seems to be hillier than the “Alter”-route and therefore may cause higher emissions.

To have a common starting point for RDE testing, prior every PEMS trip a “Green Flag Lap” in the city of Graz of approximately 0.5 h was driven (→ engine oil temperature on 80°C).

Below a short overview on the routes driven:

1. 5 x Green Flag Lap: Graz route, ~ 0.5h, 13km
2. 10 x RDE Route#1: Ries route, ~ 1.5h, 101km
    a. Urban: Graz
    b. Rural: Ries – Gleisdorf - Sinabelkirchen
    c. Motorway: Sinabelkirchen – Ilz - Graz Ost
3. 7 x RDE Route#2: Alternative route, ~ 1.75h, 105km
    a. Urban: Graz
    b. Rural: Pirka – Lannach – Mooskirchen – Rosenthal – Mooskirchen
    c. Motorway: Mooskirchen – Lassnitzhöhe – Graz Ost

Table 3-2: Frequency of routes driven with different driving styles

Routes	Graz route	"Ries" route			"Alternative" route		
Style of driving	Normal	Economic	Normal	Aggressive	Economic	Normal	Aggressive
Driver 1	1x	1x	1x	1x			
Driver 2	2x	1x	1x	1x	1x	1x	1x
Driver 3	1x	1x	1x	1x		1x	
Driver 4	1x		1x		1x	1x	1x

3.3 Data collection and analysis

3.3.1 Complementary data supply and emission test

Several NEDC and WLTC for each car had been driven on chassis dynamometer (JRC, BMW, TUG) prior onroad PEMS-tests in order to check if the tested vehicles comply with the latest applicable emission limits. Furthermore, it was necessary to determine Vehicle-Willans-Coefficients for calculation of the power at the wheel hubs in order to normalise the emissions by CLEAR in the next step.

Measuring instruments on the dynamometer: AVL AMA, SEMTECH, Dynamometer

Measured variables with AVL AMA: Emissions

Measured variables with SEMTECH: Emissions

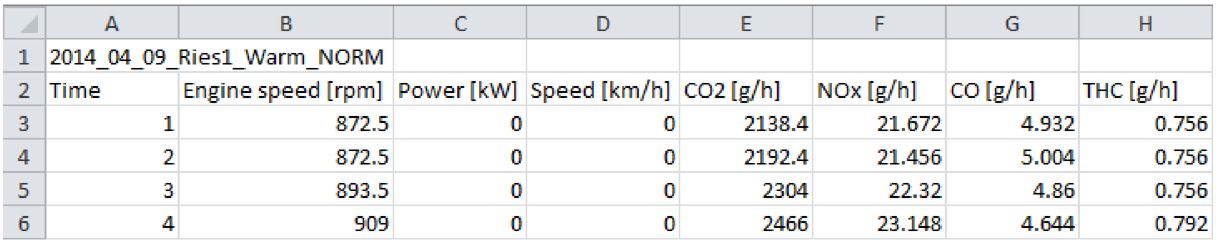
Measured variables with dynamometer: vehicle velocity, vehicle acceleration

All tested vehicle complied with the emissions limits also concering NO_x-emissions (Mazda CX5 and BMW 320d → EURO 6, VW Bus → EURO 5)

3.3.2 Trip file compiling and data analysis

A CLEAR input file of a trip has a specific format. Such a file has to be compiled by hand based on the result file from the data logger of SEMTECH-DS and the data of VAG-Com for each trip. PEMS measures emissions and the velocity by a GPS sensor with a time resolution of 1 second. VAG-Com does the same with the velocity and engine speed signal, but with a much better accuracy.

1. Check if both velocity signals (SEMTECH DS and VAG-Com) are chronologically the same (otherwise shift it)
2. Convert measured PEMS-emissions from [g/s] to [g/h]
3. Calulate the power signal based on Vehcile-Willans-Line coefficients k [g/kWh] and D [g/h]
4. Time, engine speed, power, velocity, and emission (CO_2, NO_x, CO and THC) values are merged in one CLEAR trip input file.



	A	B	C	D	E	F	G	H
1	2014_04_09_Ries1_Warm_NORM							
2	Time	Engine speed [rpm]	Power [kW]	Speed [km/h]	CO2 [g/h]	NOx [g/h]	CO [g/h]	THC [g/h]
3	1	872.5	0	0	2138.4	21.672	4.932	0.756
4	2	872.5	0	0	2192.4	21.456	5.004	0.756
5	3	893.5	0	0	2304	22.32	4.86	0.756
6	4	909	0	0	2466	23.148	4.644	0.792

Figure 3-2: Example of a trip specific CLEAR input file

This CLEAR trip input file is merged for every trip and contains all relevant data for further calculations needed by CLEAR.

The data analysis by CLEAR starts after the appropriate “Vehicle” and “Config”-File were selected and uploaded (2.3.2).

The “Standard CLEAR method” is the use of the explained target power pattern (“target frequency map”) representing the engine load frequency distribution of “normal driving”. Here the measured emissions of a trip are binned into the single vehicle specific power bins

PB_i (depending on P_{drive}) according to the actual load. Then the average emissions per cell are weighted according to the time share of the particular power bin as explained already in chapter 2.3.1 before.

The other approach, the “Extended CLEAR method”, developed in this thesis is based on a 3 dimensional target frequency map. Additionally to the time share of different power bins representing engine load categories of normal driving engine speed bins have been introduced. This means that the time share of one power bin is additionally splitted in several engine speed bins. The results of this splitting are power and engine speed bins with own time shares. Now measured emissions of a trip can be binned into single specific power and engine speed bins (depending on P_{drive} and n_{ilde}) according to the actual load and engine speed. These binned emissions are averaged and weighted according to the time shares of each particular engine speed - and power-bin cell of a P-rpm-map.

In both cases the result of the CLEAR calculation is a corresponding trip result file containing weighted emissions.

These weighted emission results have to be compared with the measured emission results of a trip. In the best case all weighted emissions of trips characterized by different driving styles lay on one line representing normal driving. So the influence of the driver and or the road was eliminated by the CLEAR weighting method (emissions of too economic driven trips are enhanced and emissions of too aggressive driven trips are lowered).

3.4 Influence of engine speed change and engine speed

In order to identify the influence of engine speed and its change first the engine speed change (henceforth Δn) of each trip is calculated. The general assumption is that only positive Δn, cause relevant emissions. Therefore the investigations concentrate on positive Δn. If there is a signigficant difference of Δn between different driving styles (assumption: $\Delta n_{agg} > \Delta n_{norm} > \Delta n_{eco}$) the approach of analysing the influence of engine speed is based on the method explained in 2.4.1.

The basic idea to identify the influence of engine speed on emissions is to weight measured emissions not only by a target power pattern but also by the engine speed. This approach led us to several 3 dimensional target frequency maps calculated by CLEAR, the already explaned P-rpm-maps. In order to produce these P-rpm-maps the setting of CLEAR has to be the “From file”-mode. This mode requires files with a specific goal pattern. In our case a template with predefined power and engine speed bins containing specific time shares has to be uploaded. In the next step all trips with interest on the P-rpm-maps have to be uploaded. CLEAR calulcates beside the weighted emissions for each uploaded trip an engine speed and power frequency map – a P-rpm-map. In the next step frequency maps of the same driving style are averaged by hand. The result is a averaged P-rpm-map for each driving style.

These averaged maps serve CLEAR as new “Goal pattern”-files (Figure 2-) for weighting of emissions of different trips. The results are emissions that have been weighted by the created averaged P-rpm maps (3 dimensional goal patterns). If the difference between maximum and minimum value after this “new” normalisation (“Extended CLEAR method”) is smaller compared to the “original” normalisation (“Standard CLEAR method”) by the target power pattern then the engine speed and its change explain the max/min ratio reduction and their influence on emissions of PEMS-tests is evident.

3.4.1 Analysis

3.4.1.1 Analysis of influence of Δn

Investigations on the average positive Δn of different trips and driving styles confirmed the assumption that $\Delta n_{agg} > \Delta n_{norm} > \Delta n_{eco}$ (see Table 3-3 below).

Table 3-3: Overview of Δn of different routes, driving styles and drivers (RIES = “Ries” route, Alter = “Alternative” Route; green indicates an economic, blue a normal, red an aggressive driving style and white: no driving style information is available (expect WLTC); the “ROUTE1” of the Mazda CX5 is different to the “ROUTE1” of the BMW320d)

Mazda CX5	
Trip	average pos. Δn [1/min]
WLTC	105.83
ROUTE1_ECO	73.60
ROUTE1_NORM	103.83
ROUTE1_AGG	125.25
ROUTE2	61.83
ROM_Test1	69.77
ROM_Test2	86.89

BMW 320d	
Trip	average pos. Δn [1/min]
WLTC	66.70
ROUTE1_ECO1	40.92
ROUTE1_ECO2	40.92
ROUTE1_ECO3	40.54
Average	**40.79**
ROUTE1_NORM1	43.19
ROUTE1_NORM2	44.87
Avergage	**44.03**
ROUTE1_AGG1	69.00
ROUTE1_AGG2	57.53
Average	**63.26**

VW Bus T5		
Trip	average pos. Δn [1/min]	Driver
WLTC	100.95	-
Alter4_ECO	45.84	4
Alter6_ECO	50.60	2
RIES4_ECO	41.85	1
RIES5_ECO	61.11	3
RIES8_ECO	45.76	2
Average	**49.03**	
Alter2_NORM	65.19	2
Alter3_NORM	71.83	4
Alter8_NORM	70.49	3
RIES1_NORM	63.24	3
RIES2_NORM	71.41	2
RIES3_NORM	60.34	1
RIES10_NORM	65.00	4
Avergage	**66.79**	
Alter5_AGG	86.73	4
Alter7_AGG	89.27	2
RIES6_AGG	110.13	3
RIES7_AGG	71.85	1
RIES9_AGG	97.07	2
Average	**91.01**	

An interesting finding is the fact that the average positive Δn of different driving styles of the VW Bus T5 (Δn_{eco_VWBus} = 49.03rpm, Δn_{norm_VWBus} = 66.79rpm, Δn_{agg_VWBus} = 91.01rpm) is by trend higher than those of the BMW (Δn_{eco_BMW} = 40.79rpm, Δn_{norm_BMW} = 44.03rpm, Δn_{agg_BMW} = 63.26rpm). Concerning average positive Δn of the Mazda CX5 the conclusion is that just one trip of each driving style is not representive for comparing the cars to each other. But nevertheless all three cars show the tendency that an aggressive trip is characterised by a high average positive Δn_{agg}.

Concerning the Δn level of different divers at same trips Table 3-3 gives an overview, too. E.g. is the Δn-level of driver “1” by trend lower than the level driver “2” considering all different driving styles. An extreme result delivers “RIES2_NORM_D2” with Δn_{norm_VWBus} = 71.41rpm driven by driver “2” and “RIES7_AGG_D1” driven by driver “1”. One and the same route has the same Δn but with two by different driving styles and two different drivers. That alone shows the great influence of the driver. Also the influence of the route can be clearly seen in Table 3-3 (e.g. driver “2”: Δn_{Alter7_AGG} = 89.27rpm, Δn_{RIES9_AGG} = 97.07rpm).

Following Figure 3-3 shows the investigation results regarding a possible NO_x and Δn correlation.

Figure 3-3: NO_x and Δn correlation of Mazda CX5, BMW 320d and VW Bus T5 (D1, D2, D3 and D4 stands for the driver; total trips are considered)

Figure 3-3 shows in case of the Mazda CX5 and BMW 320d a relative good correlation of NO_x and Δn. High positive average Δn of an aggressive trip indicate high NO_x emissions and inverse. Taking a closer look at the economic and normal trips a similar but not that precise behaviour can be found. The VW Bus T5 shows no clear trend for all routes like the discovered correlation behaviour for weighted NO_x emissions and Δn of the two other cars. Comparing the economical driven "Alter"-routes to the normal ones in case of the VW Bus a similar correlation between the level of Δn and the NO_x emissions can be found. In case of the aggressive routes the assumption would be that due to the higher Δn also the emissions are higher. This is not the case. Considering the "Ries"-route trips the behaviour seems to be completely inverse. Here the economical driven routes cause higher emissions than the normal or aggressive driven ones. So no clear correlation could be found for the VW Bus T5. The reason could be found in the different height profile of the tracks. The "Alter"-route seems to have a smooth profile whereas the "Ries"-route is very hilly (Figure 3-1). So a very hilly profile combined with a very economic driving style (low rpm, early up-shifting etc.)

driven with a vehicle with a relative low power-to-weight ratio like 0,042kW/kg in case of the VW Bus T5 (Mazda CX5: 0.074kW/kg, BMW 320d: 0.088kW/kg) can be an explanation for different emission levels. A detailed analysis of the effects is given in chapter 3.4.1.2.2.

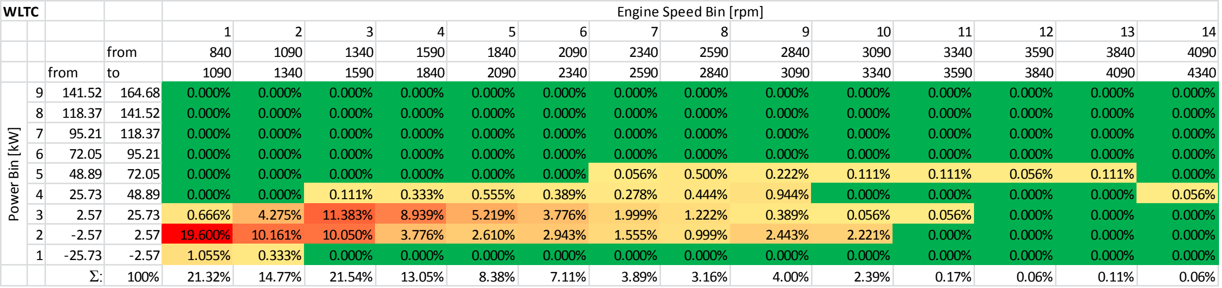
3.4.1.2 Analysis of influence of n - Emissions weighted by P-rpm-maps with CLEAR

Following tables show P-rpm-maps and CLEAR-Input-maps of different trips of the VW Bus T5. Chapter 5.1 contains the same kind of maps for the Mazda CX5 and the BMW 320d.

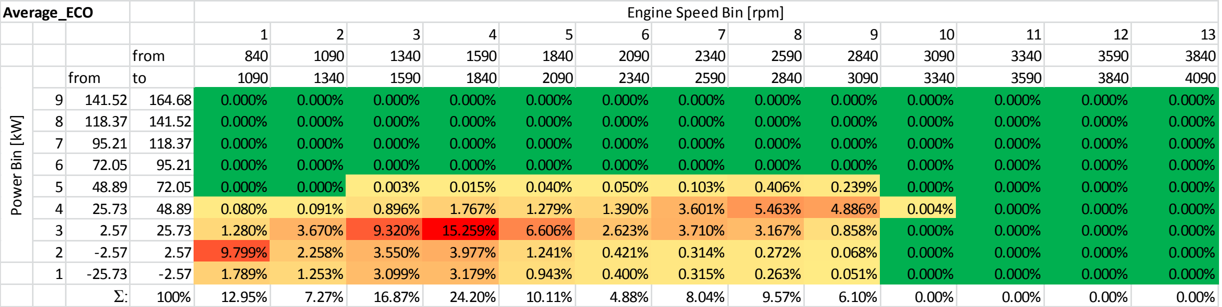
The “WLTC” P-rpm-map is based on the frequency distribution of the WLTC test. Its CLEAR-Input file contains exactly the time shares of the of the different engine speed and power bins of the WLTC test driven on the dynamometer. All other CLEAR-Input files are created by the method explained in 2.4.1. “WLTC_Extended”, “Average_ECO”, “Average_NORM” and “Average_AGG” stands for averaged engine speed and power distribution maps (P-rpm-maps) of several trips of one and the same driving style (ECO, NORM and AGG). “Average_All” averages all trips and delivers one P-rpm-map representing the average of all trips.

3.4.1.2.1 P-rpm- and CLEAR-Input-maps

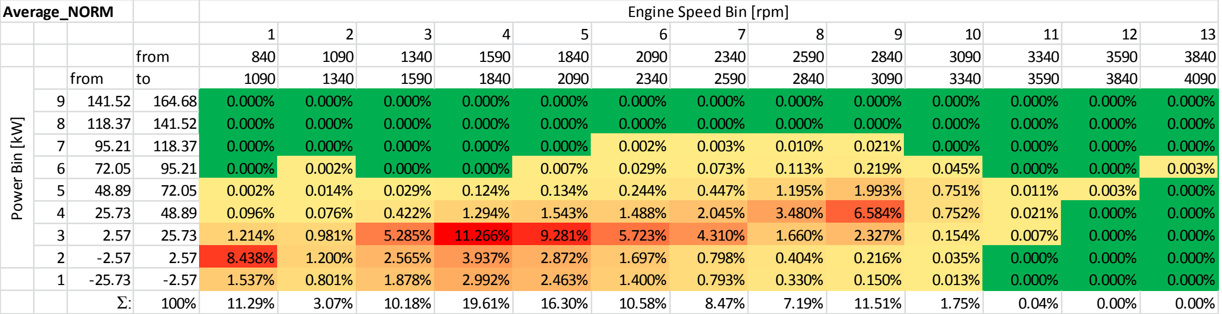
Following figures show the averaged P-rpm- and CLEAR-Input maps of the WLTC, all driving styles (“Average_ECO”,”Average_NORM”, “Average_AGG”) and the combination of all driving styles (“Average_ALL”).



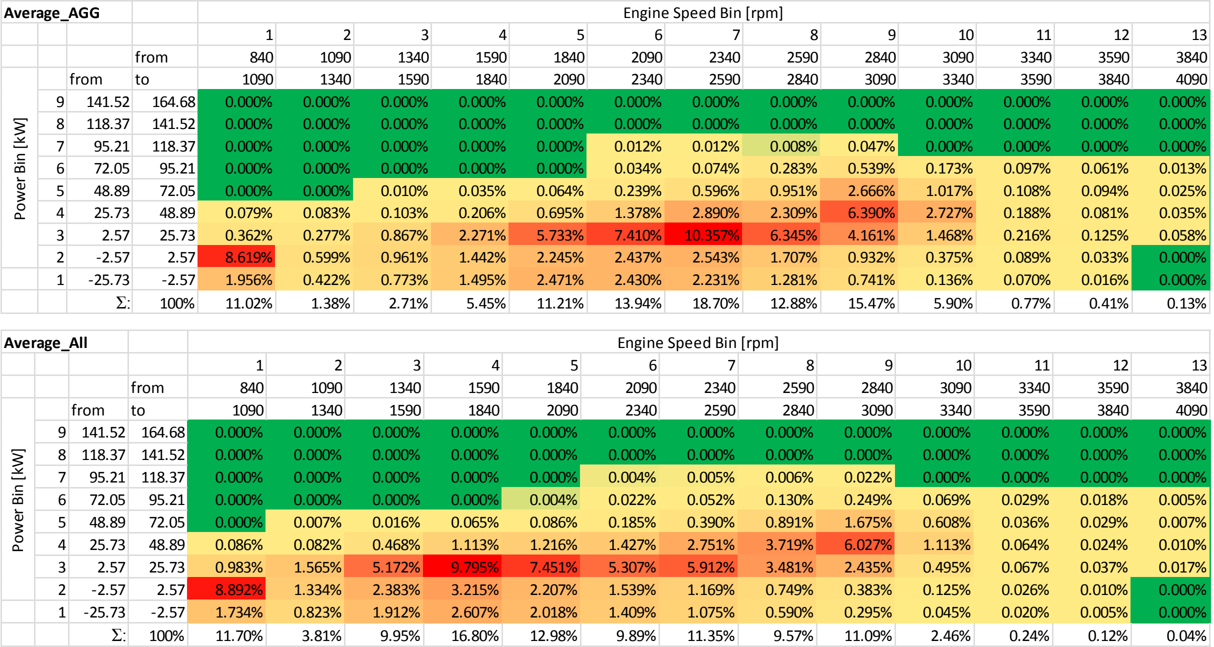
WLTC				Engine Speed Bin [rpm]													
				1	2	3	4	5	6	7	8	9	10	11	12	13	14
			from	840	1090	1340	1590	1840	2090	2340	2590	2840	3090	3340	3590	3840	4090
		from	to	1090	1340	1590	1840	2090	2340	2590	2840	3090	3340	3590	3840	4090	4340
Power Bin [kW]	9	141.52	164.68	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
	8	118.37	141.52	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
	7	95.21	118.37	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
	6	72.05	95.21	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
	5	48.89	72.05	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.056%	0.500%	0.222%	0.111%	0.111%	0.056%	0.111%	0.000%
	4	25.73	48.89	0.000%	0.000%	0.111%	0.333%	0.555%	0.389%	0.278%	0.444%	0.944%	0.000%	0.000%	0.000%	0.000%	0.056%
	3	2.57	25.73	0.666%	4.275%	11.383%	8.939%	5.219%	3.776%	1.999%	1.222%	0.389%	0.056%	0.056%	0.000%	0.000%	0.000%
	2	-2.57	2.57	19.600%	10.161%	10.050%	3.776%	2.610%	2.943%	1.555%	0.999%	2.443%	2.221%	0.000%	0.000%	0.000%	0.000%
	1	-25.73	-2.57	1.055%	0.333%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
		Σ:	100%	21.32%	14.77%	21.54%	13.05%	8.38%	7.11%	3.89%	3.16%	4.00%	2.39%	0.17%	0.06%	0.11%	0.06%



Average_ECO				Engine Speed Bin [rpm]												
				1	2	3	4	5	6	7	8	9	10	11	12	13
			from	840	1090	1340	1590	1840	2090	2340	2590	2840	3090	3340	3590	3840
		from	to	1090	1340	1590	1840	2090	2340	2590	2840	3090	3340	3590	3840	4090
Power Bin [kW]	9	141.52	164.68	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
	8	118.37	141.52	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
	7	95.21	118.37	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
	6	72.05	95.21	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
	5	48.89	72.05	0.000%	0.000%	0.003%	0.015%	0.040%	0.050%	0.103%	0.406%	0.239%	0.000%	0.000%	0.000%	0.000%
	4	25.73	48.89	0.080%	0.091%	0.896%	1.767%	1.279%	1.390%	3.601%	5.463%	4.886%	0.004%	0.000%	0.000%	0.000%
	3	2.57	25.73	1.280%	3.670%	9.320%	15.259%	6.606%	2.623%	3.710%	3.167%	0.858%	0.000%	0.000%	0.000%	0.000%
	2	-2.57	2.57	9.799%	2.258%	3.550%	3.977%	1.241%	0.421%	0.314%	0.272%	0.068%	0.000%	0.000%	0.000%	0.000%
	1	-25.73	-2.57	1.789%	1.253%	3.099%	3.179%	0.943%	0.400%	0.315%	0.263%	0.051%	0.000%	0.000%	0.000%	0.000%
		Σ:	100%	12.95%	7.27%	16.87%	24.20%	10.11%	4.88%	8.04%	9.57%	6.10%	0.00%	0.00%	0.00%	0.00%



Average_NORM				Engine Speed Bin [rpm]												
				1	2	3	4	5	6	7	8	9	10	11	12	13
			from	840	1090	1340	1590	1840	2090	2340	2590	2840	3090	3340	3590	3840
		from	to	1090	1340	1590	1840	2090	2340	2590	2840	3090	3340	3590	3840	4090
Power Bin [kW]	9	141.52	164.68	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
	8	118.37	141.52	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
	7	95.21	118.37	0.000%	0.000%	0.000%	0.000%	0.000%	0.002%	0.003%	0.010%	0.021%	0.000%	0.000%	0.000%	0.000%
	6	72.05	95.21	0.000%	0.002%	0.000%	0.000%	0.007%	0.029%	0.073%	0.113%	0.219%	0.045%	0.000%	0.000%	0.003%
	5	48.89	72.05	0.002%	0.014%	0.029%	0.124%	0.134%	0.244%	0.447%	1.195%	1.993%	0.751%	0.011%	0.003%	0.000%
	4	25.73	48.89	0.096%	0.076%	0.422%	1.294%	1.543%	1.488%	2.045%	3.480%	6.584%	0.752%	0.021%	0.000%	0.000%
	3	2.57	25.73	1.214%	0.981%	5.285%	11.266%	9.281%	5.723%	4.310%	1.660%	2.327%	0.154%	0.007%	0.000%	0.000%
	2	-2.57	2.57	8.438%	1.200%	2.565%	3.937%	2.872%	1.697%	0.798%	0.404%	0.216%	0.035%	0.000%	0.000%	0.000%
	1	-25.73	-2.57	1.537%	0.801%	1.878%	2.992%	2.463%	1.400%	0.793%	0.330%	0.150%	0.013%	0.000%	0.000%	0.000%
		Σ:	100%	11.29%	3.07%	10.18%	19.61%	16.30%	10.58%	8.47%	7.19%	11.51%	1.75%	0.04%	0.00%	0.00%

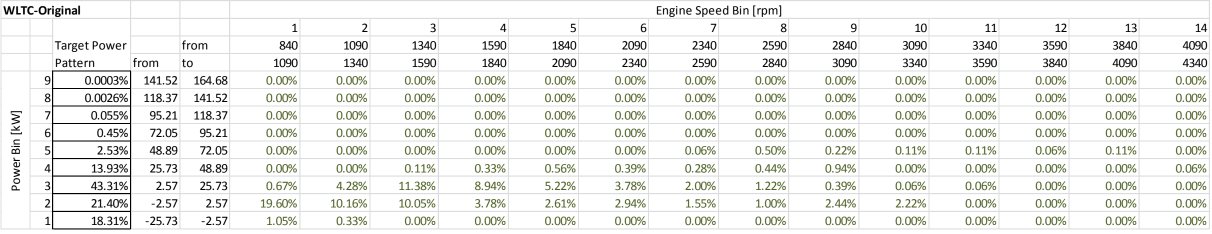


Average_AGG				Engine Speed Bin [rpm]												
				1	2	3	4	5	6	7	8	9	10	11	12	13
			from	840	1090	1340	1590	1840	2090	2340	2590	2840	3090	3340	3590	3840
		from	to	1090	1340	1590	1840	2090	2340	2590	2840	3090	3340	3590	3840	4090
Power Bin [kW]	9	141.52	164.68	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
	8	118.37	141.52	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
	7	95.21	118.37	0.000%	0.000%	0.000%	0.000%	0.000%	0.012%	0.012%	0.008%	0.047%	0.000%	0.000%	0.000%	0.000%
	6	72.05	95.21	0.000%	0.000%	0.000%	0.000%	0.000%	0.034%	0.074%	0.283%	0.539%	0.173%	0.097%	0.061%	0.013%
	5	48.89	72.05	0.000%	0.000%	0.010%	0.035%	0.064%	0.239%	0.596%	0.951%	2.666%	1.017%	0.108%	0.094%	0.025%
	4	25.73	48.89	0.079%	0.083%	0.103%	0.206%	0.695%	1.378%	2.890%	2.309%	6.390%	2.727%	0.188%	0.081%	0.035%
	3	2.57	25.73	0.362%	0.277%	0.867%	2.271%	5.733%	7.410%	10.357%	6.345%	4.161%	1.468%	0.216%	0.125%	0.058%
	2	-2.57	2.57	8.619%	0.599%	0.961%	1.442%	2.245%	2.437%	2.543%	1.707%	0.932%	0.375%	0.089%	0.033%	0.000%
	1	-25.73	-2.57	1.956%	0.422%	0.773%	1.495%	2.471%	2.430%	2.231%	1.281%	0.741%	0.136%	0.070%	0.016%	0.000%
		Σ:	100%	11.02%	1.38%	2.71%	5.45%	11.21%	13.94%	18.70%	12.88%	15.47%	5.90%	0.77%	0.41%	0.13%

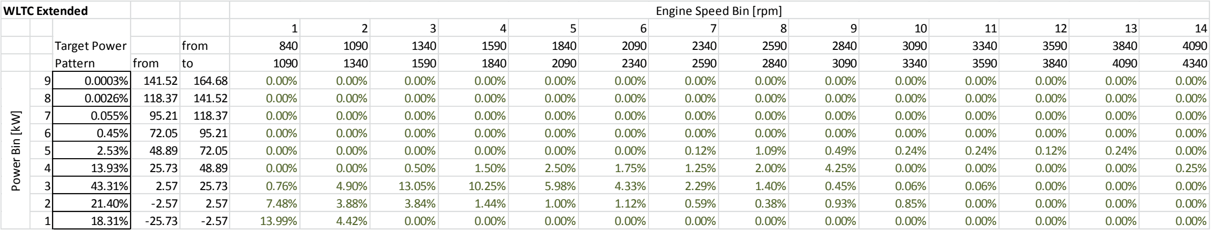
Average_All				Engine Speed Bin [rpm]												
				1	2	3	4	5	6	7	8	9	10	11	12	13
			from	840	1090	1340	1590	1840	2090	2340	2590	2840	3090	3340	3590	3840
		from	to	1090	1340	1590	1840	2090	2340	2590	2840	3090	3340	3590	3840	4090
Power Bin [kW]	9	141.52	164.68	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
	8	118.37	141.52	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
	7	95.21	118.37	0.000%	0.000%	0.000%	0.000%	0.000%	0.004%	0.005%	0.006%	0.022%	0.000%	0.000%	0.000%	0.000%
	6	72.05	95.21	0.000%	0.000%	0.000%	0.000%	0.004%	0.022%	0.052%	0.130%	0.249%	0.069%	0.029%	0.018%	0.005%
	5	48.89	72.05	0.000%	0.007%	0.016%	0.065%	0.086%	0.185%	0.390%	0.891%	1.675%	0.608%	0.036%	0.029%	0.007%
	4	25.73	48.89	0.086%	0.082%	0.468%	1.113%	1.216%	1.427%	2.751%	3.719%	6.027%	1.113%	0.064%	0.024%	0.010%
	3	2.57	25.73	0.983%	1.565%	5.172%	9.795%	7.451%	5.307%	5.912%	3.481%	2.435%	0.495%	0.067%	0.037%	0.017%
	2	-2.57	2.57	8.892%	1.334%	2.383%	3.215%	2.207%	1.539%	1.169%	0.749%	0.383%	0.125%	0.026%	0.010%	0.000%
	1	-25.73	-2.57	1.734%	0.823%	1.912%	2.607%	2.018%	1.409%	1.075%	0.590%	0.295%	0.045%	0.020%	0.005%	0.000%
		Σ:	100%	11.70%	3.81%	9.95%	16.80%	12.98%	9.89%	11.35%	9.57%	11.09%	2.46%	0.24%	0.12%	0.04%

Figure 3-4: Averaged P-rpm-maps VW Bus T5 of different driving styles (red = high time share in [%], slightly red/yellow = mid to low time shares in [%], green = time share of 0%)

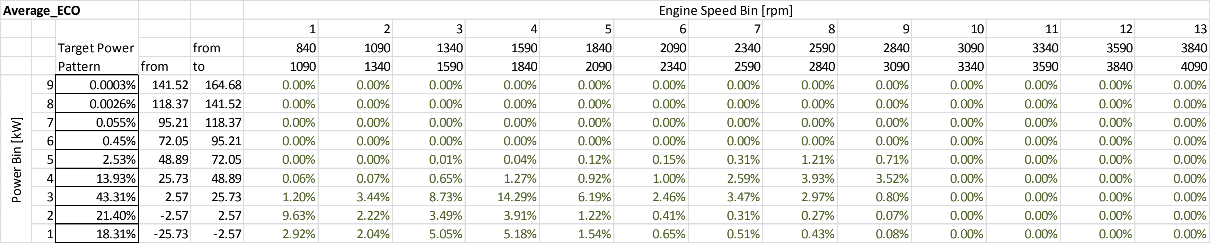
Based on these P-rpm-maps CLEAR-Input maps calibrated to the target power pattern time shares are created with the method explained in 2.4.1.



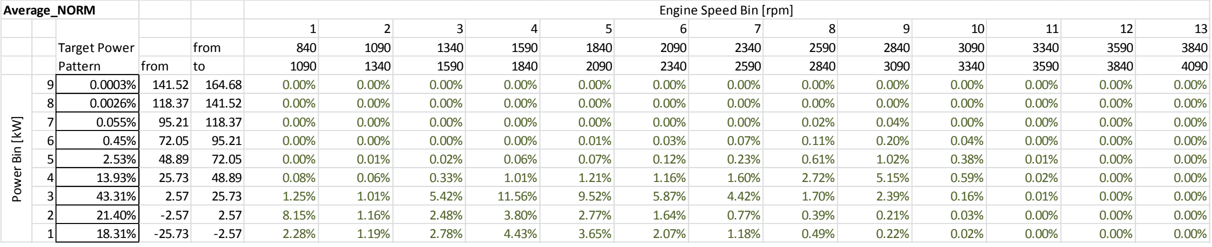
WLTC-Original					Engine Speed Bin [rpm]													
					1	2	3	4	5	6	7	8	9	10	11	12	13	14
		Target Power		from	840	1090	1340	1590	1840	2090	2340	2590	2840	3090	3340	3590	3840	4090
		Pattern	from	to	1090	1340	1590	1840	2090	2340	2590	2840	3090	3340	3590	3840	4090	4340
Power Bin [kW]	9	0.0003%	141.52	164.68	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	8	0.0026%	118.37	141.52	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	7	0.055%	95.21	118.37	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	6	0.45%	72.05	95.21	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	5	2.53%	48.89	72.05	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.06%	0.50%	0.22%	0.11%	0.11%	0.06%	0.11%	0.00%
	4	13.93%	25.73	48.89	0.00%	0.00%	0.11%	0.33%	0.56%	0.39%	0.28%	0.44%	0.94%	0.00%	0.00%	0.00%	0.00%	0.06%
	3	43.31%	2.57	25.73	0.67%	4.28%	11.38%	8.94%	5.22%	3.78%	2.00%	1.22%	0.39%	0.06%	0.06%	0.00%	0.00%	0.00%
	2	21.40%	-2.57	2.57	19.60%	10.16%	10.05%	3.78%	2.61%	2.94%	1.55%	1.00%	2.44%	2.22%	0.00%	0.00%	0.00%	0.00%
	1	18.31%	-25.73	-2.57	1.05%	0.33%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%



WLTC Extended					Engine Speed Bin [rpm]													
					1	2	3	4	5	6	7	8	9	10	11	12	13	14
		Target Power		from	840	1090	1340	1590	1840	2090	2340	2590	2840	3090	3340	3590	3840	4090
		Pattern	from	to	1090	1340	1590	1840	2090	2340	2590	2840	3090	3340	3590	3840	4090	4340
Power Bin [kW]	9	0.0003%	141.52	164.68	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	8	0.0026%	118.37	141.52	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	7	0.055%	95.21	118.37	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	6	0.45%	72.05	95.21	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	5	2.53%	48.89	72.05	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.12%	1.09%	0.49%	0.24%	0.24%	0.12%	0.24%	0.00%
	4	13.93%	25.73	48.89	0.00%	0.00%	0.50%	1.50%	2.50%	1.75%	1.25%	2.00%	4.25%	0.00%	0.00%	0.00%	0.00%	0.25%
	3	43.31%	2.57	25.73	0.76%	4.90%	13.05%	10.25%	5.98%	4.33%	2.29%	1.40%	0.45%	0.06%	0.06%	0.00%	0.00%	0.00%
	2	21.40%	-2.57	2.57	7.48%	3.88%	3.84%	1.44%	1.00%	1.12%	0.59%	0.38%	0.93%	0.85%	0.00%	0.00%	0.00%	0.00%
	1	18.31%	-25.73	-2.57	13.99%	4.42%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%



Average_ECO					Engine Speed Bin [rpm]												
					1	2	3	4	5	6	7	8	9	10	11	12	13
		Target Power		from	840	1090	1340	1590	1840	2090	2340	2590	2840	3090	3340	3590	3840
		Pattern	from	to	1090	1340	1590	1840	2090	2340	2590	2840	3090	3340	3590	3840	4090
Power Bin [kW]	9	0.0003%	141.52	164.68	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	8	0.0026%	118.37	141.52	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	7	0.055%	95.21	118.37	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	6	0.45%	72.05	95.21	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	5	2.53%	48.89	72.05	0.00%	0.00%	0.01%	0.04%	0.12%	0.15%	0.31%	1.21%	0.71%	0.00%	0.00%	0.00%	0.00%
	4	13.93%	25.73	48.89	0.06%	0.07%	0.65%	1.27%	0.92%	1.00%	2.59%	3.93%	3.52%	0.00%	0.00%	0.00%	0.00%
	3	43.31%	2.57	25.73	1.20%	3.44%	8.73%	14.29%	6.19%	2.46%	3.47%	2.97%	0.80%	0.00%	0.00%	0.00%	0.00%
	2	21.40%	-2.57	2.57	9.63%	2.22%	3.49%	3.91%	1.22%	0.41%	0.31%	0.27%	0.07%	0.00%	0.00%	0.00%	0.00%
	1	18.31%	-25.73	-2.57	2.92%	2.04%	5.05%	5.18%	1.54%	0.65%	0.51%	0.43%	0.08%	0.00%	0.00%	0.00%	0.00%



Average_NORM					Engine Speed Bin [rpm]												
					1	2	3	4	5	6	7	8	9	10	11	12	13
		Target Power		from	840	1090	1340	1590	1840	2090	2340	2590	2840	3090	3340	3590	3840
		Pattern	from	to	1090	1340	1590	1840	2090	2340	2590	2840	3090	3340	3590	3840	4090
Power Bin [kW]	9	0.0003%	141.52	164.68	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	8	0.0026%	118.37	141.52	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	7	0.055%	95.21	118.37	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.02%	0.04%	0.00%	0.00%	0.00%	0.00%
	6	0.45%	72.05	95.21	0.00%	0.00%	0.00%	0.00%	0.01%	0.03%	0.07%	0.11%	0.20%	0.04%	0.00%	0.00%	0.00%
	5	2.53%	48.89	72.05	0.00%	0.01%	0.02%	0.06%	0.07%	0.12%	0.23%	0.61%	1.02%	0.38%	0.01%	0.00%	0.00%
	4	13.93%	25.73	48.89	0.08%	0.06%	0.33%	1.01%	1.21%	1.16%	1.60%	2.72%	5.15%	0.59%	0.02%	0.00%	0.00%
	3	43.31%	2.57	25.73	1.25%	1.01%	5.42%	11.56%	9.52%	5.87%	4.42%	1.70%	2.39%	0.16%	0.01%	0.00%	0.00%
	2	21.40%	-2.57	2.57	8.15%	1.16%	2.48%	3.80%	2.77%	1.64%	0.77%	0.39%	0.21%	0.03%	0.00%	0.00%	0.00%
	1	18.31%	-25.73	-2.57	2.28%	1.19%	2.78%	4.43%	3.65%	2.07%	1.18%	0.49%	0.22%	0.02%	0.00%	0.00%	0.00%

Average_AGG					Engine Speed Bin [rpm]												
					1	2	3	4	5	6	7	8	9	10	11	12	13
		Target Power		from	840	1090	1340	1590	1840	2090	2340	2590	2840	3090	3340	3590	3840
		Pattern	from	to	1090	1340	1590	1840	2090	2340	2590	2840	3090	3340	3590	3840	4090
Power Bin [kW]	9	0.0003%	141.52	164.68	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	8	0.0026%	118.37	141.52	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	7	0.055%	95.21	118.37	0.00%	0.00%	0.00%	0.00%	0.00%	0.01%	0.01%	0.01%	0.03%	0.00%	0.00%	0.00%	0.00%
	6	0.45%	72.05	95.21	0.00%	0.00%	0.00%	0.00%	0.00%	0.01%	0.03%	0.10%	0.19%	0.06%	0.03%	0.02%	0.00%
	5	2.53%	48.89	72.05	0.00%	0.00%	0.00%	0.02%	0.03%	0.10%	0.26%	0.42%	1.16%	0.44%	0.05%	0.04%	0.01%
	4	13.93%	25.73	48.89	0.06%	0.07%	0.08%	0.17%	0.56%	1.12%	2.35%	1.87%	5.19%	2.21%	0.15%	0.07%	0.03%
	3	43.31%	2.57	25.73	0.40%	0.30%	0.95%	2.48%	6.26%	8.09%	11.31%	6.93%	4.55%	1.60%	0.24%	0.14%	0.06%
	2	21.40%	-2.57	2.57	8.39%	0.58%	0.94%	1.40%	2.19%	2.37%	2.48%	1.66%	0.91%	0.37%	0.09%	0.03%	0.00%
	1	18.31%	-25.73	-2.57	2.55%	0.55%	1.01%	1.95%	3.23%	3.17%	2.91%	1.67%	0.97%	0.18%	0.09%	0.02%	0.00%

Average_All					Engine Speed Bin [rpm]												
					1	2	3	4	5	6	7	8	9	10	11	12	13
		Target Power		from	840	1090	1340	1590	1840	2090	2340	2590	2840	3090	3340	3590	3840
		Pattern	from	to	1090	1340	1590	1840	2090	2340	2590	2840	3090	3340	3590	3840	4090
Power Bin [kW]	9	0.0003%	141.52	164.68	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	8	0.0026%	118.37	141.52	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	7	0.055%	95.21	118.37	0.00%	0.00%	0.00%	0.00%	0.00%	0.01%	0.01%	0.01%	0.03%	0.00%	0.00%	0.00%	0.00%
	6	0.45%	72.05	95.21	0.00%	0.00%	0.00%	0.00%	0.00%	0.02%	0.04%	0.10%	0.20%	0.05%	0.02%	0.01%	0.00%
	5	2.53%	48.89	72.05	0.00%	0.00%	0.01%	0.04%	0.05%	0.12%	0.25%	0.57%	1.06%	0.39%	0.02%	0.02%	0.00%
	4	13.93%	25.73	48.89	0.07%	0.06%	0.36%	0.86%	0.94%	1.10%	2.12%	2.86%	4.64%	0.86%	0.05%	0.02%	0.01%
	3	43.31%	2.57	25.73	1.00%	1.59%	5.24%	9.93%	7.56%	5.38%	6.00%	3.53%	2.47%	0.50%	0.07%	0.04%	0.02%
	2	21.40%	-2.57	2.57	8.64%	1.30%	2.31%	3.12%	2.14%	1.50%	1.14%	0.73%	0.37%	0.12%	0.03%	0.01%	0.00%
	1	18.31%	-25.73	-2.57	2.53%	1.20%	2.79%	3.81%	2.95%	2.06%	1.57%	0.86%	0.43%	0.07%	0.03%	0.01%	0.00%

Figure 3-5: CLEAR-Input maps of different driving styles for VW Bus T5(→ CSV-file)

If there is a reduction by the normalisation with the P-rpm-maps of the difference between the minimum and maximum of the emission values compared to normalisation with the standard power goal pattern, the engine speed will be the explanation for this reduction.

Taking a closer look at the P-rpm-maps so different time shares in upper engine speed and power bins are visible. E.g. the aggressive P-rpm-map has much higher time shares in upper areas or at least time shares exist. Especially if you take a closer look at the “WLTC”-P-rpm-map there are no or no significant time shares in higher power and engine speed bins. Also both the “WLTC”-P-rpm-map of the Mazda CX5 and the BMW 320d (Figure 5-1, Figure 5-3) seem to have very economical time shares mainly existing in lower engine speed and power bin regions. Based on these results the WLTC test seems to represent rather an economic driving style than a normal European one. It can be seen that the “WLTC”-maps of all three cars have an almost similar frequency distribution within engine speed and power bins (Figure 3-4, Figure 5-1, Figure 5-3). So if there is a P-rpm-map for each car that reduces the emission value max/min ratio and standard deviation of trips of different driving styles, maybe it will be possible to identify a correlation factor between this car specific P-rpm-map and the car specific “WLTC”-map, which should be for all cars a car specific reference point.

To identify a possible correlation normalisations with different kinds of P-rpm-maps have been examined. Following chapter deals with the results of these normalisations.

3.4.1.2.2 Normalisation results for NO_x

The general approach is to compare emission results of the “new” normalisation (“Extended CLEAR method”) to the emission results of the “original” (“Standard CLEAR method”) normalisation. The consideration concentrates on NO_x emissions because of the already mentioned new EURO 6 legislation limits, which are especially for diesel cars a challenge to comply with (2.2.1). The “new” normalisations are based on

1. a “WLTC”- and “WLTC-Extended”-map
2. a “Economic”-map,
3. a “Normal”-map,
4. an “Aggressive”-map and
5. an “Average_All”-map.

Following two figures show the measured emissions of all trips driven with the BMW 320d (EURO 6) and the VW Bus T5 (EURO 5). There is no categorization in urban, road or motorway driving, so the total trips are considered. The “original” normalisation (“Standard CLEAR method) shows a visible reduction of the ratio between minimum and maximum values (Figure 3-6).

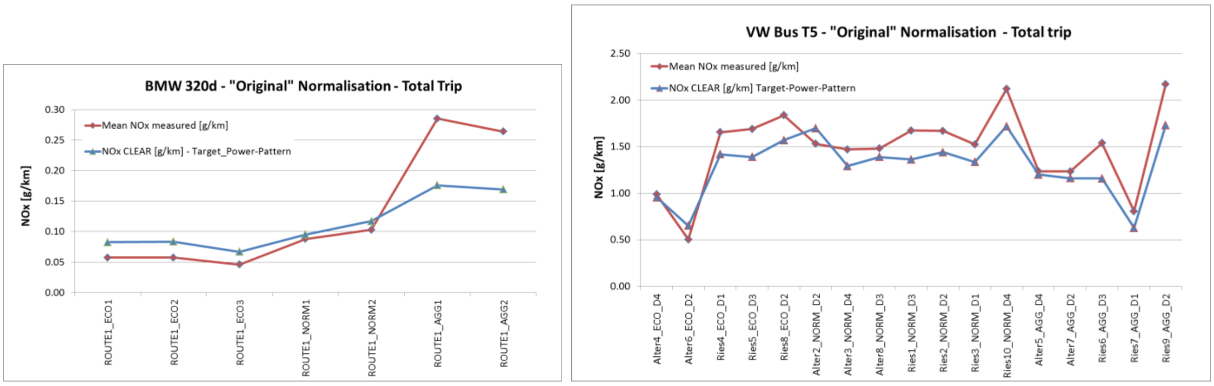


Figure 3-6: Normalisation results by the “Standard CLEAR method” - Total trip for BMW 320d (EURO 6) and VW Bus T5 (EURO 5) T5 (red: measured emissions, blue: weighted emissions by the “Standard CLEAR method”)

Taking a closer look at the emissions of the different driving styles, BMW 320d shows an expected behaviour. An aggressive driving causes rather higher emissions than a normal or economic one ($NO_{x\_avg\_AGG} > NO_{x\_avg\_NORM} > NO_{x\_avg\_ECO}$). In case of the VW Bus T5 this behaviour can’t be seen. Additionally, the NO_x emission values of the BMW 320d are much lower than the VW Bus T5. Different exhaust aftertreatment strategies may be the explanation for this phenomenon. The BMW uses a NSC and EGR-system whereas the VW Bus just uses an EGR-system in order to reduce its NO_x-emissions.

For further analysis following Table 3-4 gives a good overview above speed and NO_x-emissions in different units.

Table 3-4: Mean and by the “Standard CLEAR method” weighted values of speed and NO_x of different routes with different drivers

Trip	Mean Speed [km/h]	Mean NOx [g/h]	Mean NOx [g/km]	Weighted Speed [km/h]	Weighted NOx [g/h]	Weighted NOx [g/km]
Alter4_ECO_D4	59.45	58.65	0.99	61.09	58.37	0.96
Alter6_ECO_D2	58.48	29.41	0.50	57.63	37.46	0.65
Ries4_ECO_D1	64.42	106.54	1.65	59.66	84.58	1.42
Ries5_ECO_D3	67.26	113.62	1.69	61.65	85.58	1.39
Ries8_ECO_D2	68.63	126.08	1.84	64.50	101.24	1.57
Alter2_NORM_D2	56.56	86.58	1.53	57.40	97.51	1.70
Alter3_NORM_D4	64.35	94.64	1.47	61.39	79.29	1.29
Alter8_NORM_D3	59.99	88.79	1.48	59.62	82.85	1.39
Ries1_NORM_D3	61.86	103.49	1.67	60.07	81.87	1.36
Ries2_NORM_D2	70.07	116.92	1.67	63.86	92.00	1.44
Ries3_NORM_D1	65.69	100.16	1.52	61.76	82.48	1.34
Ries10_NORM_D4	72.54	153.75	2.12	65.46	112.52	1.72
Alter5_AGG_D4	59.96	74.11	1.24	58.54	70.25	1.20
Alter7_AGG_D2	58.12	71.74	1.23	58.43	67.82	1.16
Ries6_AGG_D3	69.94	107.65	1.54	64.74	74.98	1.16
Ries7_AGG_D1	69.79	56.20	0.81	64.75	40.71	0.63
Ries9_AGG_D2	67.08	145.70	2.17	62.47	108.21	1.73

Considering the emission levels of the VW Bus T5 just the "Alter"-routes show partly the expected behaviour regarding the NO_x-emissions ($NO_{x\_"Alter\_ECO"-routes} < NO_{x\_"Alter\_NORM"-routes}$). Unexpected is the fact that the emissions of the $NO_{x\_"Alter\_AGG"-routes}$ are lower than those of the normal driven routes independent of the driver. Taking a closer look at the "Ries"-routes the different level of the NO_x-emissions is not expected at all. Especially the routes "Ries4_ECO", "Ries3_NORM" and "Ries7_AGG" driven by driver "1" are conspicuous. In case of driver "2" an expected behaviour regarding the NO_x-emissions of "Ries2_NORM" and "Ries9_AGG" can be seen, whereas the emission level of the "Ries8_ECO" is higher then the level of "Ries2_NORM" (see chapter 5.5.2).

Maybe specific NO_x-emission maps in [g/h] of each trip can deliver an explanation for this unexpected behaviour. The approach is to identify the region of the NO_x-emission map in which a trip mostly of the time takes place. These emission maps are created with simulation software called PHEM. It creates these maps by an interpolation based on the measured NO_x-emissions, which are connected to a power and engine speed signal. These maps contain the normalised power on the y axis (normalised with $P_{rated}=1$), the normalised rpm on the x-axis (normalised with $n_{rated}=1$ and $n_{idle}=0$) and the related NO_x emissions in g/km. Each red point in the map stands for a normalised-power and –engine speed point. Due to the NO_x-emission map it is possible to assign every point to a specific NO_x value. The limiting curve of each NO_x-emission map represents the normalised full load curve of the engine. Red points above this curve are outliers due to measurement failures.

In case of the "Alter"-trips the arrangement of the power points in the NO_x-emission maps reveals different driving styles. In the "Alter4_Eco_D4" NO_x-emission map (Figure 3-7) the points are mostly arranged in low load and low to mid engine speed areas, whereas the points of "Alter3_NORM_D4" (Figure 3-7) are arranged in the mid load and mid to high engine speed areas. Considering the "Alter5_AGG_D4" the points are arranged in high load and engine speed areas (see Figure 3-7). The same phenomenon can be seen for the "Alter" trips of the driver "2" in Figure 5-12 and Figure 5-13.

If you take a look at the NO_x-emission points of "Alter3_NORM_D4" and "Alter5_AGG_D4"" (Figure 3-7) the NO_x emission points are located corresponding to the frequency distribution of a "normal" and "aggressive" trip shown Figure 3-4. Under closer inspection you can see that the trip points of "Alter3_NORM_D4" are allocated in slightly higher NO_x-emission regions than of "Alter5_AGG_D4"– an unexpected behaviour. This finding is confirmed by the conspicuous level of the measured mean NO_x-values (in [g/h]: $NO_{x\_Alter4\_Eco}=58.65$, $NO_{x\_Alter3\_Norm}=94.64$ and $NO_{x\_Alter5\_Agg}$ 74.11, Table 3-4**)**. In case of the driver "2" the same behaviour is visible (Table 3-4). At least "Alter4_ECO_D4","Alter3_NORM_D4", "Alter6_ECO_D2" and "Alter2_NORM_D2" confirm the assumption that the NO_x-emission values of an economic trip are lower than those of a normal trip (Table 3-4).

Considering the weighted NO_x-values of the "Standard CLEAR method" in Table 3-4 the positive effects of the CLEAR-method are visible. Emissions of trips with an aggressive driving style or too high emissions are lowered and emissions of trips with an economic driving style are enhanced (mean: $NO_{x\_Alter6\_Eco}=0.50$, $NO_{x\_Alter3\_Norm}=1.47$, $NO_{x\_Alter5\_Agg}=1.24$ in [g/km]; weighted: $NO_{x\_Alter6\_Eco}=0.65$, $NO_{x\_Alter3\_Norm}=1.29$, $NO_{x\_Alter5\_Agg}=1.20$ in [g/km]).

The NO_x emission maps of all trips of the VW BUS T5 can be found in 5.5.2 categorized by the route and their driving style.

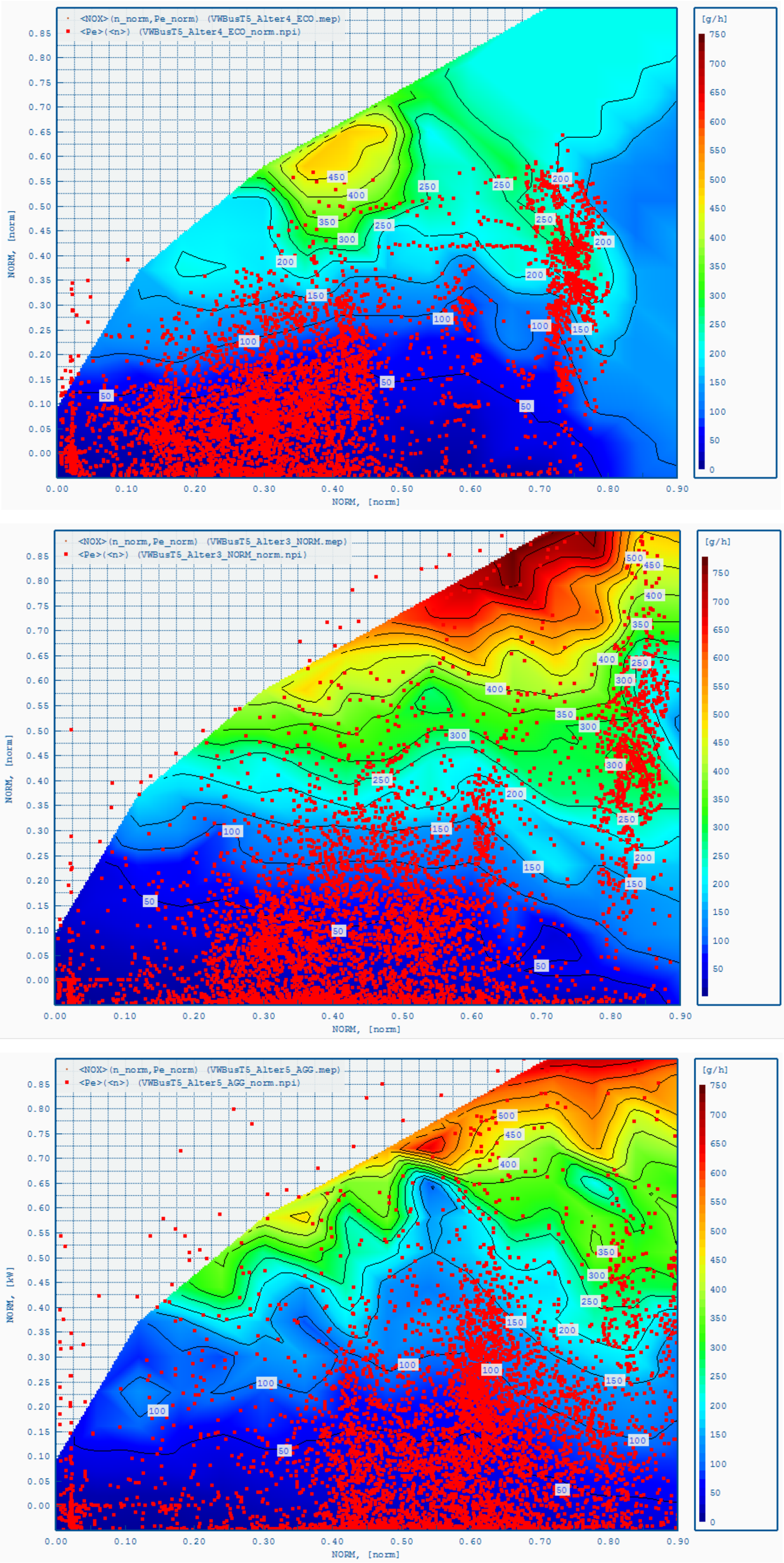
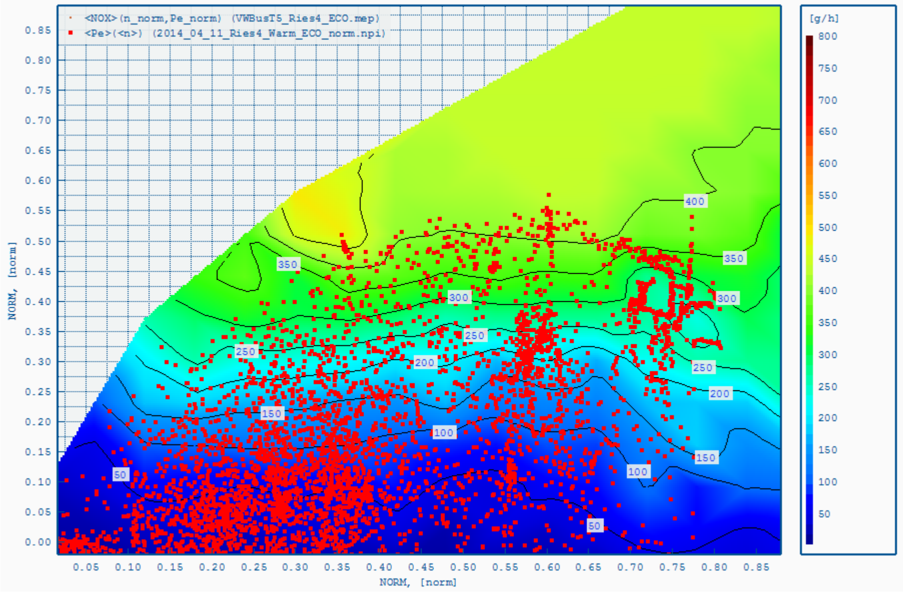
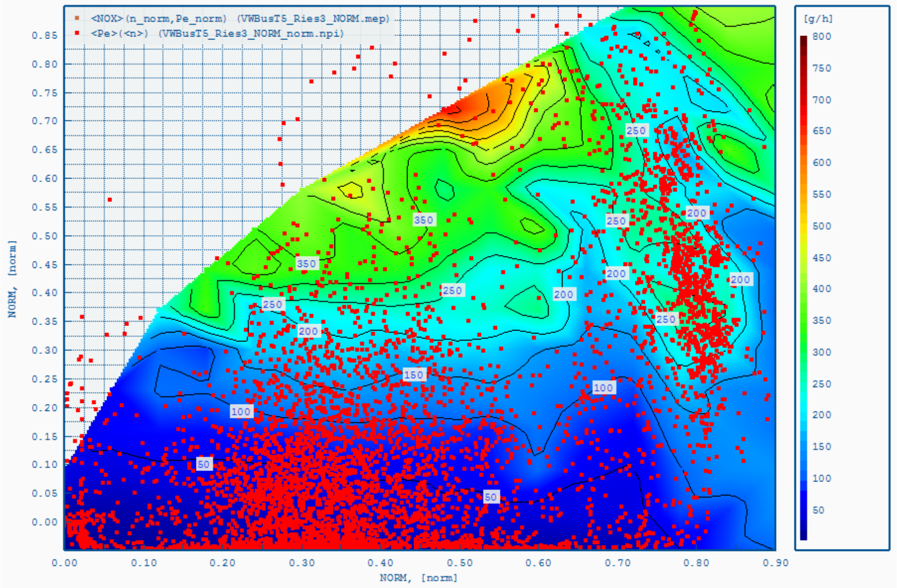


Figure 3-7: Trip specific NO_x-emission maps for VW Bus T5 for “Alter4_ECO_D4“, “Alter3_NORM_D4” and “Alter5_AGG_D4” (blue: low NO_x-emissions [g/h], red: high NO_x-emissions [g/h])

Figure 3-8 shows the NO_x-emission maps of different “Ries”-route trips driven by driver “1” (“Ries4_ECO_D1”, “Ries3_NORM_D1” and “Ries7_AGG_D1”). Compared to NO_x-emission maps of the “Alter”-routes in Figure 3-7 the differentiation between the different driving styles is not so clear. The power points are much more scattered and not so clear allocated like in the “Alter”-routes NO_x-emission maps. Very conspicuous and difficult to describe is the behaviour of of NO_x-emission levels shown in Table 3-4 regarding the “Ries”-route trips, where $NO_{x\_Ries4\_Eco} > NO_{x\_Ries3\_Norm} > NO_{x\_Ries7\_Agg}$. The expectation would have been the other way around. The reasons for this behaviour can be various, but it may be ascribed to the vehicle, route, driver and driving style combination. The profile of the “Ries”-route is very hilly so an economic driving style characterised by a low engine speed and early up-shifting causes in case of the VW Bus T5 visible higher emissions than with a normal or aggressive driving style. Comparing the NO_x-emission maps of the different routes it is visible that the aggressive driven trip concentrates in lower emission regions than the economic driven one.





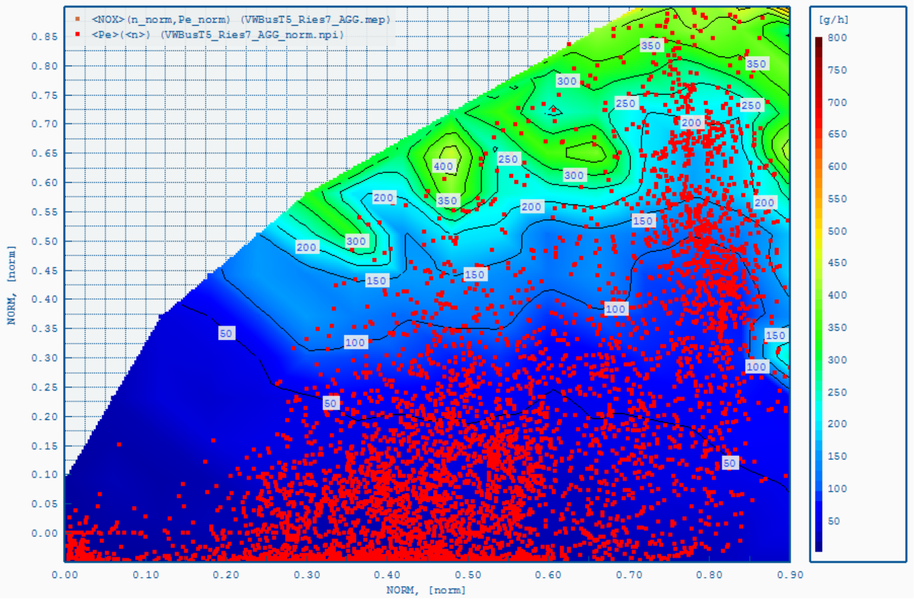
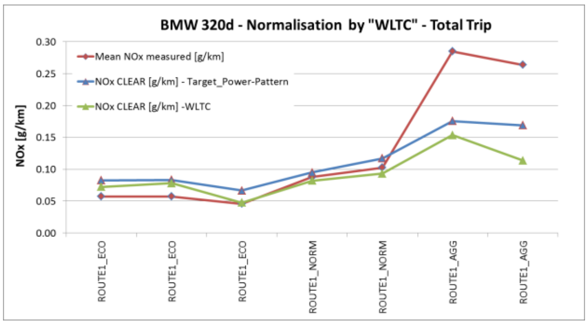


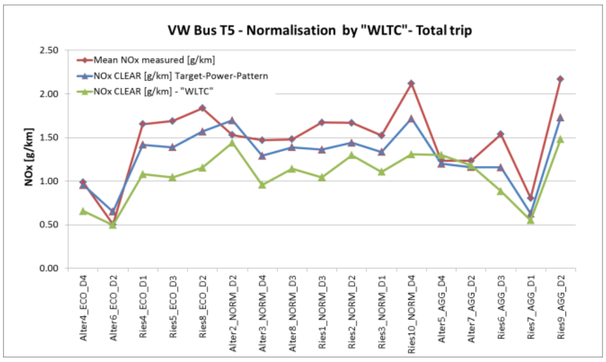
Figure 3-8: Trip specific NO_x-emission maps for VW Bus T5 "Ries4_ECO_D1", "Ries3_NORM_D1" and "Ries7_AGG_D1" (blue: low NO_x-emissions [g/h], red: high NO_x-emissions [g/h])

Explanations for these findings may be also found in the engine and exhaust after treatment systems application (exhaust aftertreatment strategy mainly considering EGR-rate).The strategy in case of the VW Bus T5 seems to pursue a reduction of emissions in regions of higher engine speed and low to mid engine load (Figure 3-7, Figure 3-8)

The assessment whether a normalisation by a P-rpm-map ("Extended CLEAR method, Figure 3-4, Figure 5-1) is good or not is done by the comparison of the max/min ratio and the standard deviation of the emission values of the "original" normalisation ("Standard CLEAR method, " target power pattern).

Following figures show the measured emissions (red), the weighted emissions by the "Standard CLEAR method" (blue) and the weighted emissions by the "Extended CLEAR method". Additionally the max/min ratios and standard deviations are shown in tables below the figures, which serve as mentioned before as assessment criterion for the "Extended CLEAR method". Inveisitgations are made on NOx-emissions weighted by different P-rpm-maps representing different driving styles.



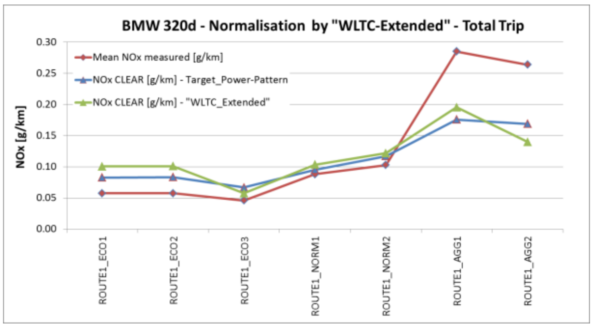


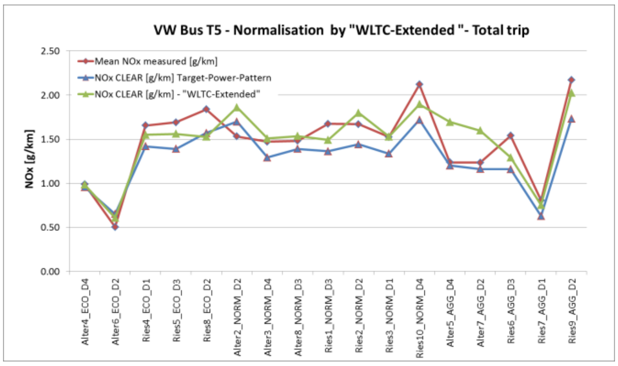
	Mean NOx measured[g/km]	NOx CLEAR [g/km] - Target-Power-Pattern	NOx CLEAR [g/km] - "WLTC"
Average	0.129	0.113	0.092
Maximum value	0.285	0.176	0.154
Minimum value	0.046	0.067	0.048
Max/Min	6.220	2.631	3.217
Standard deviation	73.25%	35.70%	34.32%

	Mean NOx measured[g/km]	NOx CLEAR [g/km] - Target-Power-Pattern	NOx CLEAR [g/km] - "WLTC"
Average	1.478	1.300	1.066
Maximum value	2.172	1.732	1.483
Minimum value	0.503	0.629	0.497
Max/Min	4.319	2.755	2.987
Standard deviation	28.16%	24.25%	26.06%

Figure 3-9: ”WLTC”- Normalisation results for BMW 320d and VW Bus T5 (red: measured emissions, blue: weighted emissions by the “Standard CLEAR method”, green: weighted emissions by the “Extended CLEAR method”)

For both cars the normalisation with a “WLTC”-P-rpm-map works not as good as the target power pattern – normalisation (TPP). The standard deviation and absolute difference between minimum and maximum value gets smaller (BMW: TPP: 0,109 g/km → “WLTC”: 0,106g/km, VW Bus T5: TPP: 1,103g/km → “WLTC”:0,986g/km) but the max/min ratio gets bigger (BMW: TPP: 2,631 → “WLTC”: 3,217, VW Bus T5: TPP: 2,755 → “WLTC”: 2,987).





	Mean NOx measured[g/km]	NOx CLEAR [g/km] - Target-Power-Pattern	NOx CLEAR [g/km] - "WLTC_Extended"
Average	0.129	0.113	0.117
Maximum value	0.285	0.176	0.195
Minimum value	0.046	0.067	0.057
Max/Min	6.220	2.631	3.413
Standard deviation	73.25%	35.70%	33.89%

	Mean NOx measured[g/km]	NOx CLEAR [g/km] - Target-Power-Pattern	NOx CLEAR [g/km] - "WLTC-Extended"
Average	1.478	1.300	1.482
Maximum value	2.172	1.732	2.026
Minimum value	0.503	0.629	0.606
Max/Min	4.319	2.755	3.341
Standard deviation	28.16%	23.28%	25.19%

Figure 3-10: “WLTC-Extended“- Normalisation result for BMW 320d ans VW Bus T5 (red: measured emissions, blue: weighted emissions by the “Standard CLEAR method”, green: weighted emissions by the “Extended CLEAR method”)

The normalisation based on a “WLTC-Extended” map shows no improvement regarding the standard deviation and the max /min ratio reduction, too. No satisfactory normalisation results are deliverd. Furthermore these normalisations eliminate a lot of data, because of the fact that there are no time shares in areas of higher engine speed and power bins.

These two “WLTC” - approaches show no improvement regarding the difference of the minimum and maximum values, but nevertheless in case of the BMW 320d the main demand, that emission values of an economic driving should be enhanced and those of an aggressive driving should be lowered, is fulfilled.

Following figure shows the normalisation results with the “Extended CLEAR method” based on several other P-rpm-maps by CLEAR (Figure 3-4, Figure 5-1) characterized by different driving styles like “ECO”, “NORM” and “AGG”.

BMW 320d	Mean NOx measured[g/km]	NOx CLEAR [g/km] - Target-Power-Pattern	NOx CLEAR [g/km] - "Average_ECO"	NOx CLEAR [g/km] - "Average_NORM"	NOx CLEAR [g/km] - "Average_AGG"	NOx CLEAR [g/km] - "Average_ALL"
Average	0.129	0.113	0.110	0.112	0.171	0.121
Maximum value	0.285	0.176	0.203	0.197	0.240	0.193
Minimum value	0.046	0.067	0.058	0.061	0.119	0.066
Max/Min	6.220	2.631	3.494	3.228	2.019	2.901
Standard deviation	73.25%	35.70%	41.09%	37.51%	21.24%	30.91%

VW Bus T5	Mean NOx measured[g/km]	NOx CLEAR [g/km] - Target-Power-Pattern	NOx CLEAR [g/km] - "Average_ECO"	NOx CLEAR [g/km] - "Average_NORM"	NOx CLEAR [g/km] - "Average_AGG"	NOx CLEAR [g/km] - "Average_ALL"
Average	1.478	1.300	1.379	1.293	1.166	1.275
Maximum value	2.172	1.732	1.923	1.795	1.731	1.808
Minimum value	0.503	0.629	0.497	0.436	0.302	0.413
Max/Min	4.319	2.755	3.867	4.112	5.734	4.382
Standard deviation	28.16%	23.28%	26.44%	26.68%	28.87%	27.09%

Figure 3-11: Normalisation results by “Extended CLEAR method” with different P-rpm-maps (red encircled values are lower compared to the normalisation results of the“Standard CLEAR method” (target power pattern))

Almost all normalisation alternatives concerning the trips of both cars don’t deliver a reduction of the standard deviaton and max/min ratio. The normalisation with the “Average_AGG”- map is an exception in case of the BMW 320d (Figure 3-11, max/min ratio: TPP: 2,631 → “Average_AGG”: 2,019).

Based on these results neither a reduction of the max/min ratio of emission values of different trips nor a common correlation factor based on the car specific “WLTC”-map can be identified.

In case of the VW Bus T5 an attempt to improve the normalisation results was to separate the trips in “Ries” - and “Alternative” – route ones. Considering just “Ries” – routes a slight improvement respectively the standard normalisation and the max/min ratio is visible (Figure 5-5: Table 5-1: “Average_NORM”, “Average_AGG” and “Average_ALL”). In case of the trips of the “Alter” – route no improvement is recognisable.

The results and findings are very similar for the Mazda CX5.

Regarding other types of emissions e.g. CO and CO_2 the normalisation tendency is the same like for NO_x (Figure 3-11) for all cars (in chapter 5.3 and 5.4 exemplarily shown for the VW Bus T5).

The analysis of engine speed and its change shows, that additional normalisation over engine speed distribution does not improve the method a lot but would add complexity. As alternative boundaries for rpm distributon may be defined to check if trip is valid.

Following chapter deals with possible boundary conditions regarding the engine speed distribution.

3.4.2 Suggestions for normality boundary conditions

The Δn analysis of 3.4.1.1 already showed that Δn seems to be a suitable quantity to classify trips. In order to derive solid boundary conditions based on Δn a greater amount of cars has to be investigated in order to get representative results.

Alternative boundary limits regarding the engine speed distribution in vehicle specific engine spees bins could be defined. In this case the “WLTC” - P-rpm-map of each car with its specific time shares per engine speed bin would represent the target time share distribution regarding engine speed bins.

Following figures show the shares of time of WLTC tests and trips of different driving styles for the BMW 320d and the VW Bus T5.

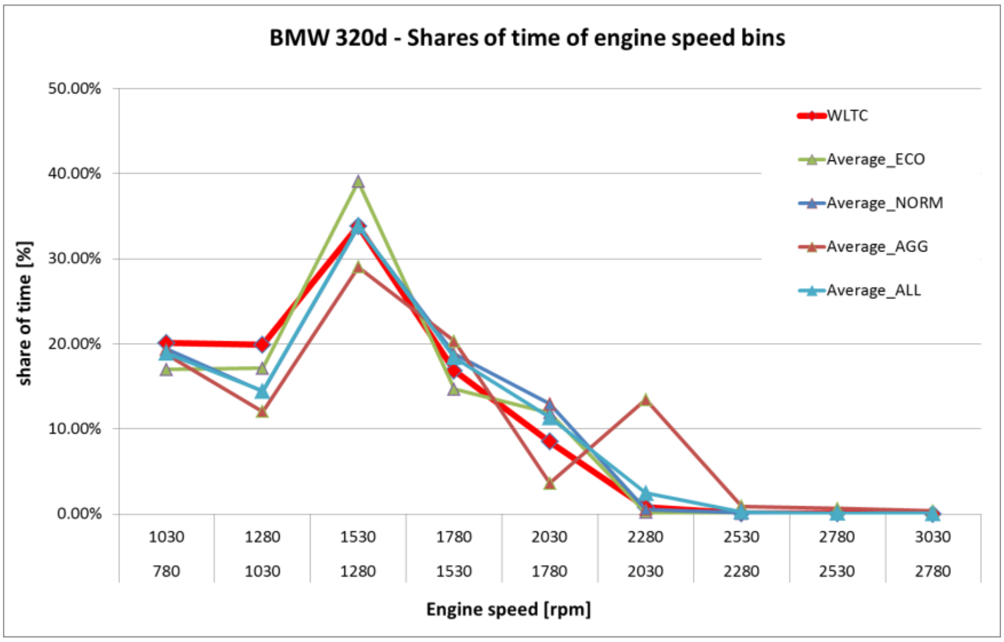


Figure 3-12: Shares of time of engine speed bins regarding several driving styles for BMW 320d

These frequency distributions show the possibility of boundary limits concerning the share of time for each engine speed bin based on the WLTC-engine speed-distribution.

The first approachs is a boundary limit 50% upper and lower than the WLTC frequency distribution values.

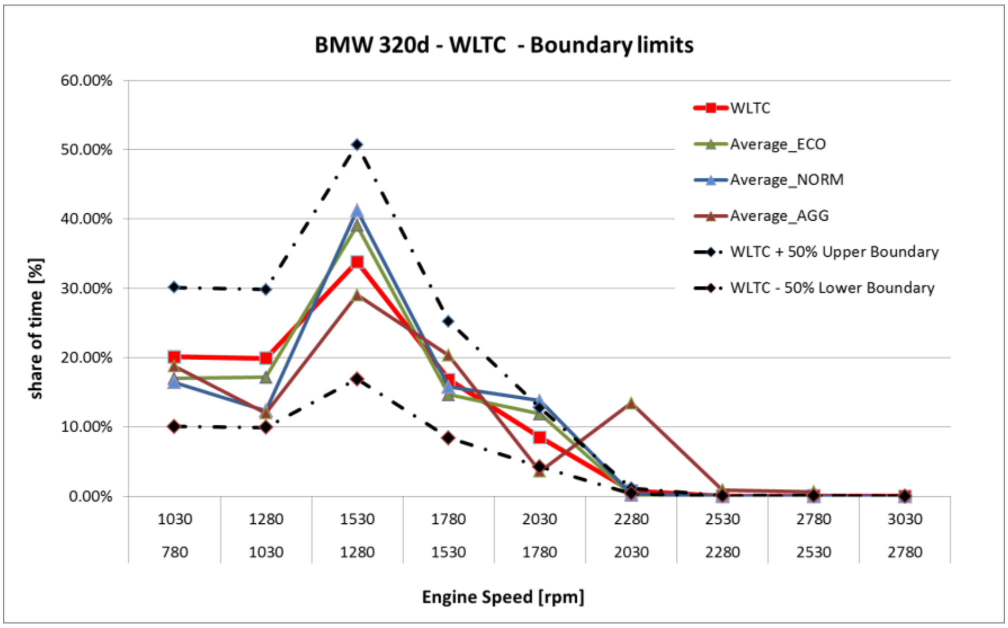


Figure 3-13: Frequency distributions and boundary limits BMW 320d

It seems to work very well concerning the exclusion e.g. of aggressive trips. But at rpm above 2230 already normal trips exceed this WLTC based thresholds. Thus the limits should be lifted in this area.

Considering economic trips the WLTC has a too economic characteristic so almost no difference between those two kinds of trips is visible.

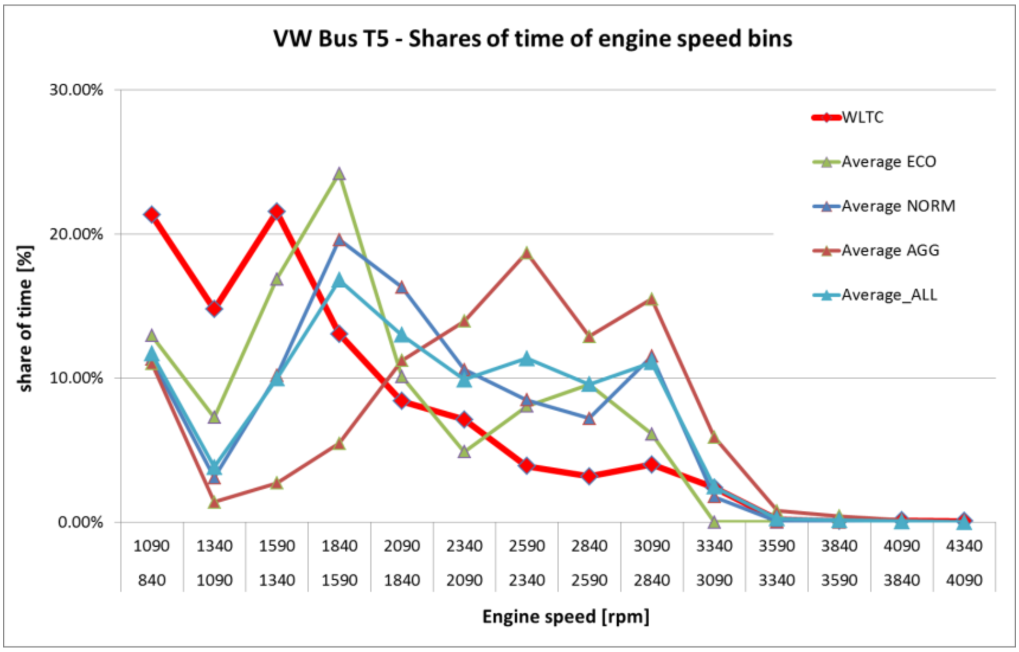


Figure 3-14: Frequency distributions and boundary limits VW Bus T5

In case of these very variable frequency distributions for the VW Bus T5 no suitable boundaries are visible.

3.4.3 Results and conclusion

The analysis of the influence of Δn in 3.4.1.1 showed a quite good correlation of Δn and the NO_x emission level for the Mazda CX5 and the BMW 320d (see Figure 3-3).

Regarding the engine speed a normalisation of the trip emissions with several kinds of P-rpm-maps by the “Extended CLEAR method” does not deliver better weighted/normalised emissions. This shows that the engine speed does not improve the emission normalisation and led to the assumption that the engine speed has a small influence on the emissions of PEMS-tests. Additionally there is no possibility to define appropriate boundary limits respectively the shares of time of several engine speed bins representing ranges, within normal PEMS-trips take place.

This awareness leads to the consideration searching parameters to define PEMS-test normality by some boundaries. These parameters may constrain the driving dynamic of a trip. Appropiate in order to describe the trip dynamics may be the power change ΔP and the quantity RPA (Realtive Positive Acceleration).

Following chapters investigate these two quantities concerning firstly correlations to emissions and secondly possible thresholds based on measurement results of several cars with different drivers and different driving styles have to be tested on several routes.

3.5 Influence of power change ΔP

In this chapter we take a close look at the influence of the dynamics of power over time on emissions of a PEMS measurement test. The weighting of measured trip emissions with the share of times of several power bins (“original” normalisation or “Standard CLEAR method”) works quite well. Considering the formula 3-1 for the power P a power change could appear simplified in three ways:

1. Change of n at constant M,
2. Change of M at constant n or
3. Combination of both variables changing.

$$P = M * \omega = M * 2 * \pi * n \tag{3-1}$$

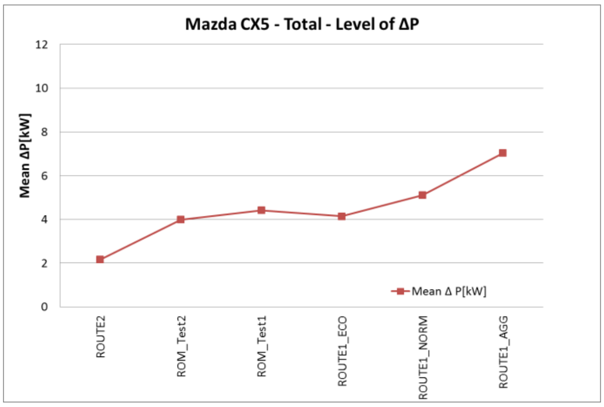
Based on findings in 3.4 emissions are not much influenced by the engine speed and its change. This leads to the assumption that the power change may be a more important driving force in influencing emission formations. And more detailed, if there is almost no influence of the engine speed change on emissions formation the change of torque will be maybe primarily responsible for this formation. In order to get an answer to this assumption several trips have been analysed respectively their power change.

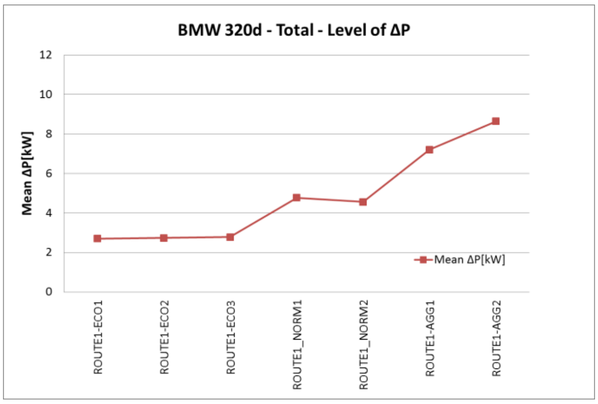
CLEAR evaluates the power change of each trip based on the available power signal, which has been calculated with the Vehicle-Willans-Line approach (see chapter 2.3.2.1). The power signal is averaged over 3 seconds (moving average, like the emission values), so a new power signal of averaged power values is generated. Based on this new signal ΔP for each line i is calculated with P_{i-1}, P_i and P_{i+1}. The method in detail applied by CLEAR is explained in 2.4.2. The evaluated ΔP for each line i is used to calculate an average ΔP for the whole trip henceforth called “Mean ΔP”.

3.5.1 Analysis

3.5.1.1 Correlation investigation of ΔP and NO_x

The same routes and trips like in the engine speed analysis are investigated for the Mazda CX5, the BMW 320d (Route1 trips) and the VW Bus T5 (“Ries”- and “Alter”-route trips). Special concentration lies again on the NO_x emissions of different trips characterized by different driving styles. The “Mean NO_x” emissions of a trip are assigned to the “Mean ΔP” result of the same trip in order to identify a possible dependency of these two quantities. In the first step just the ΔP levels are under investigation. General the total trip is under investigation.





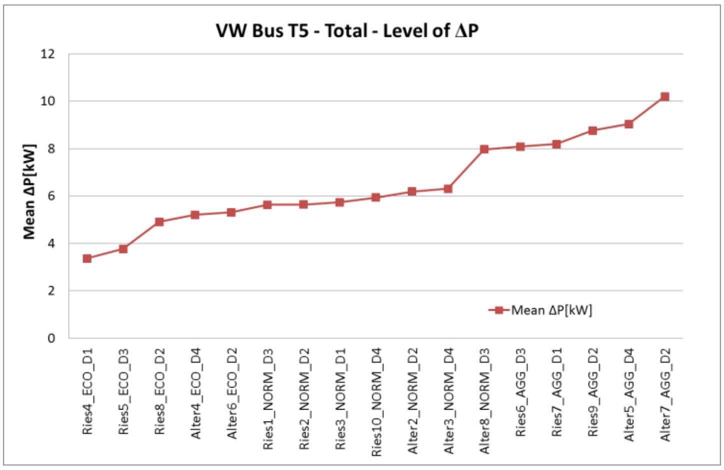
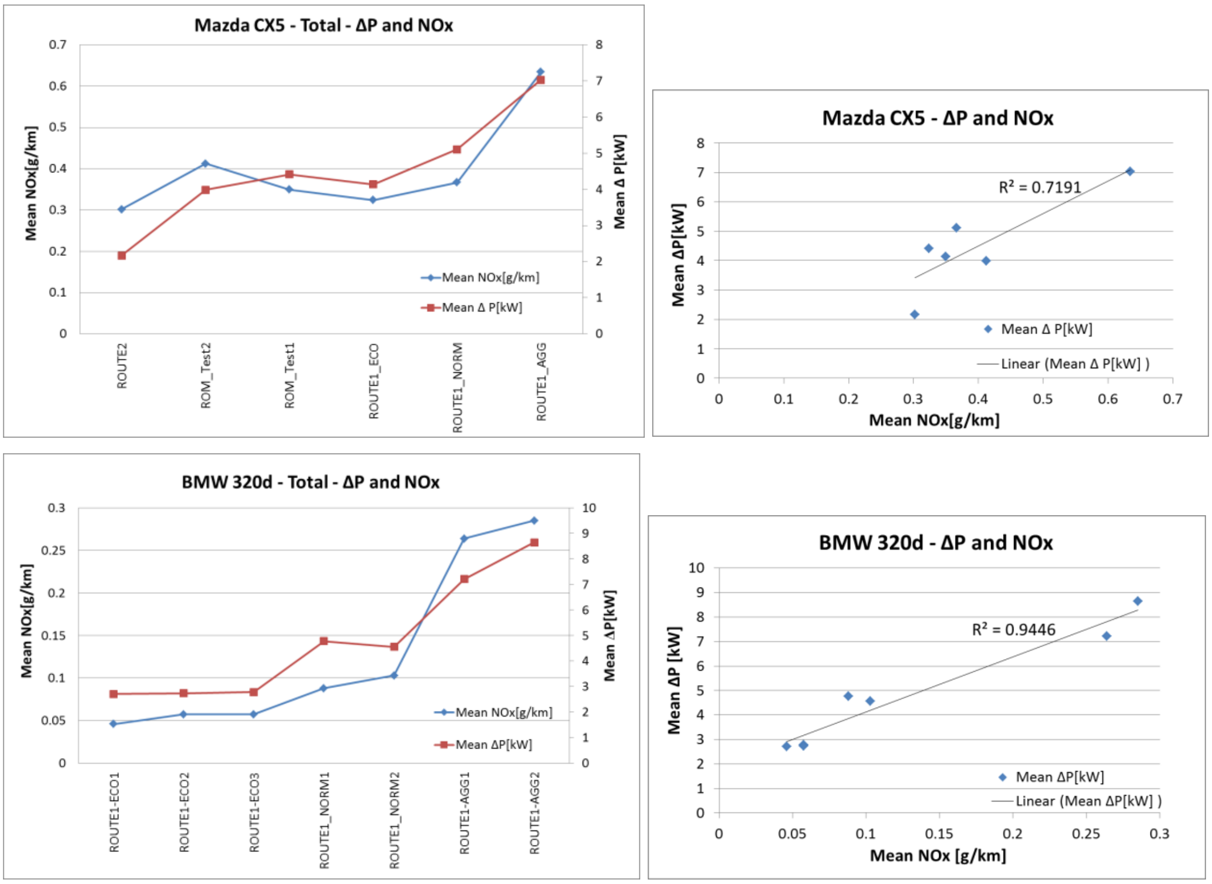


Figure 3-15: ΔP–level for different driving styles for Mazda CX5, BMW 320d and VW Bus T5

For all three vehicles the different level of ΔP indicates that in general $\Delta P_{agg} > \Delta P_{norm} > \Delta P_{eco}$ (Figure 3-15). A detailed investigation of the levels of ΔP of different driving styles and vehicles shows that the level also differs from vehicle to vehicle. This finding makes setting of normality boundaries respectively ΔP possible.

The following figure shows the “Mean NO_x” and “Mean ΔP” for several trips for each vehicle on the left side of the illustration. Right aside the correlation and the coefficient of determination for both values is shown.



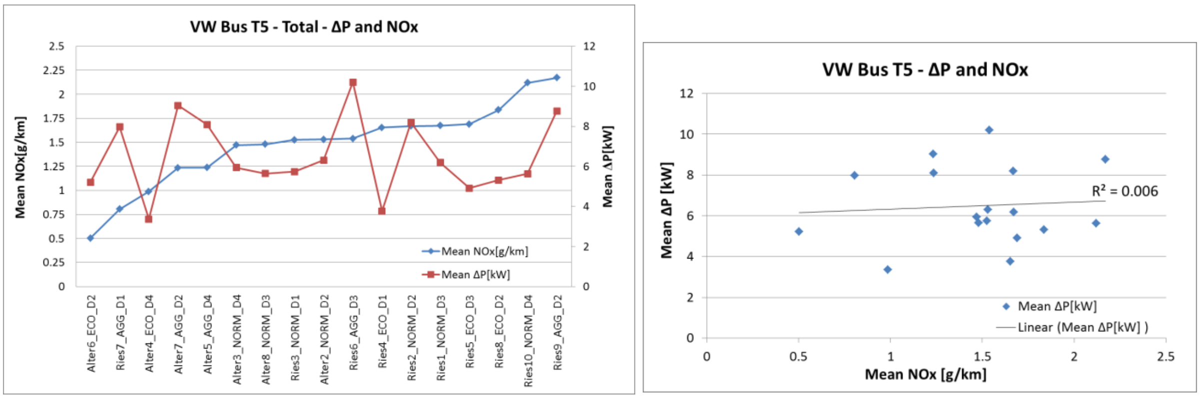


Figure 3-16: ΔP of each trip and appropriate NO_x emissions and coefficient of determination for Mazda CX5, BMW 320d and VW Bus T5

For the Mazda CX5 and the BMW 320d a quite good correlation between the NOx emissions and ΔP is visible in Figure 3-16. High ΔP of an aggressive trip indicates high NO_x emissions and low ΔP indicates low NO_x emissions. In case of the VW Bus T5 there is no correlation visible. A separate consideration of the “Alter”- and “Ries”-routes of the VW Bus shows a slightly better correlation (Figure 3-17). It is also visible that the NO_x emission level of the “Ries”-route trips is by trend higher than the NO_x emission level of the “Alter”-route trips.

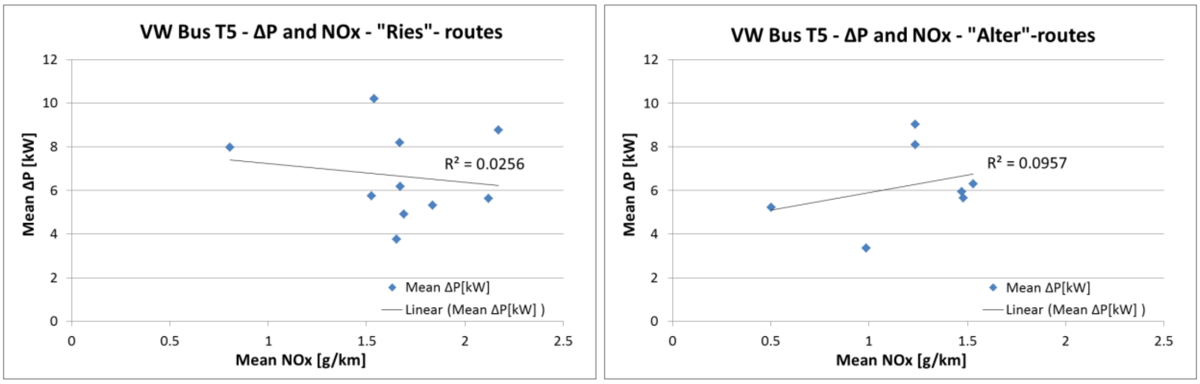


Figure 3-17: Splitted route consideration for VW Bus T5

Especially the results for the VW Bus T5 are unexpected. So it might be interesting to find out what is responsible for the ΔP change? Maybe it is possible to identify whether ΔP is more influenced by ΔM or Δn depending on the vehicle. For this analysis it is usefull to compare the NO_x- emission maps of all three cars of trips with the same driving style.

Following figure shows the NO_x-emission maps of the BMW 320d of “Route1_ECO1”, “Route1_NORM1” and “Route1_AGG1”(NO_x-emission maps for Mazda CX5 Figure 5-8). The first visible difference compared to the NO_x-emission maps of the VW Bus T5 (Figure 3-7, Figure 3-8) is that the used engine speed range is for the Mazda CX5 and the BMW 320d much smaller. Considering the denormalised used engine power range of different trips of both cars, the ΔP-range is similar. Nevertheless the VW Bus due to its low power-to-weight ratio and lower maximal available torque compared to the BMW will deliver his power possibly by a usage of a wider range of engine speed. It is also visible that in generall the NO_x-level of the BMW 320d is much lower compared to the NO_x-level of the VW Bus T5. This is also caused by the fact that the BMW has a NSC installed and the VW Bus not. But nevertheless in case of the Mazda CX5 and the BMW 320d there is a tendency respectevily the difference of driving style specific NO_x-level visible. As expected, an aggressive declared trip moves in regions of higher NO_x-emissions of the NO_x-maps and inverse.

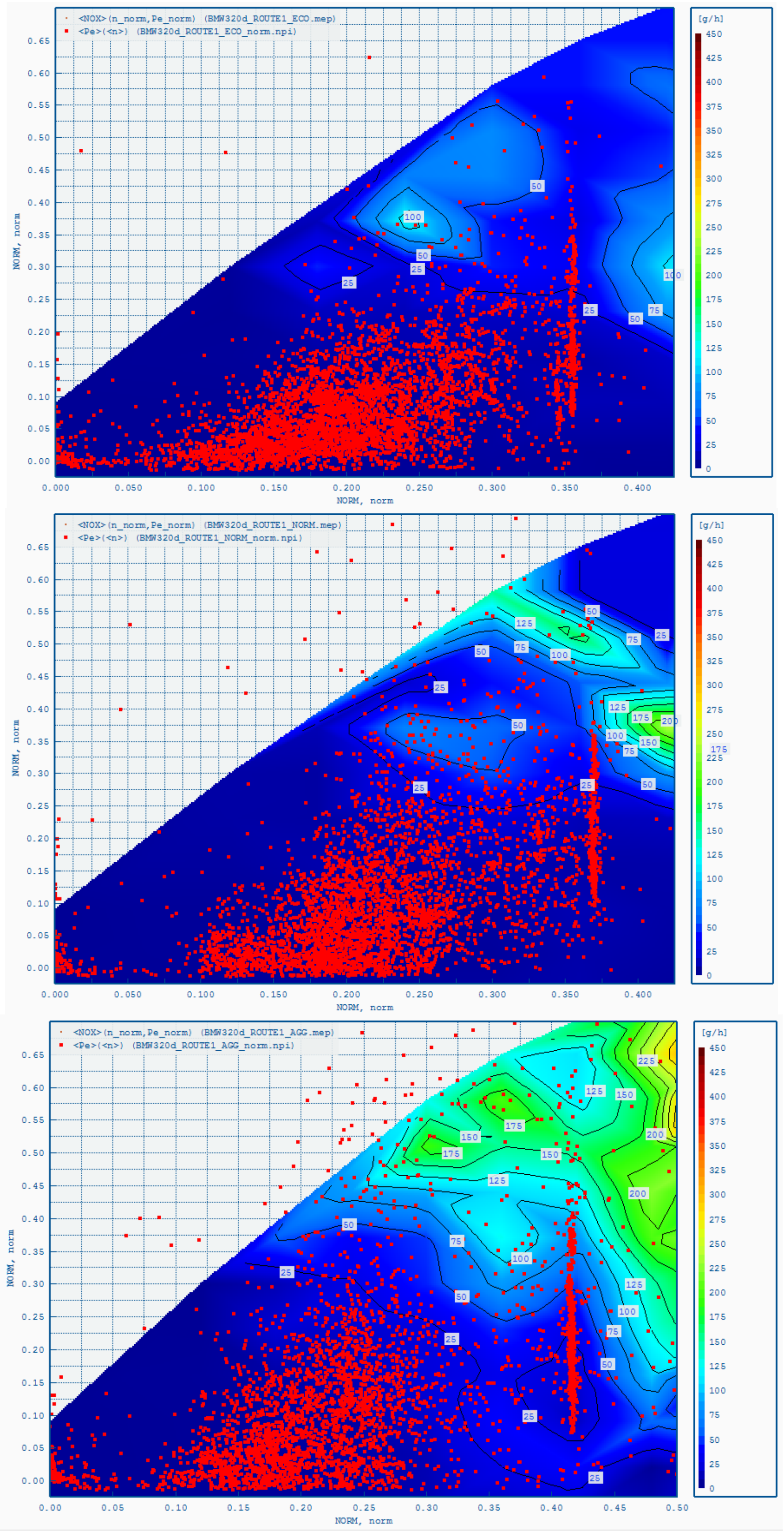


Figure 3-18: Trip specific NOx-emission maps of the BMW 320d of "Route1_ECO1", "Route1_NORM1" and "Route1_AGG1 (blue: low NO_x-emissions, red: high NO_x-emissions [g/h])

3.5.1.2 Correlation investigation of ΔP and CO_2

High ΔP caused by an aggressive driving style is reached by a high energy input. The energy input corresponds to the amount of gasoline used, which is dissipated to CO_2 and other combustion products (chemical stored energy is dissipated to kinetic energy). So the expectation is that a high energy input will cause high CO_2 emissions. Following figure illustrates possible correlations between "Mean ΔP" and "Mean CO_2" for different vehicles and trips.

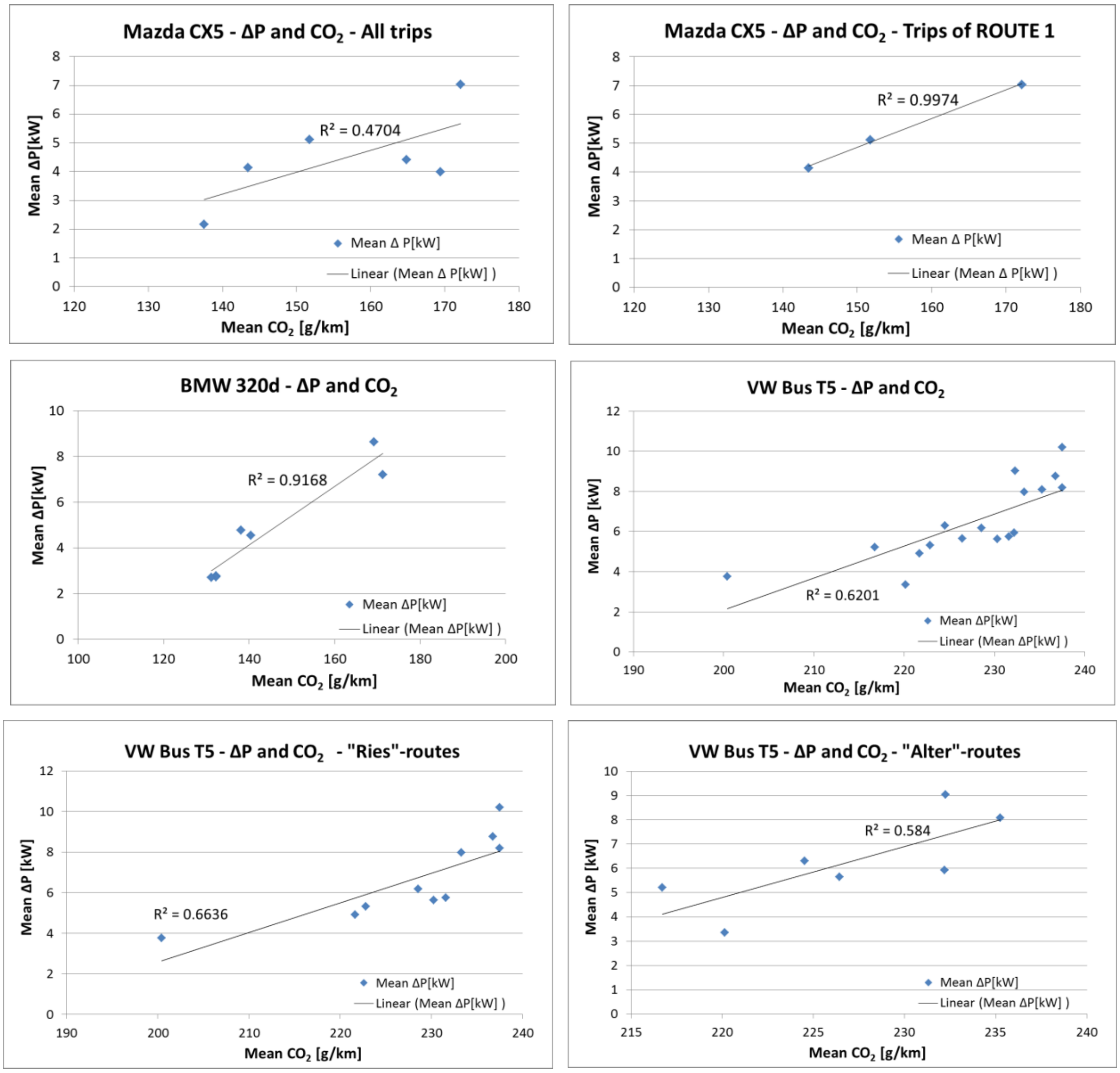


Figure 3-19: Correlation of "Mean ΔP" and "Mean CO_2" emissions for Mazda CX5, BMW 320d and VW Bus T5

In case of the BMW 320d the correlation result is as expected and quite good (Figure 3-19). Considering the VW Bus also a correlation can be spotted, but some deviations cause a correlation, which is not as good as expected. In case of the Mazda CX5 considering all trips (ROUTE1_ECO, ROUTE1_NORM ROUTE1_AGG, ROUTE2, ROM_Test1, ROM_Test1) the correlation is not as good as expected. But if you concentrate just on the trips driven on "ROUTE1" (ROUTE1_ECO, ROUTE1_NORM, ROUTE1_AGG) a quite good correlation can be seen. Seperating the routes of the VW Bus in "Ries"- and "Alter"-routes, for the "Ries"-routes a slight improvement of the coefficient of determination is visible. But nevertheless the correlation between ΔP and CO_2 of the VW Bus is not as good as it is like in case of the BMW and the Mazda CX5 (Figure 3-19).

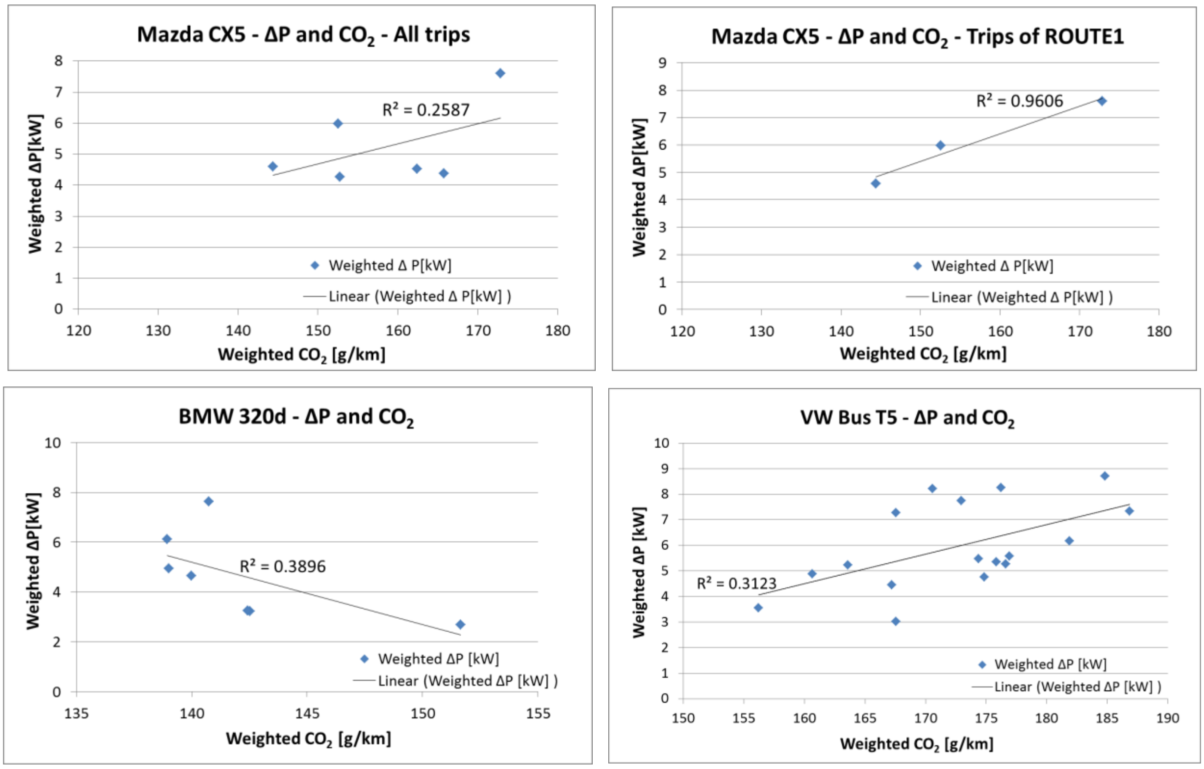


Figure 3-20: Correlation of “Weighted ΔP” and “Weighted CO_2” for Mazda CX5, BMW 320d and VW Bus T5

Considering a possible correlation between the weighted CO_2 emissions and the weighted ΔP in Figure 3-20, a slightly worse correlation can be seen at all three vehicles. The weighting of the CO_2 emissions with the shares of time of the target-power-pattern (“Standard CLEAR method”, results can be seen in 5.4) diminishes the influence of the trip different absolute used power and delivers for all trips almost the same value for the weighted CO_2 emissions. So a worse correlation between the weighted values of ΔP and CO_2 shows that the CO_2 emissions are mainly influenced by the absolute used power. This finding can be supported by some considerations, e.g. can you have a high ΔP indicating an aggressive trip and low CO_2 emissions, if the driver breaks hard and often at the declines on a route. On the other hand considering a given period a constant small acceleration for a considered period may cause more CO_2 emissions than a short big acceleration at the beginning and constant driving till the end of the period.

But nevertheless ΔP is a good quantity to indicate different types of driving styles and allows it maybe to define sufficient limits for further trip validation. Following chapter deals with possible boundary conditions for ΔP.

3.5.2 Suggestions for normality boundary conditions

The approach is to define boundary conditions for ΔP, which represent a range within the ΔP of a normal driven PEMS-test is allocated. Too economic and too aggressive driven trips would be lower or higher then these limits and for this reason not valid. In order to get significant results, the ΔP values of several cars with different driving styles on different routes have been evaluated. The comparison of the ΔP- level of different cars and trips shows that the ΔP level differs depending on the vehicle (Figure 3-21). For this reason a good approach is to consider vehicle specifications in order to define boundary conditions regarding ΔP.

Additional to the Mazda CX5, BMW 320d and the VW Bus T5 three more vehicles (Veh02, Veh03 and Veh04) are investigated concerning ΔP in order to deliver a high variability and to define appropriate limits.

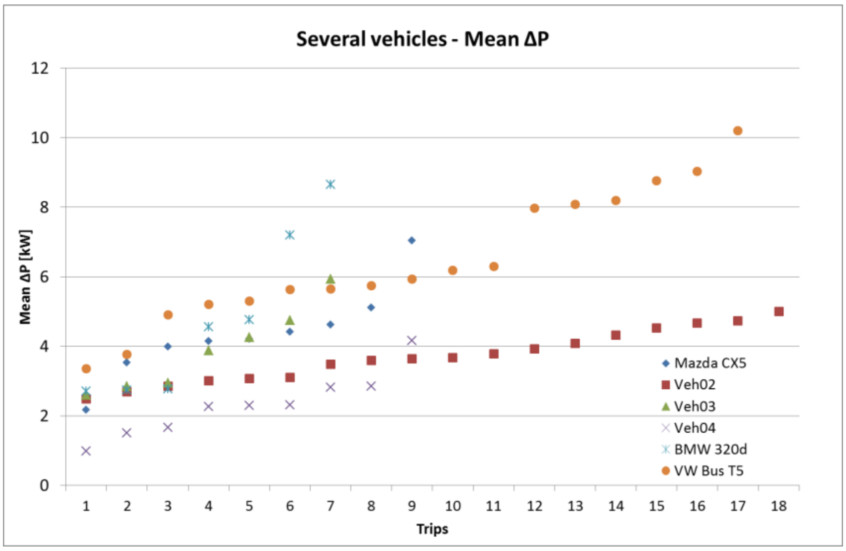


Figure 3-21: Δ P of several vehicles with different driving styles for a total trip sorted by value (Mazda CX5, BMW 320d, VW Bus T5, Veh02, Veh03, Veh04)

Following chapter deals with the results of different normalisation possibilities regarding ΔP.

3.5.2.1 Power change normalisation

The basic idea of the power change normalitstion is to eliminate the influence of the vehicle on ΔP in order to identify the influence of the driver and the route and further to establish a possible categorization of trips by their driving style in a general valid way. In chapter 2.4.2.1 several calculation approaches regarding the ΔP normalisation are explained in detail. Following chapters investigate the normalisation results for the six vehicles and compare them to eachother. Important quantities for the normalisations are listed in table Table 3-5.

Table 3-5: P_{drive} and P_{rated} for several vehicles

	Mazda CX5	Veh2	Veh3	Veh4	BMW 320d	VW Bus T5
P_{drive} [kW]	18.25	21.27	24.58	13.45	19.17	25.73
P_{rated} [kW]	109	103	180	48	135	84

3.5.2.1.1 Normalisation N_1, N_2, N_3, N_4 and N_5

Several attempts regarding the power change normalisation were made. Following figures show the results of the different normalisation approaches N_1, N_2, N_3, N_4 and N_5.

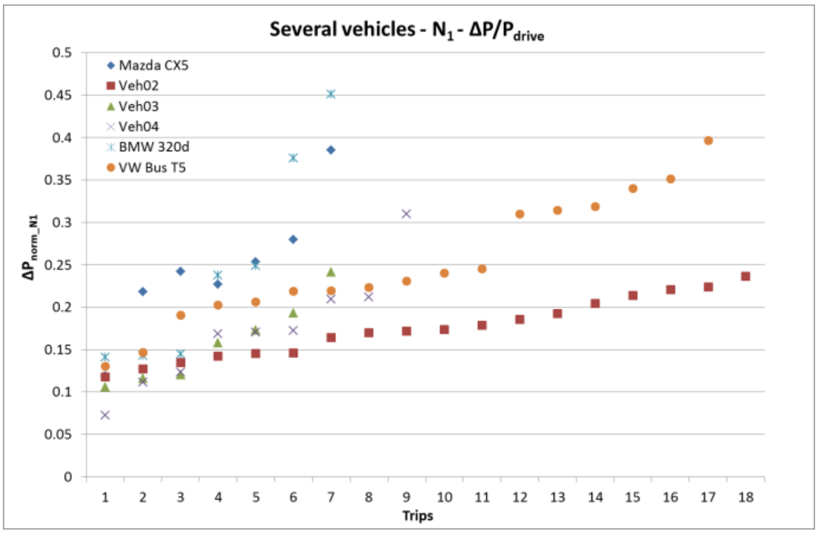


Figure 3-22: ΔP normalisation results N_1 for several vehicles

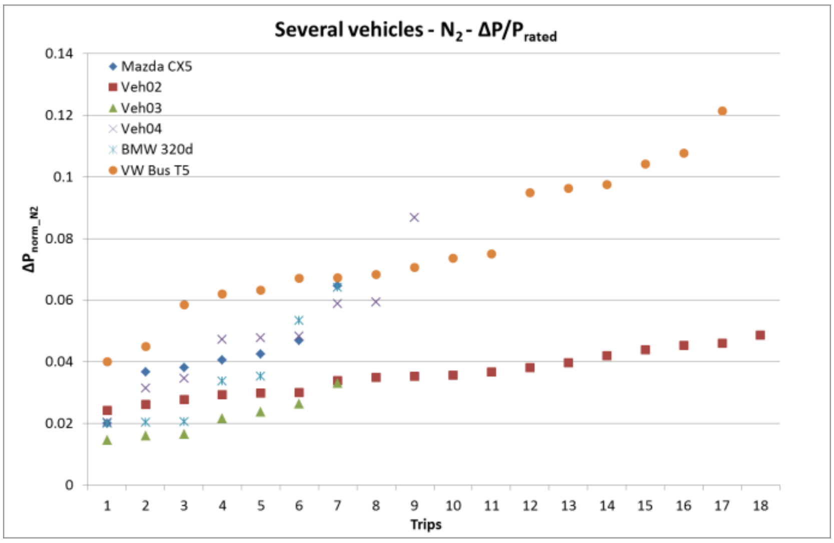


Figure 3-23: ΔP normalisation results N_2 for several vehicles

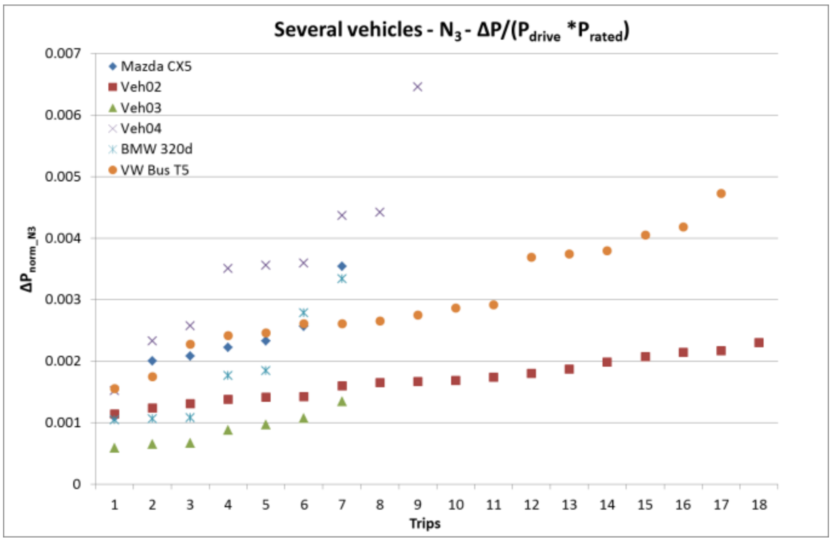


Figure 3-24: ΔP normalisation results N_3 for several vehicles

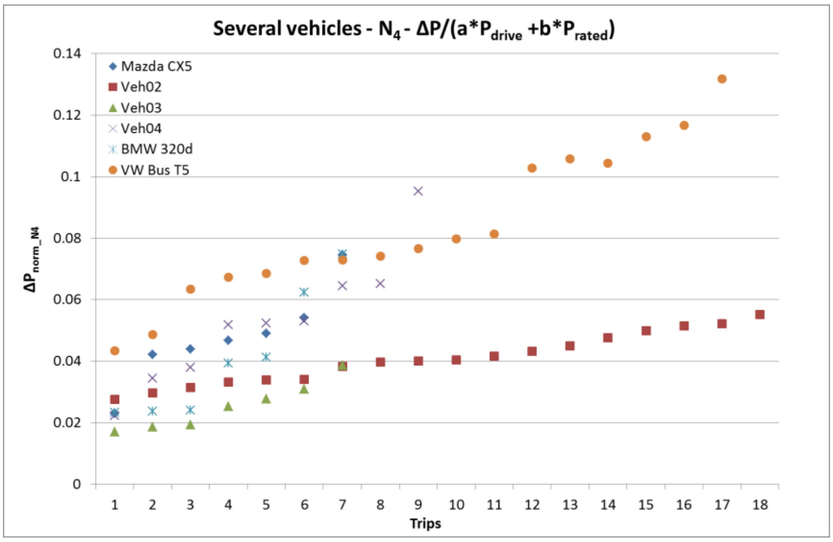


Figure 3-25: ΔP normalisation results N_4 for several vehicles (a=0.8, b=0.4)

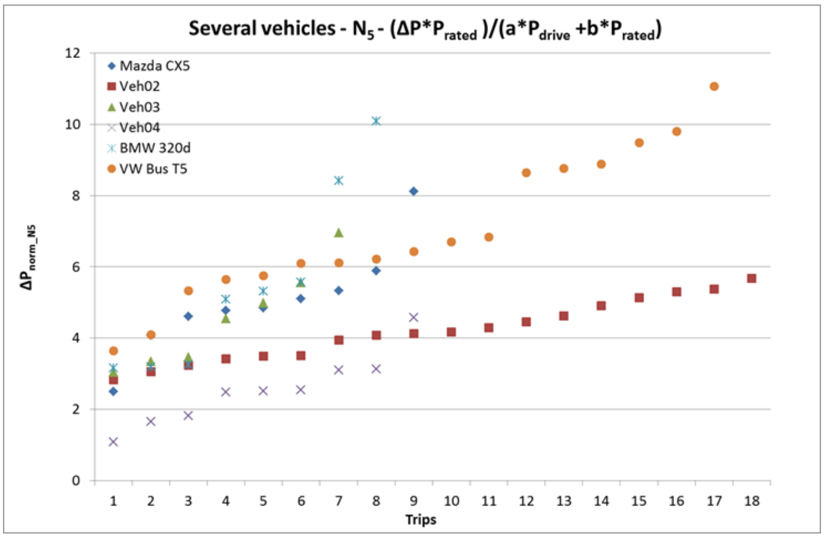


Figure 3-26: ΔP normalisation results N_5 for several vehicles (a=0.8, b=0.4)

Most normalisations show a decline of the variance of the normalised ΔP values - means the normalised ΔP values of different vehicles get closer together. Normalisation N_1, which uses the vehicle specific P_{drive} in order to normalise the trip specific ΔP, shows good results regarding the power change normalisation of the different vehicles' trips in order to identify a driving style. It is also a quite simple approach compared to the normalisation N_4 and N_5. At these two normalisations the size of the coefficients 'a' and 'b' has to be choosen, which brings additional variability into the normalisation. In order to investigate these two normalisation regarding their capabilities quite well, much more vehicles shoud be tested. So e.g. especially ΔP_{norm_N5} values of vehicles with a low P_{rated} (Veh4) are on a much lower level compared to the other normalised power change values which makes it difficult to define general boundaries. In case of the normalisation N_1 the variation between the normalised ΔP levels is small compared to the other normalisations. For this reason further boundary investigations regarding the ΔP concentrate on the normalisation approach N_1.

3.5.2.2 Suggestions forΔP boundary conditions based on P_{drive}

A suitable quantity that accounts for vehicle specifications is P_{drive} (Equation 2-4). Here the vehicle mass and vehicle specific road loads are taken into account. The idea is that each trip- and vehicle-specific ΔP_{veh} is going to be normalised by P_{drive}. This normalisation makes the vehicle specific ΔP_{veh} comparable to other vehicles and may lead to a general $\Delta P_{norm\_upper\_boundary}$ and $\Delta P_{norm\_lower\_boundary}$, which could be applicable boundaries for all vehicles.

Following equation shows the calculation rule for ΔP_{norm}:

$$\Delta P_{norm} = \frac{\Delta P_{veh}}{P_{drive\_veh}} \qquad 3\text{-}2$$

First ΔP_{norm} is calculated for several cars by division of ΔP_{veh} with the vehicle specific P_{drive} (Equation 3-2). Due to the normalisation of the trip- and vehicle-specific ΔP_{veh} with vehicle specific P_{drive} (Figure 3-27) the trip- and vehicle-specific ΔP_{norm} levels allow suggesting an upper and lower boundary, a general $\Delta P_{norm\_upper\_boundary}$ and $\Delta P_{norm\_upper\_boundary}$.

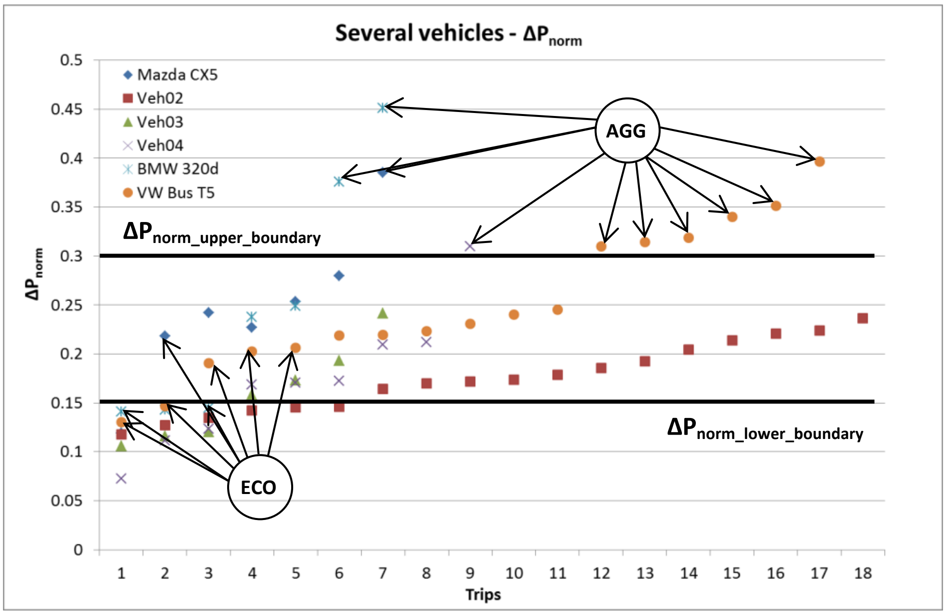


Figure 3-27: ΔP_{norm} of several vehicles with different driving styles for total trip (Mazda CX5, BMW 320d, VW Bus T5, Veh02, Veh03 and Veh04)

The results for ΔP_{norm}- boundaries based on the investigated vehicles are shown in Table 3-6.

Table 3-6: Possible ΔP boundaries

	lower_boundary	upper_boundary
$\Delta\ P_{norm}$	0.15	0.3

In general the sample should be enlarged by a bigger amount of vehicles with different kinds of driver, driving style and route combinations to proof the validity and to get more resilient boundary values for ΔP from the statistical point of view.

3.5.3 Results and conclusion

Overall the sample should be enlarged in order to get resilient thresholds for ΔP. But nevertheless the suggested ΔP thresholds deliver in some cases acceptablbe results for PEMS-test validation. E.g. $\Delta P_{norm\_upper\_boundary}$ works very well regarding the identification of aggressive driven trips of the Mazda CX5, BMW 320d and the VW Bus T5 (Figure 3-27). Considering the lower boundary in matters of these examined vehicles, some trips are identified as economically driven (all economic trips of the BMW 320d and almost all in case of the VW Bus T5) and some not (Mazda CX5). So in case of the BMW 320d all driving styles are correctly identified. Respectively the other cars, the ΔP_{norm}- boundary criterion will not work as good as at the BMW. This may be due to the route specifc effects on ΔP, which are not known yet.-

Considering the BMW this method seems to be a sufficient tool to identify driving styles and further check the validity of a PEMS-test. A disadvantage of this validation method might be that a high-quality power signal is required. This signal can be either measured during a PEMS-test at the wheel hubs in order to get the power at the wheels, which is very costly, or calulcated with a measured CO_2-signal by the Vehicle-Willans-Lines approach as described in 2.3.2.1.

For this reason another kinematik parameter which describes the dynamic of a trip in order to check its validity will be advantageous. A well known quantity in this field is the trip-specific RPA-value (detailed explanation see chapter 2.4.3). Following chapter deals with the detailed analysis of this quantity regarding correlations and possible trip dynamic boundaries.

3.6 RPA

Besides the possibility to validate a trip by its specific ΔP, the kinematic parameter RPA (Relative Positive Acceleration), also known as the positive acceleration “work” in relation to the distance covered of a trip (see equation 2-15), may be applicable for trip validation, too. The general approach is to identify the style of a trip by evaluation of its dynamic with RPA.

RPA is a quantity, which does not directly include vehicle specifities in the calculation formula (2-15) like e.g. the vehicle weight. But nevertheless the size of the RPA value is influenced by the vehicle specific power-to-weight ratio (Figure 3-28) E.g in case of a car with a low power-to-weight ratio (VW Bus T5) the higher the acceleration is, a relative higher ΔP is necessary compared to a car with a high power-to-weight ratio. So in general the RPA value doesn’t represent the actual needed wheel power and therefore maybe does not correlate as well as ΔP to the emissions.

In order illustrate the influence of the vehicles’ weight, Figure 3-28 shows the RPA and ΔP values of examined vehicles of different trips. Comparing the ΔP levels at a same RPA-value of different cars, a heavy car like the VW Bus T5 (m=2001kg, without PEMS-test measurement equipement) has a much higher mean ΔP to achieve the same acceleration like a lighter one e.g. the BMW 320d (m=1530kg, without PEMS-test measurement equipement).

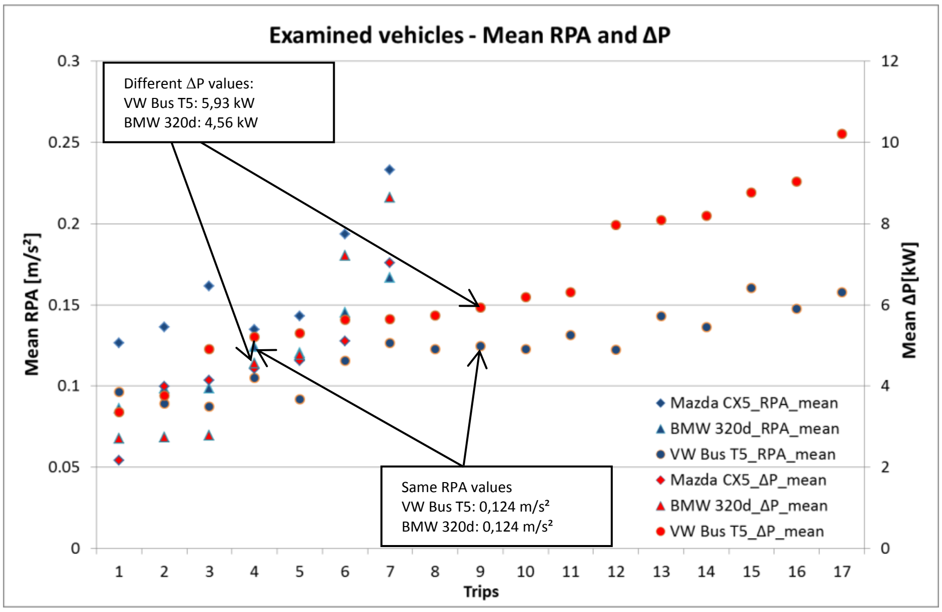


Figure 3-28: Total mean RPA and ΔP for Mazda CX5, BMW 320d and VW Bus T5 for different routes and different driving styles sorted by value ΔP

The correlation for the model case encircled above in Figure 3-28 can be shown by equation 2-4 for $P_{drive.}$ The assumption is that “v” and “a” for both cars (indices: 1=BMW 320d and 2=VW Bus T5) is the same. Beside these two quantities the vehicle mass and the road load coefficients R_0, R_1 and R_2 deteremine P_{drive}. This interrelationship is also valid for ΔP.

$$\frac{P_{drive\_2}}{P_{drive\_1}} = \frac{25{,}73kW}{19{,}17kW} = 1{,}34 \qquad \frac{\Delta P_2}{\Delta \mathrm{P}_1} = \frac{5{,}93kW}{4{,}56kW} = 1{,}30 \tag{3-3}$$

As can be seen in the equation 3-3 above the ratio of the average ΔP value and the ratio of the P_{drive} for BMW 320d and the VW Bus T5 are almost the same.

Following chapter compares two possible RPA evaluation methods. The first method evaluates the “Mean RPA” value like described in chapter 2.4.3. The second approach is to calculate the RPA value for each powerbin and weight each value with the appropriate share of time of the target-power-pattern (“Standard CLEAR method”) – “Weighted RPA”. In both cases the total trips are analysed and the RPA values are sorted by value of “Mean ΔP” or “Weighted ΔP”.

3.6.1 Analysis

3.6.1.1 Method comparison “Mean RPA” and “Weighted RPA”

In order to get a better overview, this comparison concentrates on the three examined vehicles of this thesis (Mazda CX5, BMW 320d and VW Bus T5)

Figure 3-29 on the right sight shows for the VW Bus and for the BMW that the CLEAR-method weighting the ΔP works quite well – the ΔP max/min-ratio is at the weighted figure smaller than at the mean one on the left side. Conspicuous is the aggressive trip of the Mazda CX5, where the ΔP value is enhanced. It could be that the averaged ΔP value of high power bins is build just by a few values located within this bin. For this reason it may be that the weighted ΔP results are slightly higher than the mean ones. The same phenomenon is visible for the RPA value. In case of the VW Bus and the BMW the RPA values of aggressive trips are lowered.

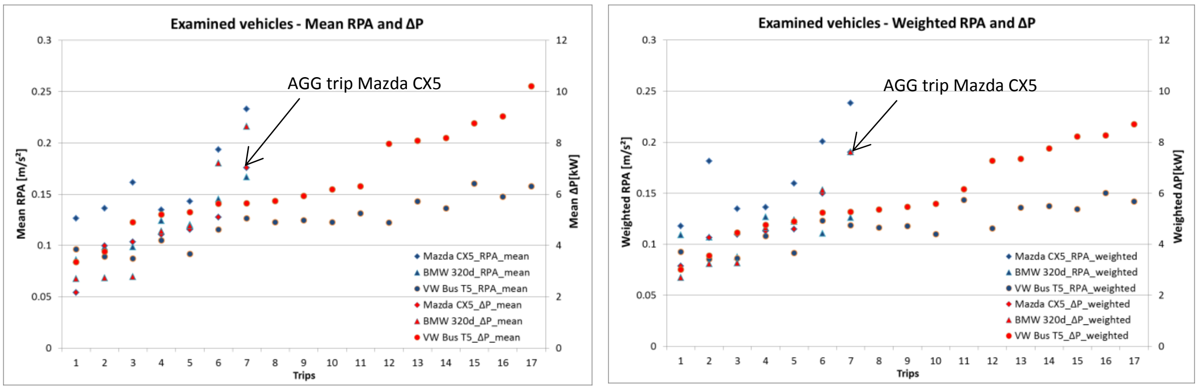


Figure 3-29: Total “Mean”- and “Weighted”- RPA and ΔP for Mazda CX5, BMW 320d and VW Bus T5 for different routes and different driving styles sorted by value ΔP

The application of the CLEAR-method modifies the real trip specific RPA value, which is especially in case of aggressive (values are lowered or sometimes enhanced) and economic (values are enhanced or sometimes lowered) trips not desireable for future trip validation. For this reason further investigations regarding dynamic boundaries based on RPA values are made with the “Mean RPA” calculated with the method explained in chapter 2.4.3.

Following chapter investigates possible correlations regarding mean RPA and emissions.

3.6.1.2 Correlation investigation of RPA and NO_x

The following investigations try to identify a correlation between the averaged NO_x emissions and the RPA value of a trip. In order to derive a profound statement regarding a possible correlation several trips with different kinds of driving styles for all three cars have been investigated. The expectation regarding this correlation between NO_x and RPA is that it is not quite as good as the correlation of ΔP and NO_x because of the mentioned reason before.

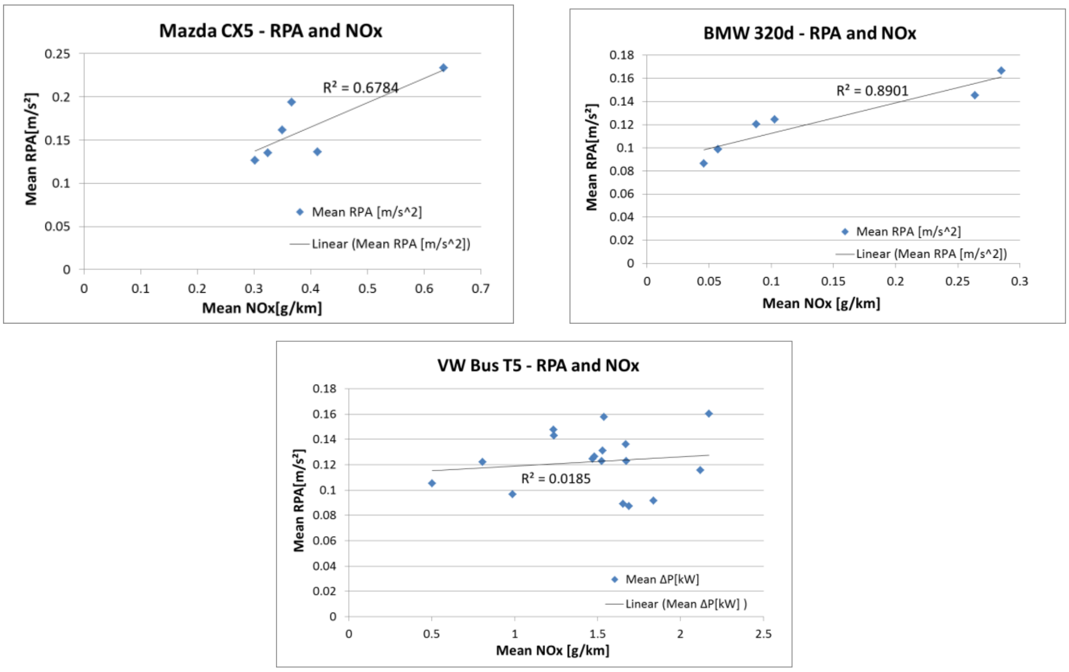
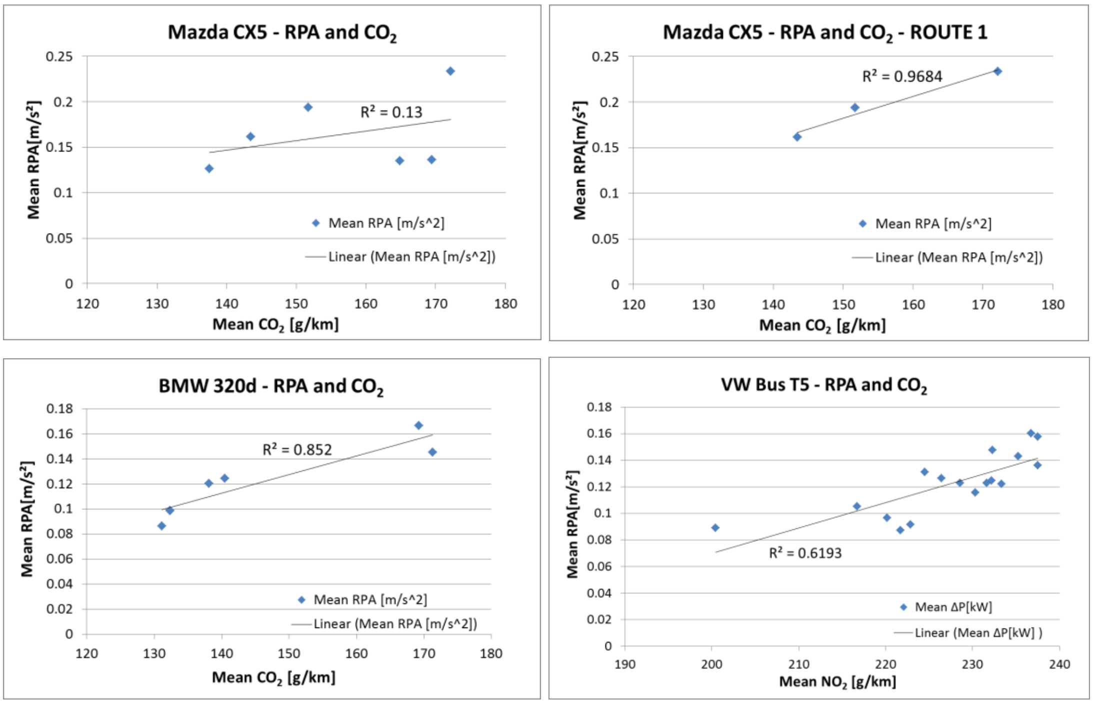


Figure 3-30: Correlation of RPA and NO_x for Mazda CX5, BMW 320d and VW Bus T5

In fact the correlation is not quite as good as the in case of ΔP and NO_x Figure 3-30 shows for the BMW 320d a quite good correlation between RPA and NO_x. The same effect can be seen for the Mazda CX 5. For the VW Bus T5 the coefficient of determination gets slightly better, but stays at very low level where almost no correlation can be identified.

3.6.1.3 Correlation investigation of RPA and CO_2

Regarding the correlation of RPA and CO_2 similar behaviour like in case of the ΔP and CO_2 is expected. Trips characterized by a high RPA value may cause high CO_2 emissions and inverse. The following figure shows the correlation between RPA and CO_2 for different cars driven with different driving styles on different routes.



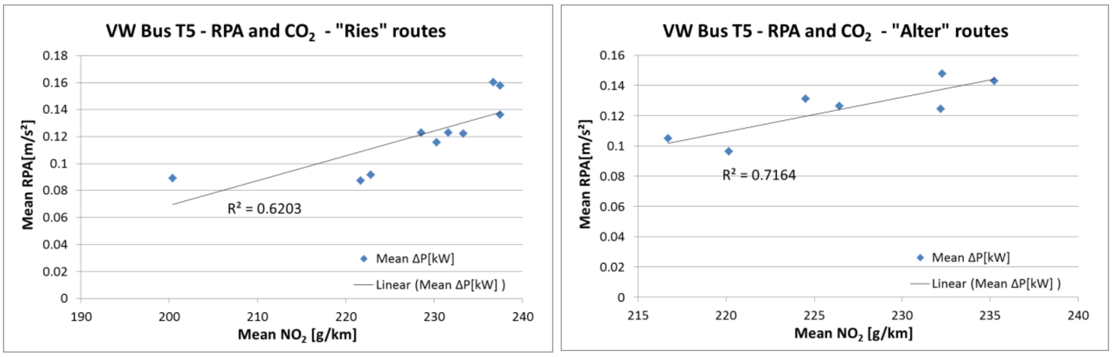


Figure 3-31: Correlation of RPA and CO_2 for Mazda CX5, BMW 320d and VW Bus T5

In case of the BMW 320d the correlation is quite good. In case of the Mazda CX5, when we concentrate just on “ROUTE1”-trips, the correlation is very good. The VW Bus T5 shows a good correlation regarding all trips and the different consideration of the trips separated by the two routes. Nevertheless all coefficients of determination are in this case by trend lower compared to those of the ΔP and CO_2 correlations.

3.6.2 Suggestions for normality boundary conditions

Respectively an overall relative good correlation of RPA with different kinds of emissions of trips with different driving styles, RPA is an adequate parameter to describe the dynamic of a trip. Furthermore it may be possible to identify the driving style of a trip with the RPA value of the trip. If it is applicable for driving style identification, it will be possible to define an upper and a lower limit for RPA values. These limits can represent a range for the RPA value of a valid PEMS-trip.

In order to derive maintainable limits, additional to the examined vehicles of this thesis the PEMS-trips of three more vehicles were analysed concerning the trip specific RPA value. The more vehicles, the higher is the variability and the better is the basis to derive applicable thresholds for RPA from the statistical point of view.

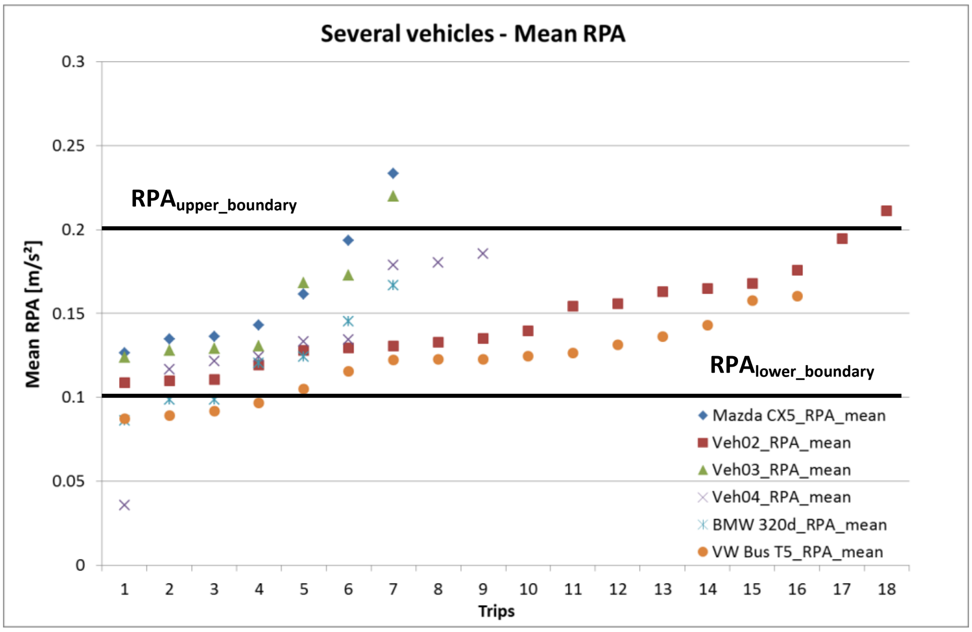


Figure 3-32: Mean RPA of different vehicles sorted by value and boundary suggestions

Considering the “Mean RPA” values of Figure 3-32 for different vehicles the first finding is that the level and the absolute range of the RPA values differs from vehicle to vehicle and is for the VW Bus by trend the smallest one (Table 3-8). This may cause difficulties regarding a general definition of RPA boundaries. But nevertheless based on Figure 3-32 possible RPA thresholds for further PEMS-trip validation respectively the driving dynamic may be as shown in Table 3-7**:** Thresholds for trip validation with RPA

Table 3-7: Thresholds for trip validation with RPA

	lower_boundary	upper_boundary
RPA [m/s²]	0.1	0.2

3.6.3 Results and conclusion

Due to the fact that the “Mean RPA” value differs from vehicle to vehicle (the power-to weight ratio is a driving force for the size of this quantity) and the definition of overall valid thresholds for an upper and lower RPA level seems to be difficult, further investigations may concentrate on vehicle or vehicle class specific RPA boundaries.

An interesting finding regarding vehicle class specific boundaries may disclose following consideration. Here the concentration lies on the ratio of Max/Min RPA values and the vehicle specific power-to-weight ratio. Regarding the Max/Min ratio of all examined vehicles it is almost the same value (Table 3-8).

Table 3-8: Max/Min ratio for RPA-values of different vehicles

	Mazda CX5	Veh 2	Veh3	Veh4	BMW	VW Bus T5
Min RPA [m/s²]	0.124	0.108	0.124	0.110	0.086	0.087
Max RPA [m/s²]	0.233	0.211	0.220	0.186	0.166	0.160
Δ(Max,Min)	0.109	0.103	0.096	0.076	0.080	0.073
Max/Min ratio	1.88	1.95	1.77	1.70	1.93	1.84
Power-to-weight ratio [kW/kg]	0.074	0.060	0.0978	0.047	0.088	0.042

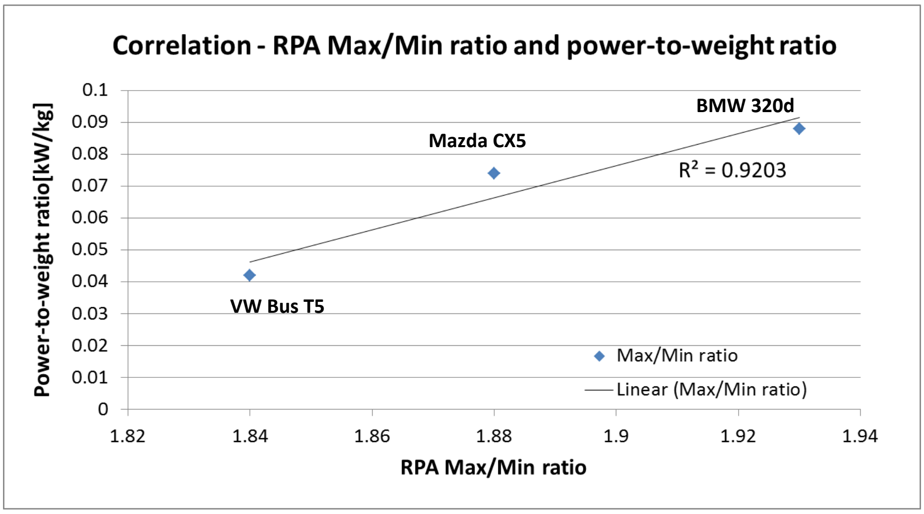


Figure 3-33: Correlation of RPA Max/Min ratio and power-to-weight ratio

Considering the Mazda CX5, BMW 320d and the VW Bus a relative good correlation between the Max/Min-ratio and the power-to-weight ratio is visible (Figure 3-33).

Maybe based on these findings possible vehicle class specific “Mean-RPA” values could be found. The range (above and below the “Mean-RPA” value) for valid trips may be calculated based above the explained correlation of “Power-to-weight ratio” and “RPA Max/Min ratio” for each vehicle.

In order to check if this approach is possible many vehicles of different vehicle classes will have to be investigated in order to get reliable values from the statistical point of view.

4 Conclusion and outlook

Overall the investigations and results of this thesis regarding the emission normalisation and and possible driving dynamic parameters, which should represent boundaries for normal driving, showed that the topic of actual RDE investigations to identify and eliminate the drivers and route influence on the emission measurement during PEMS-Test is very complex.

The results of this thesis confirmed that the emissions are very much influenced by the driver and the route and for this reason future investigation regarding PEMS-tests will have to concentrate on possibilities to diminish these influences. The results of the PEMS-tests should represent the actual and real vehicle performance regarding the emission level without being falsified by several circumstances like the driver or the route. Investigations in this thesis concerning the influence of the engine speed on emissions indicated less dependency between those two quantities than expected. The proof was brought by the try of an additional normalisation of emissions with P-rpm-maps, which showed no or just few improvement of the emission level of trips with different driving styles. ΔP showed adequate results in order to constrain the driving dynamic of a trip by normalised thresholds.These suggested thresholds are part of latest discussions concerning a legal text for the future WLTP. The RPA quantity on the other hand showed difficulties in deriving general valid thresholds. The power-to-weight ratio is very important for the size of this parameter, whereby investigations concerning possible vehicle class specific RPA values have been suggested. So the aim of future investigations will be to investigate these and find other possible parameters by testing many different vehicles on road (enlarging the sample size from the statistical point of view) in order to get resilient driving dynamic limits which could be used to describe normal driving of PEMS-tests.

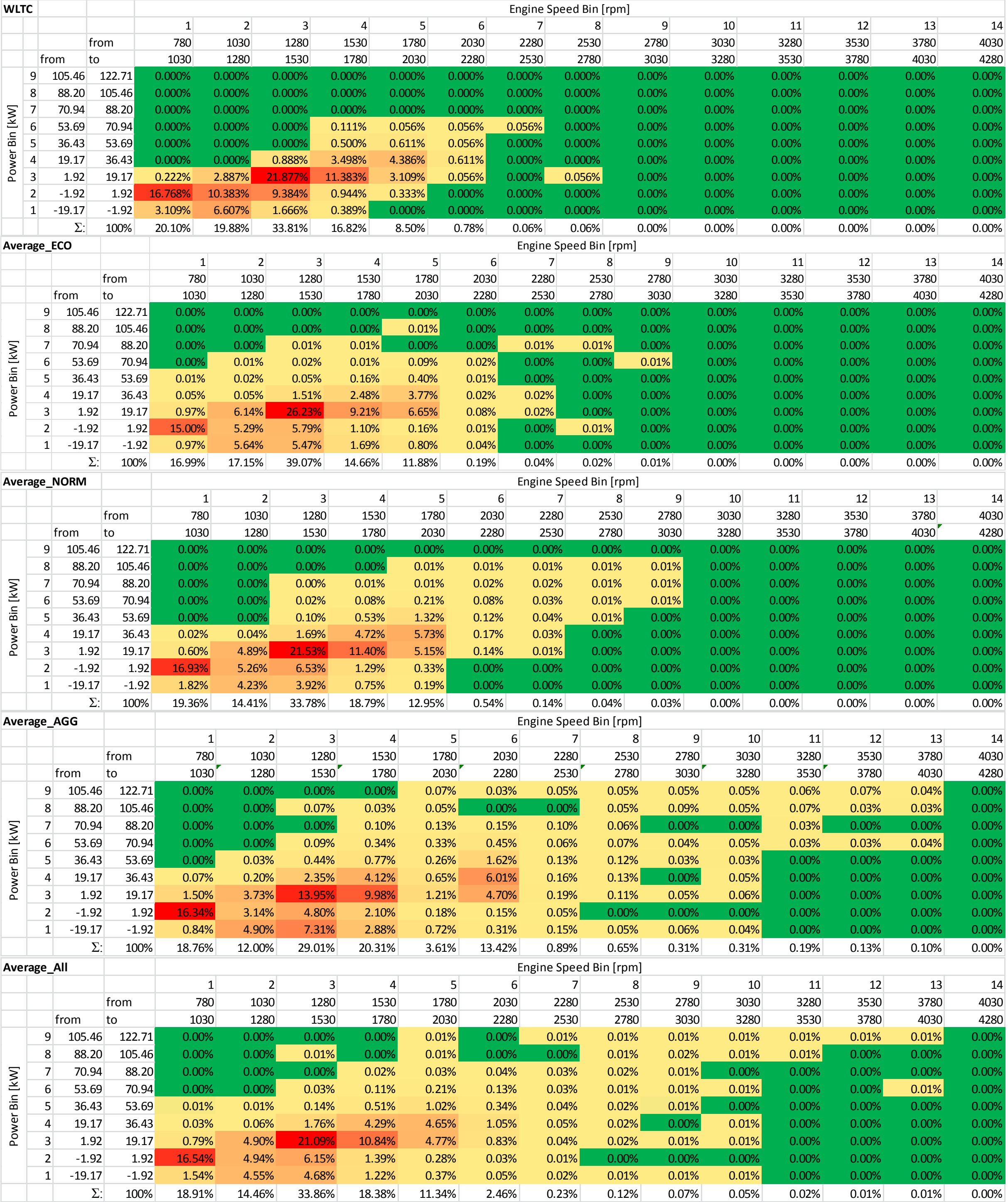
5 Appendix

5.1 Averaged P-rpm- and CLEAR-Input-maps

Following chapters 5.1.1 and 5.1.2 contain averaged P-rpm-maps and CLEAR-Input-maps. A detailed description of the method, how CLEAR-Input maps are compiled, is explained in chapter 2.4.1.

5.1.1 BMW 320d

5.1.1.1 Averaged P-rpm-maps for different driving styles



WLTC				Engine Speed Bin [rpm]													
				1	2	3	4	5	6	7	8	9	10	11	12	13	14
			from	780	1030	1280	1530	1780	2030	2280	2530	2780	3030	3280	3530	3780	4030
		from	to	1030	1280	1530	1780	2030	2280	2530	2780	3030	3280	3530	3780	4030	4280
Power Bin [kW]	9	105.46	122.71	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	8	88.20	105.46	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	7	70.94	88.20	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	6	53.69	70.94	0.000%	0.000%	0.000%	0.111%	0.056%	0.056%	0.056%	0.000%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	5	36.43	53.69	0.000%	0.000%	0.000%	0.500%	0.611%	0.056%	0.000%	0.000%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	4	19.17	36.43	0.000%	0.000%	0.888%	3.498%	4.386%	0.611%	0.000%	0.000%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	3	1.92	19.17	0.222%	2.887%	21.877%	11.383%	3.109%	0.056%	0.000%	0.056%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	2	-1.92	1.92	16.768%	10.383%	9.384%	0.944%	0.333%	0.000%	0.000%	0.000%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	1	-19.17	-1.92	3.109%	6.607%	1.666%	0.389%	0.000%	0.000%	0.000%	0.000%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
		Σ:	100%	20.10%	19.88%	33.81%	16.82%	8.50%	0.78%	0.06%	0.06%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%

Average_ECO				Engine Speed Bin [rpm]													
				1	2	3	4	5	6	7	8	9	10	11	12	13	14
			from	780	1030	1280	1530	1780	2030	2280	2530	2780	3030	3280	3530	3780	4030
		from	to	1030	1280	1530	1780	2030	2280	2530	2780	3030	3280	3530	3780	4030	4280
Power Bin [kW]	9	105.46	122.71	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	8	88.20	105.46	0.00%	0.00%	0.00%	0.00%	0.01%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	7	70.94	88.20	0.00%	0.00%	0.01%	0.01%	0.00%	0.00%	0.01%	0.01%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	6	53.69	70.94	0.00%	0.01%	0.02%	0.01%	0.09%	0.02%	0.00%	0.00%	0.01%	0.00%	0.00%	0.00%	0.00%	0.00%
	5	36.43	53.69	0.01%	0.02%	0.05%	0.16%	0.40%	0.01%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	4	19.17	36.43	0.05%	0.05%	1.51%	2.48%	3.77%	0.02%	0.02%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	3	1.92	19.17	0.97%	6.14%	26.23%	9.21%	6.65%	0.08%	0.02%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	2	-1.92	1.92	15.00%	5.29%	5.79%	1.10%	0.16%	0.01%	0.00%	0.01%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	1	-19.17	-1.92	0.97%	5.64%	5.47%	1.69%	0.80%	0.04%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
		Σ:	100%	16.99%	17.15%	39.07%	14.66%	11.88%	0.19%	0.04%	0.02%	0.01%	0.00%	0.00%	0.00%	0.00%	0.00%

Average_NORM				Engine Speed Bin [rpm]													
				1	2	3	4	5	6	7	8	9	10	11	12	13	14
			from	780	1030	1280	1530	1780	2030	2280	2530	2780	3030	3280	3530	3780	4030
		from	to	1030	1280	1530	1780	2030	2280	2530	2780	3030	3280	3530	3780	4030	4280
Power Bin [kW]	9	105.46	122.71	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	8	88.20	105.46	0.00%	0.00%	0.00%	0.00%	0.01%	0.01%	0.01%	0.01%	0.01%	0.00%	0.00%	0.00%	0.00%	0.00%
	7	70.94	88.20	0.00%	0.00%	0.00%	0.01%	0.01%	0.02%	0.02%	0.01%	0.01%	0.00%	0.00%	0.00%	0.00%	0.00%
	6	53.69	70.94	0.00%	0.00%	0.02%	0.08%	0.21%	0.08%	0.03%	0.01%	0.01%	0.00%	0.00%	0.00%	0.00%	0.00%
	5	36.43	53.69	0.00%	0.00%	0.10%	0.53%	1.32%	0.12%	0.04%	0.01%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	4	19.17	36.43	0.02%	0.04%	1.69%	4.72%	5.73%	0.17%	0.03%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	3	1.92	19.17	0.60%	4.89%	21.53%	11.40%	5.15%	0.14%	0.01%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	2	-1.92	1.92	16.93%	5.26%	6.53%	1.29%	0.33%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	1	-19.17	-1.92	1.82%	4.23%	3.92%	0.75%	0.19%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
		Σ:	100%	19.36%	14.41%	33.78%	18.79%	12.95%	0.54%	0.14%	0.04%	0.03%	0.00%	0.00%	0.00%	0.00%	0.00%

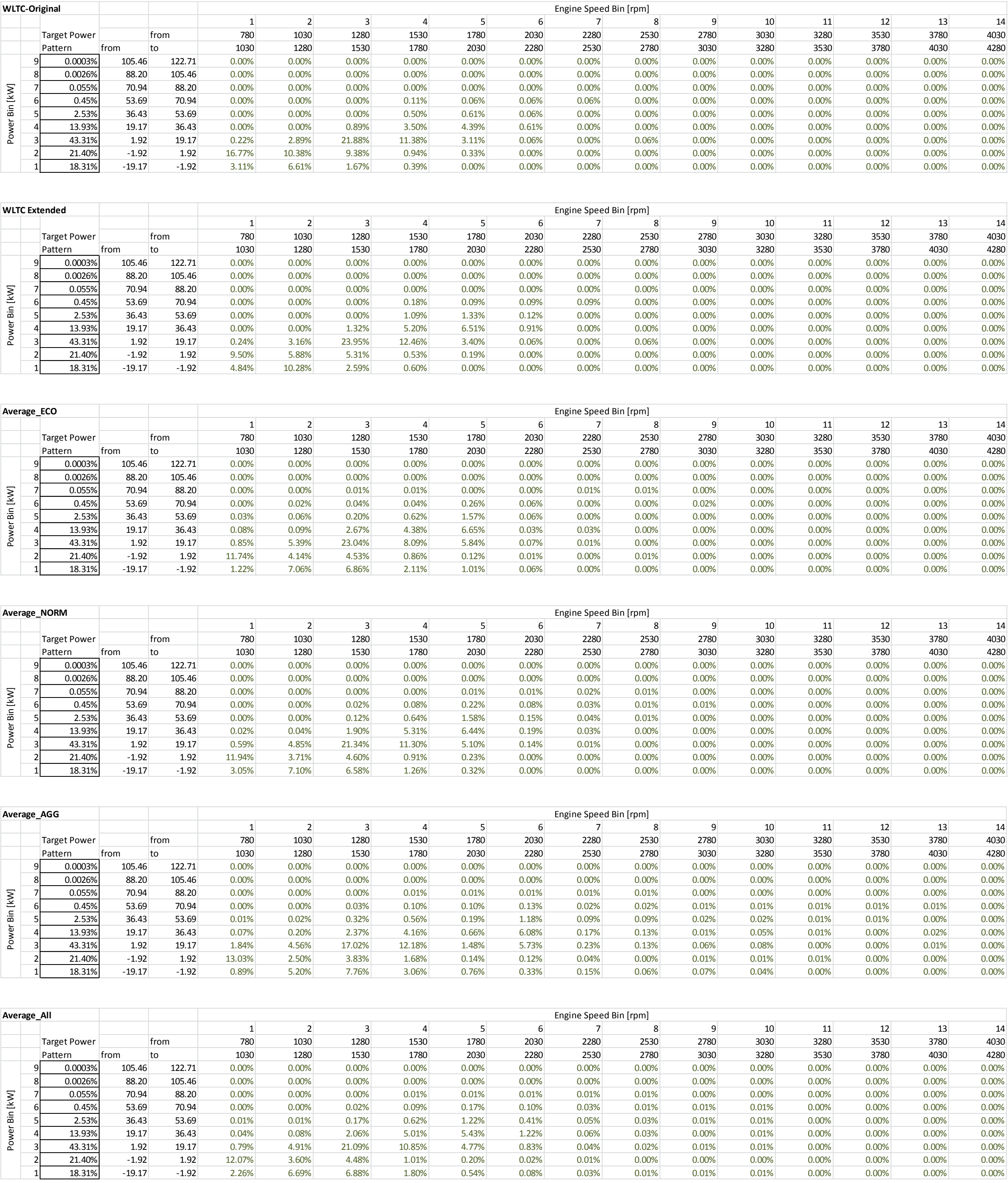
Average_AGG				Engine Speed Bin [rpm]													
				1	2	3	4	5	6	7	8	9	10	11	12	13	14
			from	780	1030	1280	1530	1780	2030	2280	2530	2780	3030	3280	3530	3780	4030
		from	to	1030	1280	1530	1780	2030	2280	2530	2780	3030	3280	3530	3780	4030	4280
Power Bin [kW]	9	105.46	122.71	0.00%	0.00%	0.00%	0.00%	0.07%	0.03%	0.05%	0.05%	0.05%	0.05%	0.06%	0.07%	0.04%	0.00%
	8	88.20	105.46	0.00%	0.00%	0.07%	0.03%	0.05%	0.00%	0.00%	0.05%	0.09%	0.05%	0.07%	0.03%	0.03%	0.00%
	7	70.94	88.20	0.00%	0.00%	0.00%	0.10%	0.13%	0.15%	0.10%	0.06%	0.00%	0.00%	0.03%	0.00%	0.00%	0.00%
	6	53.69	70.94	0.00%	0.00%	0.09%	0.34%	0.33%	0.45%	0.06%	0.07%	0.04%	0.05%	0.03%	0.03%	0.04%	0.00%
	5	36.43	53.69	0.00%	0.03%	0.44%	0.77%	0.26%	1.62%	0.13%	0.12%	0.03%	0.03%	0.00%	0.00%	0.00%	0.00%
	4	19.17	36.43	0.07%	0.20%	2.35%	4.12%	0.65%	6.01%	0.16%	0.13%	0.00%	0.05%	0.00%	0.00%	0.00%	0.00%
	3	1.92	19.17	1.50%	3.73%	13.95%	9.98%	1.21%	4.70%	0.19%	0.11%	0.05%	0.06%	0.00%	0.00%	0.00%	0.00%
	2	-1.92	1.92	16.34%	3.14%	4.80%	2.10%	0.18%	0.15%	0.05%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	1	-19.17	-1.92	0.84%	4.90%	7.31%	2.88%	0.72%	0.31%	0.15%	0.05%	0.06%	0.04%	0.00%	0.00%	0.00%	0.00%
		Σ:	100%	18.76%	12.00%	29.01%	20.31%	3.61%	13.42%	0.89%	0.65%	0.31%	0.31%	0.19%	0.13%	0.10%	0.00%

Average_All				Engine Speed Bin [rpm]													
				1	2	3	4	5	6	7	8	9	10	11	12	13	14
			from	780	1030	1280	1530	1780	2030	2280	2530	2780	3030	3280	3530	3780	4030
		from	to	1030	1280	1530	1780	2030	2280	2530	2780	3030	3280	3530	3780	4030	4280
Power Bin [kW]	9	105.46	122.71	0.00%	0.00%	0.00%	0.00%	0.01%	0.00%	0.01%	0.01%	0.01%	0.01%	0.01%	0.01%	0.01%	0.00%
	8	88.20	105.46	0.00%	0.00%	0.01%	0.00%	0.01%	0.00%	0.00%	0.01%	0.02%	0.01%	0.01%	0.00%	0.00%	0.00%
	7	70.94	88.20	0.00%	0.00%	0.00%	0.02%	0.03%	0.04%	0.03%	0.02%	0.01%	0.00%	0.00%	0.00%	0.00%	0.00%
	6	53.69	70.94	0.00%	0.00%	0.03%	0.11%	0.21%	0.13%	0.03%	0.01%	0.01%	0.01%	0.00%	0.00%	0.01%	0.00%
	5	36.43	53.69	0.01%	0.01%	0.14%	0.51%	1.02%	0.34%	0.04%	0.02%	0.01%	0.00%	0.00%	0.00%	0.00%	0.00%
	4	19.17	36.43	0.03%	0.06%	1.76%	4.29%	4.65%	1.05%	0.05%	0.02%	0.00%	0.01%	0.00%	0.00%	0.00%	0.00%
	3	1.92	19.17	0.79%	4.90%	21.09%	10.84%	4.77%	0.83%	0.04%	0.02%	0.01%	0.01%	0.00%	0.00%	0.00%	0.00%
	2	-1.92	1.92	16.54%	4.94%	6.15%	1.39%	0.28%	0.03%	0.01%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	1	-19.17	-1.92	1.54%	4.55%	4.68%	1.22%	0.37%	0.05%	0.02%	0.01%	0.01%	0.01%	0.00%	0.00%	0.00%	0.00%
		Σ:	100%	18.91%	14.46%	33.86%	18.38%	11.34%	2.46%	0.23%	0.12%	0.07%	0.05%	0.02%	0.01%	0.01%	0.00%

Figure 5-1: Averaged P-rpm-maps of different driving styles of BMW 320d(red = high time

share in [%], slightly red/yellow = mid to low time shares in [%], green = time share of 0%)

5.1.1.2 CLEAR-Input maps for different driving styles



WLTC-Original					Engine Speed Bin [rpm]													
					1	2	3	4	5	6	7	8	9	10	11	12	13	14
		Target Power		from	780	1030	1280	1530	1780	2030	2280	2530	2780	3030	3280	3530	3780	4030
		Pattern	from	to	1030	1280	1530	1780	2030	2280	2530	2780	3030	3280	3530	3780	4030	4280
Power Bin [kW]	9	0.0003%	105.46	122.71	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	8	0.0026%	88.20	105.46	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	7	0.055%	70.94	88.20	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	6	0.45%	53.69	70.94	0.00%	0.00%	0.00%	0.11%	0.06%	0.06%	0.06%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	5	2.53%	36.43	53.69	0.00%	0.00%	0.00%	0.50%	0.61%	0.06%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	4	13.93%	19.17	36.43	0.00%	0.00%	0.89%	3.50%	4.39%	0.61%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	3	43.31%	1.92	19.17	0.22%	2.89%	21.88%	11.38%	3.11%	0.06%	0.00%	0.06%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	2	21.40%	-1.92	1.92	16.77%	10.38%	9.38%	0.94%	0.33%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	1	18.31%	-19.17	-1.92	3.11%	6.61%	1.67%	0.39%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%

WLTC Extended					Engine Speed Bin [rpm]													
					1	2	3	4	5	6	7	8	9	10	11	12	13	14
		Target Power		from	780	1030	1280	1530	1780	2030	2280	2530	2780	3030	3280	3530	3780	4030
		Pattern	from	to	1030	1280	1530	1780	2030	2280	2530	2780	3030	3280	3530	3780	4030	4280
Power Bin [kW]	9	0.0003%	105.46	122.71	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	8	0.0026%	88.20	105.46	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	7	0.055%	70.94	88.20	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	6	0.45%	53.69	70.94	0.00%	0.00%	0.00%	0.18%	0.09%	0.09%	0.09%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	5	2.53%	36.43	53.69	0.00%	0.00%	0.00%	1.09%	1.33%	0.12%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	4	13.93%	19.17	36.43	0.00%	0.00%	1.32%	5.20%	6.51%	0.91%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	3	43.31%	1.92	19.17	0.24%	3.16%	23.95%	12.46%	3.40%	0.06%	0.00%	0.06%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	2	21.40%	-1.92	1.92	9.50%	5.88%	5.31%	0.53%	0.19%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	1	18.31%	-19.17	-1.92	4.84%	10.28%	2.59%	0.60%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%

Average_ECO					Engine Speed Bin [rpm]													
					1	2	3	4	5	6	7	8	9	10	11	12	13	14
		Target Power		from	780	1030	1280	1530	1780	2030	2280	2530	2780	3030	3280	3530	3780	4030
		Pattern	from	to	1030	1280	1530	1780	2030	2280	2530	2780	3030	3280	3530	3780	4030	4280
Power Bin [kW]	9	0.0003%	105.46	122.71	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	8	0.0026%	88.20	105.46	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	7	0.055%	70.94	88.20	0.00%	0.00%	0.01%	0.01%	0.00%	0.00%	0.01%	0.01%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	6	0.45%	53.69	70.94	0.00%	0.02%	0.04%	0.04%	0.26%	0.06%	0.00%	0.00%	0.02%	0.00%	0.00%	0.00%	0.00%	0.00%
	5	2.53%	36.43	53.69	0.03%	0.06%	0.20%	0.62%	1.57%	0.06%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	4	13.93%	19.17	36.43	0.08%	0.09%	2.67%	4.38%	6.65%	0.03%	0.03%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	3	43.31%	1.92	19.17	0.85%	5.39%	23.04%	8.09%	5.84%	0.07%	0.01%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	2	21.40%	-1.92	1.92	11.74%	4.14%	4.53%	0.86%	0.12%	0.01%	0.00%	0.01%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	1	18.31%	-19.17	-1.92	1.22%	7.06%	6.86%	2.11%	1.01%	0.06%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%

Average_NORM					Engine Speed Bin [rpm]													
					1	2	3	4	5	6	7	8	9	10	11	12	13	14
		Target Power		from	780	1030	1280	1530	1780	2030	2280	2530	2780	3030	3280	3530	3780	4030
		Pattern	from	to	1030	1280	1530	1780	2030	2280	2530	2780	3030	3280	3530	3780	4030	4280
Power Bin [kW]	9	0.0003%	105.46	122.71	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	8	0.0026%	88.20	105.46	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	7	0.055%	70.94	88.20	0.00%	0.00%	0.00%	0.00%	0.01%	0.01%	0.02%	0.01%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	6	0.45%	53.69	70.94	0.00%	0.00%	0.02%	0.08%	0.22%	0.08%	0.03%	0.01%	0.01%	0.00%	0.00%	0.00%	0.00%	0.00%
	5	2.53%	36.43	53.69	0.00%	0.00%	0.12%	0.64%	1.58%	0.15%	0.04%	0.01%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	4	13.93%	19.17	36.43	0.02%	0.04%	1.90%	5.31%	6.44%	0.19%	0.03%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	3	43.31%	1.92	19.17	0.59%	4.85%	21.34%	11.30%	5.10%	0.14%	0.01%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	2	21.40%	-1.92	1.92	11.94%	3.71%	4.60%	0.91%	0.23%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	1	18.31%	-19.17	-1.92	3.05%	7.10%	6.58%	1.26%	0.32%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%

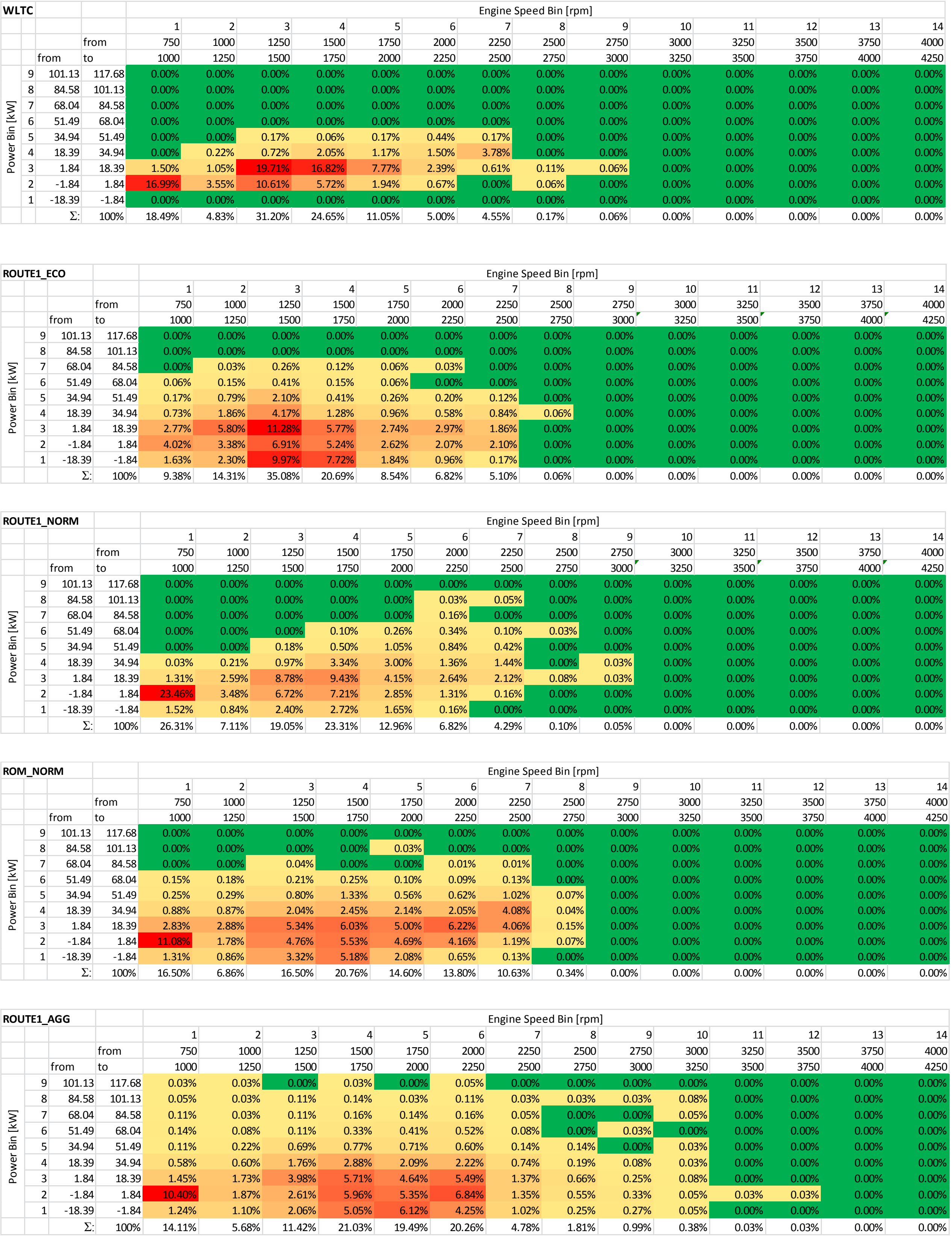
Average_AGG					Engine Speed Bin [rpm]													
					1	2	3	4	5	6	7	8	9	10	11	12	13	14
		Target Power		from	780	1030	1280	1530	1780	2030	2280	2530	2780	3030	3280	3530	3780	4030
		Pattern	from	to	1030	1280	1530	1780	2030	2280	2530	2780	3030	3280	3530	3780	4030	4280
Power Bin [kW]	9	0.0003%	105.46	122.71	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	8	0.0026%	88.20	105.46	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	7	0.055%	70.94	88.20	0.00%	0.00%	0.00%	0.01%	0.01%	0.01%	0.01%	0.01%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	6	0.45%	53.69	70.94	0.00%	0.00%	0.03%	0.10%	0.10%	0.13%	0.02%	0.02%	0.01%	0.01%	0.01%	0.01%	0.01%	0.00%
	5	2.53%	36.43	53.69	0.01%	0.02%	0.32%	0.56%	0.19%	1.18%	0.09%	0.09%	0.02%	0.02%	0.01%	0.01%	0.00%	0.00%
	4	13.93%	19.17	36.43	0.07%	0.20%	2.37%	4.16%	0.66%	6.08%	0.17%	0.13%	0.01%	0.05%	0.01%	0.00%	0.02%	0.00%
	3	43.31%	1.92	19.17	1.84%	4.56%	17.02%	12.18%	1.48%	5.73%	0.23%	0.13%	0.06%	0.08%	0.00%	0.00%	0.01%	0.00%
	2	21.40%	-1.92	1.92	13.03%	2.50%	3.83%	1.68%	0.14%	0.12%	0.04%	0.00%	0.01%	0.01%	0.01%	0.00%	0.00%	0.00%
	1	18.31%	-19.17	-1.92	0.89%	5.20%	7.76%	3.06%	0.76%	0.33%	0.15%	0.06%	0.07%	0.04%	0.00%	0.00%	0.00%	0.00%

Average_All					Engine Speed Bin [rpm]													
					1	2	3	4	5	6	7	8	9	10	11	12	13	14
		Target Power		from	780	1030	1280	1530	1780	2030	2280	2530	2780	3030	3280	3530	3780	4030
		Pattern	from	to	1030	1280	1530	1780	2030	2280	2530	2780	3030	3280	3530	3780	4030	4280
Power Bin [kW]	9	0.0003%	105.46	122.71	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	8	0.0026%	88.20	105.46	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	7	0.055%	70.94	88.20	0.00%	0.00%	0.00%	0.01%	0.01%	0.01%	0.01%	0.01%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	6	0.45%	53.69	70.94	0.00%	0.00%	0.02%	0.09%	0.17%	0.10%	0.03%	0.01%	0.01%	0.01%	0.00%	0.00%	0.00%	0.00%
	5	2.53%	36.43	53.69	0.01%	0.01%	0.17%	0.62%	1.22%	0.41%	0.05%	0.03%	0.01%	0.01%	0.00%	0.00%	0.00%	0.00%
	4	13.93%	19.17	36.43	0.04%	0.08%	2.06%	5.01%	5.43%	1.22%	0.06%	0.03%	0.00%	0.01%	0.00%	0.00%	0.00%	0.00%
	3	43.31%	1.92	19.17	0.79%	4.91%	21.09%	10.85%	4.77%	0.83%	0.04%	0.02%	0.01%	0.01%	0.00%	0.00%	0.00%	0.00%
	2	21.40%	-1.92	1.92	12.07%	3.60%	4.48%	1.01%	0.20%	0.02%	0.01%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	1	18.31%	-19.17	-1.92	2.26%	6.69%	6.88%	1.80%	0.54%	0.08%	0.03%	0.01%	0.01%	0.01%	0.00%	0.00%	0.00%	0.00%

Figure 5-2: CLEAR-Input maps based ond P-rpm-maps of BMW 320d

5.1.2 Mazda CX5

5.1.2.1 P-rpm-maps for different driving styles



WLTC				Engine Speed Bin [rpm]													
				1	2	3	4	5	6	7	8	9	10	11	12	13	14
			from	750	1000	1250	1500	1750	2000	2250	2500	2750	3000	3250	3500	3750	4000
		from	to	1000	1250	1500	1750	2000	2250	2500	2750	3000	3250	3500	3750	4000	4250
Power Bin [kW]	9	101.13	117.68	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	8	84.58	101.13	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	7	68.04	84.58	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	6	51.49	68.04	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	5	34.94	51.49	0.00%	0.00%	0.17%	0.06%	0.17%	0.44%	0.17%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	4	18.39	34.94	0.00%	0.22%	0.72%	2.05%	1.17%	1.50%	3.78%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	3	1.84	18.39	1.50%	1.05%	19.71%	16.82%	7.77%	2.39%	0.61%	0.11%	0.06%	0.00%	0.00%	0.00%	0.00%	0.00%
	2	-1.84	1.84	16.99%	3.55%	10.61%	5.72%	1.94%	0.67%	0.00%	0.06%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	1	-18.39	-1.84	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
		Σ:	100%	18.49%	4.83%	31.20%	24.65%	11.05%	5.00%	4.55%	0.17%	0.06%	0.00%	0.00%	0.00%	0.00%	0.00%

ROUTE1_ECO				Engine Speed Bin [rpm]													
				1	2	3	4	5	6	7	8	9	10	11	12	13	14
			from	750	1000	1250	1500	1750	2000	2250	2500	2750	3000	3250	3500	3750	4000
		from	to	1000	1250	1500	1750	2000	2250	2500	2750	3000	3250	3500	3750	4000	4250
Power Bin [kW]	9	101.13	117.68	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	8	84.58	101.13	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	7	68.04	84.58	0.00%	0.03%	0.26%	0.12%	0.06%	0.03%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	6	51.49	68.04	0.06%	0.15%	0.41%	0.15%	0.06%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	5	34.94	51.49	0.17%	0.79%	2.10%	0.41%	0.26%	0.20%	0.12%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	4	18.39	34.94	0.73%	1.86%	4.17%	1.28%	0.96%	0.58%	0.84%	0.06%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	3	1.84	18.39	2.77%	5.80%	11.28%	5.77%	2.74%	2.97%	1.86%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	2	-1.84	1.84	4.02%	3.38%	6.91%	5.24%	2.62%	2.07%	2.10%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	1	-18.39	-1.84	1.63%	2.30%	9.97%	7.72%	1.84%	0.96%	0.17%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
		Σ:	100%	9.38%	14.31%	35.08%	20.69%	8.54%	6.82%	5.10%	0.06%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%

ROUTE1_NORM				Engine Speed Bin [rpm]													
				1	2	3	4	5	6	7	8	9	10	11	12	13	14
			from	750	1000	1250	1500	1750	2000	2250	2500	2750	3000	3250	3500	3750	4000
		from	to	1000	1250	1500	1750	2000	2250	2500	2750	3000	3250	3500	3750	4000	4250
Power Bin [kW]	9	101.13	117.68	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	8	84.58	101.13	0.00%	0.00%	0.00%	0.00%	0.00%	0.03%	0.05%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	7	68.04	84.58	0.00%	0.00%	0.00%	0.00%	0.00%	0.16%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	6	51.49	68.04	0.00%	0.00%	0.00%	0.10%	0.26%	0.34%	0.10%	0.03%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	5	34.94	51.49	0.00%	0.00%	0.18%	0.50%	1.05%	0.84%	0.42%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	4	18.39	34.94	0.03%	0.21%	0.97%	3.34%	3.00%	1.36%	1.44%	0.00%	0.03%	0.00%	0.00%	0.00%	0.00%	0.00%
	3	1.84	18.39	1.31%	2.59%	8.78%	9.43%	4.15%	2.64%	2.12%	0.08%	0.03%	0.00%	0.00%	0.00%	0.00%	0.00%
	2	-1.84	1.84	23.46%	3.48%	6.72%	7.21%	2.85%	1.31%	0.16%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	1	-18.39	-1.84	1.52%	0.84%	2.40%	2.72%	1.65%	0.16%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
		Σ:	100%	26.31%	7.11%	19.05%	23.31%	12.96%	6.82%	4.29%	0.10%	0.05%	0.00%	0.00%	0.00%	0.00%	0.00%

ROM_NORM				Engine Speed Bin [rpm]													
				1	2	3	4	5	6	7	8	9	10	11	12	13	14
			from	750	1000	1250	1500	1750	2000	2250	2500	2750	3000	3250	3500	3750	4000
		from	to	1000	1250	1500	1750	2000	2250	2500	2750	3000	3250	3500	3750	4000	4250
Power Bin [kW]	9	101.13	117.68	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	8	84.58	101.13	0.00%	0.00%	0.00%	0.00%	0.03%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	7	68.04	84.58	0.00%	0.00%	0.04%	0.00%	0.00%	0.01%	0.01%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	6	51.49	68.04	0.15%	0.18%	0.21%	0.25%	0.10%	0.09%	0.13%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	5	34.94	51.49	0.25%	0.29%	0.80%	1.33%	0.56%	0.62%	1.02%	0.07%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	4	18.39	34.94	0.88%	0.87%	2.04%	2.45%	2.14%	2.05%	4.08%	0.04%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	3	1.84	18.39	2.83%	2.88%	5.34%	6.03%	5.00%	6.22%	4.06%	0.15%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	2	-1.84	1.84	11.08%	1.78%	4.76%	5.53%	4.69%	4.16%	1.19%	0.07%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	1	-18.39	-1.84	1.31%	0.86%	3.32%	5.18%	2.08%	0.65%	0.13%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
		Σ:	100%	16.50%	6.86%	16.50%	20.76%	14.60%	13.80%	10.63%	0.34%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%

ROUTE1_AGG				Engine Speed Bin [rpm]													
				1	2	3	4	5	6	7	8	9	10	11	12	13	14
			from	750	1000	1250	1500	1750	2000	2250	2500	2750	3000	3250	3500	3750	4000
		from	to	1000	1250	1500	1750	2000	2250	2500	2750	3000	3250	3500	3750	4000	4250
Power Bin [kW]	9	101.13	117.68	0.03%	0.03%	0.00%	0.03%	0.00%	0.05%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	8	84.58	101.13	0.05%	0.03%	0.11%	0.14%	0.03%	0.11%	0.03%	0.03%	0.03%	0.08%	0.00%	0.00%	0.00%	0.00%
	7	68.04	84.58	0.11%	0.03%	0.11%	0.16%	0.14%	0.16%	0.05%	0.00%	0.00%	0.05%	0.00%	0.00%	0.00%	0.00%
	6	51.49	68.04	0.14%	0.08%	0.11%	0.33%	0.41%	0.52%	0.08%	0.00%	0.03%	0.00%	0.00%	0.00%	0.00%	0.00%
	5	34.94	51.49	0.11%	0.22%	0.69%	0.77%	0.71%	0.60%	0.14%	0.14%	0.00%	0.03%	0.00%	0.00%	0.00%	0.00%
	4	18.39	34.94	0.58%	0.60%	1.76%	2.88%	2.09%	2.22%	0.74%	0.19%	0.08%	0.03%	0.00%	0.00%	0.00%	0.00%
	3	1.84	18.39	1.45%	1.73%	3.98%	5.71%	4.64%	5.49%	1.37%	0.66%	0.25%	0.08%	0.00%	0.00%	0.00%	0.00%
	2	-1.84	1.84	10.40%	1.87%	2.61%	5.96%	5.35%	6.84%	1.35%	0.55%	0.33%	0.05%	0.03%	0.03%	0.00%	0.00%
	1	-18.39	-1.84	1.24%	1.10%	2.06%	5.05%	6.12%	4.25%	1.02%	0.25%	0.27%	0.05%	0.00%	0.00%	0.00%	0.00%
		Σ:	100%	14.11%	5.68%	11.42%	21.03%	19.49%	20.26%	4.78%	1.81%	0.99%	0.38%	0.03%	0.03%	0.00%	0.00%

Figure 5-3: Averaged P-rpm-maps of different driving styles of Mazda CX5(red = high time share in [%], slightly red/yellow = mid to low time shares in [%], green = time share of 0%)

5.1.2.2 CLEAR-Input maps for different driving styles

WLTC-Original					Engine Speed Bin [rpm]													
					1	2	3	4	5	6	7	8	9	10	11	12	13	14
		Target Power		from [rpm]	750	1000	1250	1500	1750	2000	2250	2500	2750	3000	3250	3500	3750	4000
		Pattern	from	to	1000	1250	1500	1750	2000	2250	2500	2750	3000	3250	3500	3750	4000	4250
Power Bin [kW]	9	0.0003%	101.13	117.68	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	8	0.0026%	84.58	101.13	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	7	0.055%	68.04	84.58	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	6	0.45%	51.49	68.04	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	5	2.53%	34.94	51.49	0.00%	0.00%	0.17%	0.06%	0.17%	0.44%	0.17%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	4	13.93%	18.39	34.94	0.00%	0.22%	0.72%	2.05%	1.17%	1.50%	3.78%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	3	43.31%	1.84	18.39	1.50%	1.05%	19.71%	16.82%	7.77%	2.39%	0.61%	0.11%	0.06%	0.00%	0.00%	0.00%	0.00%	0.00%
	2	21.40%	-1.84	1.84	16.99%	3.55%	10.61%	5.72%	1.94%	0.67%	0.00%	0.06%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	1	18.31%	-18.39	-1.84	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%

WLTC Extended					Engine Speed Bin [rpm]													
					1	2	3	4	5	6	7	8	9	10	11	12	13	14
		Target Power		from	750	1000	1250	1500	1750	2000	2250	2500	2750	3000	3250	3500	3750	4000
		Pattern	from	to	1000	1250	1500	1750	2000	2250	2500	2750	3000	3250	3500	3750	4000	4250
Power Bin [kW]	9	0.0003%	101.13	117.68	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	8	0.0026%	84.58	101.13	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	7	0.055%	68.04	84.58	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	6	0.45%	51.49	68.04	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	5	2.53%	34.94	51.49	0.00%	0.00%	0.42%	0.14%	0.42%	1.13%	0.42%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	4	13.93%	18.39	34.94	0.00%	0.33%	1.07%	3.03%	1.72%	2.21%	5.57%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	3	43.31%	1.84	18.39	1.30%	0.91%	17.07%	14.57%	6.73%	2.07%	0.53%	0.10%	0.05%	0.00%	0.00%	0.00%	0.00%	0.00%
	2	21.40%	-1.84	1.84	9.20%	1.92%	5.74%	3.10%	1.05%	0.36%	0.00%	0.03%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	1	18.31%	-18.39	-1.84	7.91%	1.65%	4.94%	2.66%	0.90%	0.31%	0.00%	0.03%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%

ECO					Engine Speed Bin [rpm]													
					1	2	3	4	5	6	7	8	9	10	11	12	13	14
		Target Power		from	750	1000	1250	1500	1750	2000	2250	2500	2750	3000	3250	3500	3750	4000
		Pattern	from	to	1000	1250	1500	1750	2000	2250	2500	2750	3000	3250	3500	3750	4000	4250
Power Bin [kW]	9	0.0003%	101.13	117.68	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	8	0.0026%	84.58	101.13	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	7	0.055%	68.04	84.58	0.00%	0.00%	0.03%	0.01%	0.01%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	6	0.45%	51.49	68.04	0.03%	0.08%	0.23%	0.08%	0.03%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	5	2.53%	34.94	51.49	0.11%	0.49%	1.31%	0.26%	0.16%	0.13%	0.07%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	4	13.93%	18.39	34.94	0.97%	2.48%	5.53%	1.70%	1.28%	0.77%	1.12%	0.08%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	3	43.31%	1.84	18.39	3.61%	7.57%	14.72%	7.53%	3.57%	3.88%	2.43%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	2	21.40%	-1.84	1.84	3.27%	2.75%	5.61%	4.26%	2.13%	1.68%	1.70%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	1	18.31%	-18.39	-1.84	1.21%	1.71%	7.42%	5.75%	1.37%	0.72%	0.13%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%

Average_NORM					Engine Speed Bin [rpm]													
					1	2	3	4	5	6	7	8	9	10	11	12	13	14
		Target Power		from	750	1000	1250	1500	1750	2000	2250	2500	2750	3000	3250	3500	3750	4000
		Pattern	from	to	1000	1250	1500	1750	2000	2250	2500	2750	3000	3250	3500	3750	4000	4250
Power Bin [kW]	9	0.0003%	101.13	117.68	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	8	0.0026%	84.58	101.13	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	7	0.055%	68.04	84.58	0.00%	0.00%	0.01%	0.00%	0.00%	0.04%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	6	0.45%	51.49	68.04	0.02%	0.04%	0.05%	0.10%	0.06%	0.15%	0.04%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	5	2.53%	34.94	51.49	0.06%	0.09%	0.40%	0.56%	0.50%	0.62%	0.29%	0.01%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	4	13.93%	18.39	34.94	0.40%	0.49%	2.27%	3.03%	2.81%	2.96%	1.95%	0.01%	0.01%	0.00%	0.00%	0.00%	0.00%	0.00%
	3	43.31%	1.84	18.39	3.04%	3.48%	9.63%	10.06%	6.93%	7.00%	2.97%	0.14%	0.08%	0.00%	0.00%	0.00%	0.00%	0.00%
	2	21.40%	-1.84	1.84	10.46%	1.18%	2.67%	3.23%	1.96%	1.52%	0.31%	0.04%	0.02%	0.00%	0.00%	0.00%	0.00%	0.00%
	1	18.31%	-18.39	-1.84	1.96%	1.53%	4.33%	5.86%	2.93%	1.01%	0.46%	0.21%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%

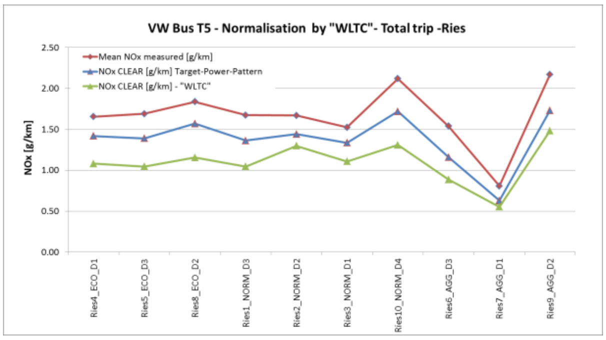
AGG					Engine Speed Bin [rpm]													
					1	2	3	4	5	6	7	8	9	10	11	12	13	14
		Target Power		from	750	1000	1250	1500	1750	2000	2250	2500	2750	3000	3250	3500	3750	4000
		Pattern	from	to	1000	1250	1500	1750	2000	2250	2500	2750	3000	3250	3500	3750	4000	4250
Power Bin [kW]	9	0.0003%	101.13	117.68	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	8	0.0026%	84.58	101.13	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	7	0.055%	68.04	84.58	0.01%	0.00%	0.01%	0.01%	0.01%	0.01%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	6	0.45%	51.49	68.04	0.04%	0.02%	0.03%	0.09%	0.11%	0.14%	0.02%	0.00%	0.01%	0.00%	0.00%	0.00%	0.00%	0.00%
	5	2.53%	34.94	51.49	0.08%	0.16%	0.51%	0.57%	0.53%	0.45%	0.10%	0.10%	0.00%	0.02%	0.00%	0.00%	0.00%	0.00%
	4	13.93%	18.39	34.94	0.72%	0.75%	2.19%	3.59%	2.60%	2.77%	0.92%	0.24%	0.10%	0.03%	0.00%	0.00%	0.00%	0.00%
	3	43.31%	1.84	18.39	2.48%	2.95%	6.80%	9.75%	7.92%	9.38%	2.34%	1.13%	0.42%	0.14%	0.00%	0.00%	0.00%	0.00%
	2	21.40%	-1.84	1.84	6.30%	1.13%	1.58%	3.61%	3.24%	4.14%	0.81%	0.33%	0.20%	0.03%	0.02%	0.02%	0.00%	0.00%
	1	18.31%	-18.39	-1.84	1.06%	0.94%	1.76%	4.32%	5.24%	3.64%	0.87%	0.21%	0.23%	0.05%	0.00%	0.00%	0.00%	0.00%

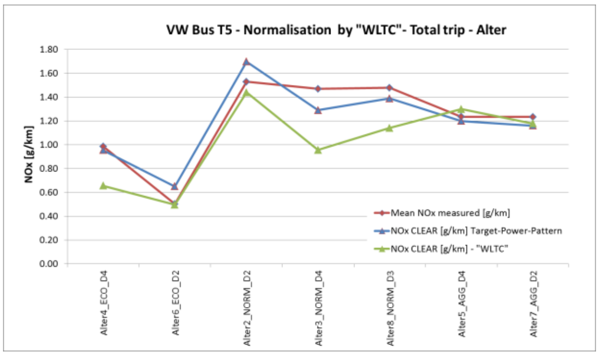
Average_ALL					Engine Speed Bin [rpm]													
					1	2	3	4	5	6	7	8	9	10	11	12	13	14
		Target Power		from	750	1000	1250	1500	1750	2000	2250	2500	2750	3000	3250	3500	3750	4000
		Pattern	from	to	1000	1250	1500	1750	2000	2250	2500	2750	3000	3250	3500	3750	4000	4250
Power Bin [kW]	9	0.0003%	101.13	117.68	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	8	0.0026%	84.58	101.13	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	7	0.055%	68.04	84.58	0.00%	0.00%	0.01%	0.01%	0.00%	0.03%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	6	0.45%	51.49	68.04	0.03%	0.04%	0.08%	0.09%	0.07%	0.12%	0.03%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	5	2.53%	34.94	51.49	0.07%	0.18%	0.61%	0.50%	0.44%	0.49%	0.21%	0.03%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	4	13.93%	18.39	34.94	0.58%	0.94%	2.91%	2.87%	2.46%	2.49%	1.58%	0.07%	0.03%	0.01%	0.00%	0.00%	0.00%	0.00%
	3	43.31%	1.84	18.39	3.04%	4.20%	10.08%	9.49%	6.46%	6.85%	2.74%	0.31%	0.13%	0.03%	0.00%	0.00%	0.00%	0.00%
	2	21.40%	-1.84	1.84	8.19%	1.48%	3.04%	3.51%	2.25%	2.08%	0.69%	0.09%	0.05%	0.01%	0.00%	0.00%	0.00%	0.00%
	1	18.31%	-18.39	-1.84	1.63%	1.45%	4.44%	5.53%	3.08%	1.48%	0.48%	0.17%	0.05%	0.01%	0.00%	0.00%	0.00%	0.00%

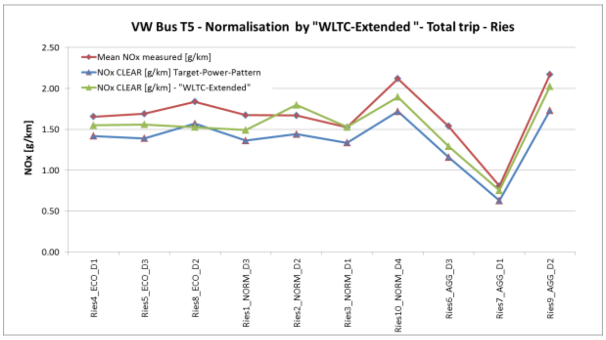
Figure 5-4: CLEAR-Input maps based ond P-rpm-maps of Mazda CX5

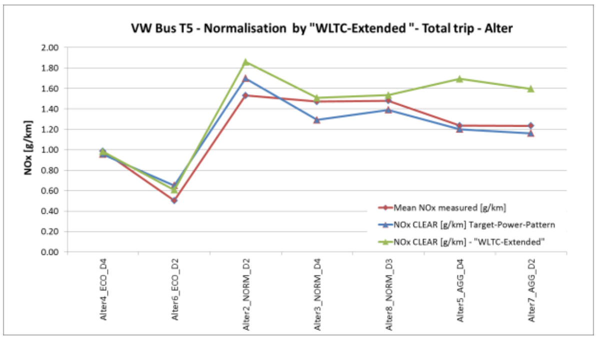
5.2 Normalisation results for NO_x for VW Bus T5 seperated by routes

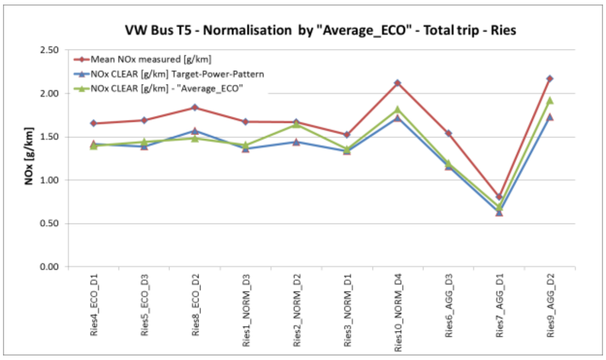
Following figures show the normalisation results for NO_x (weighted emissions) of the “Standard CLEAR method” in blue and of the “Extended CLEAR method” in green. In red the measured NO_x-emissions of each trip are shown. The assessment criterion is the max/min-ratio of the normalisation results.

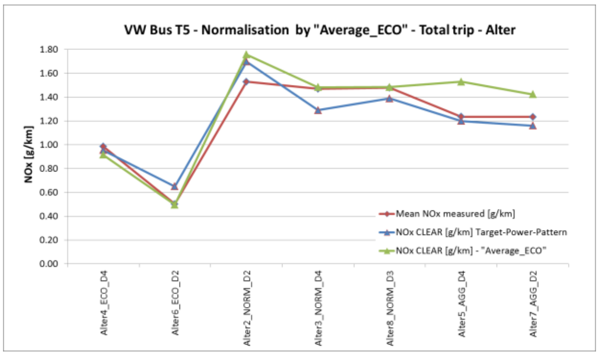


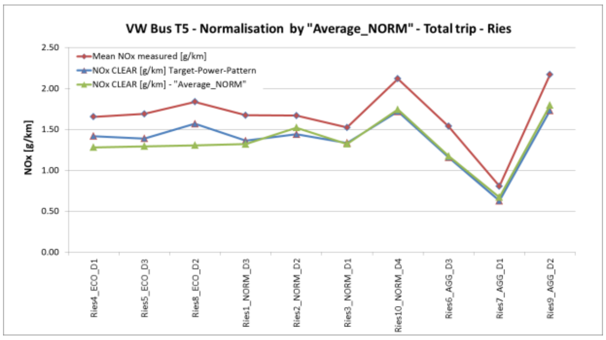


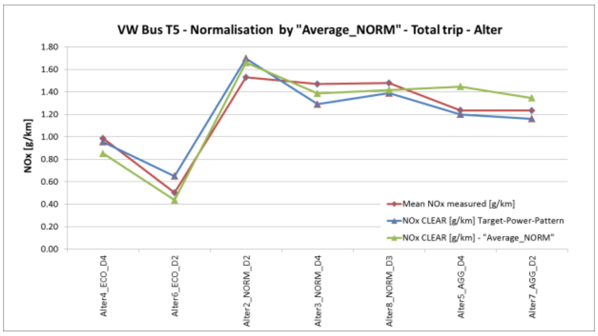












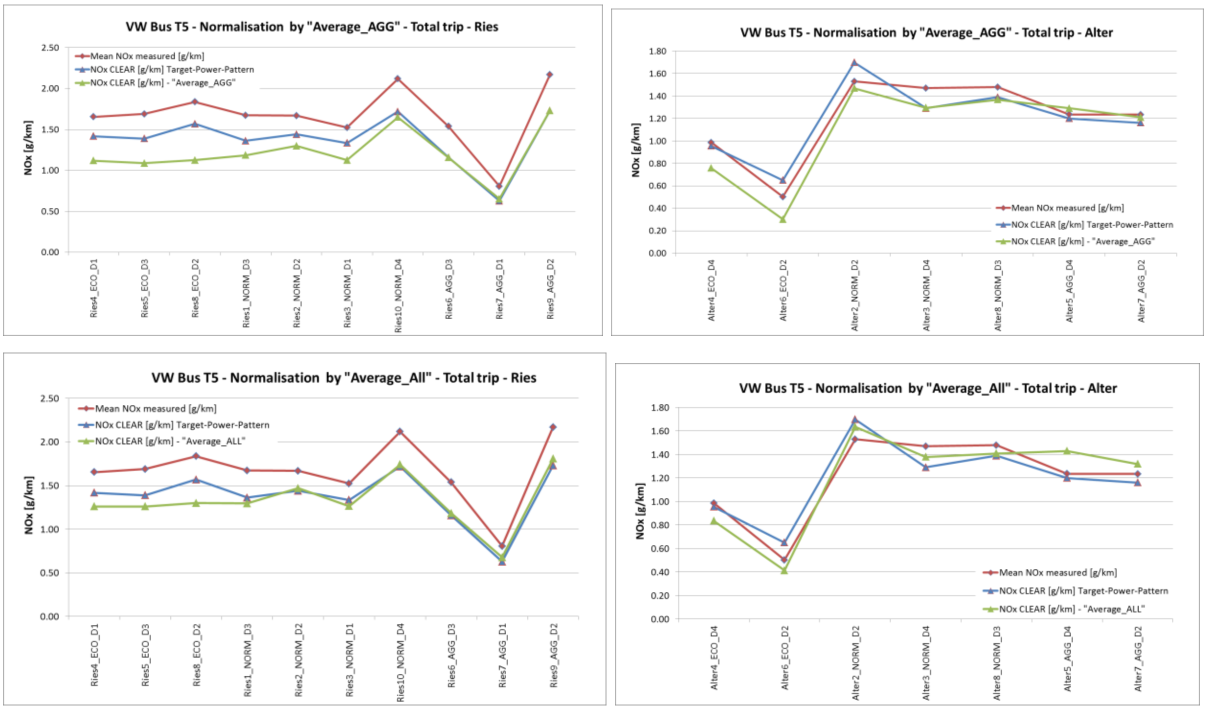


Figure 5-5: Normalisation results for NO_x for VW Bus T5 (red: measured trip emissions, blue: weighted NO_x with the “Standard CLEAR method”, green: weighted NO_x by the “Extended CLEAR method”)

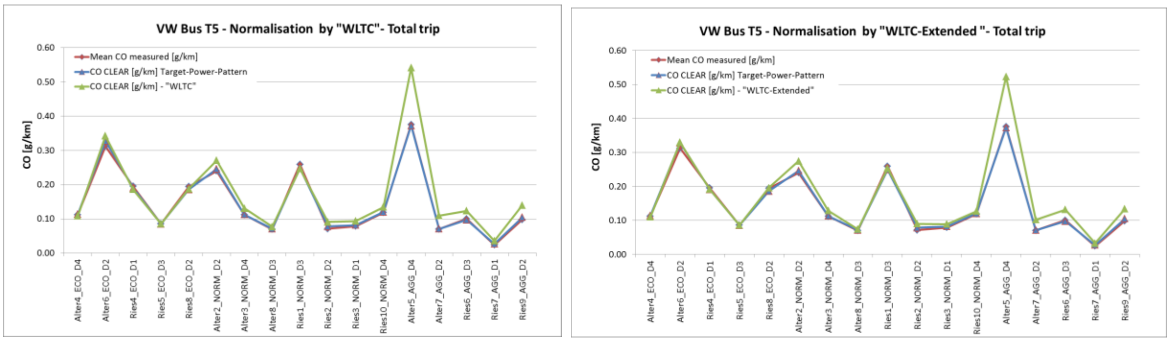
Table 5-1: Max/min ratio and standard deviation of normalisation results (red encircled values of the “Extended CLEAR method” are lower compared to the “Standard CLEAR method” (target power pattern) normalisation)

VW Bus T5 - "Ries"	Mean NOx measured[g/km]	NOx CLEAR [g/km] - Target-Power-Pattern	NOx CLEAR [g/km] - "WLTC"	NOx CLEAR [g/km] - "WLTC-Extended"	NOx CLEAR [g/km] - "Average_ECO"	NOx CLEAR [g/km] - "Average_NORM"	NOx CLEAR [g/km] - "Average_AGG"	NOx CLEAR [g/km] - "Average_ALL"
Average	1.668	1.375	1.096	1.541	1.435	1.343	1.214	1.326
Maximum value	2.172	1.732	1.483	2.026	1.923	1.795	1.731	1.808
Minimum value	0.805	0.629	0.551	0.752	0.693	0.672	0.652	0.677
Max/Min	2.697	2.755	2.691	2.692	2.776	2.672	2.656	2.671
Standard deviation	21.35%	21.76%	22.10%	21.65%	22.54%	22.13%	23.66%	22.40%

VW Bus T5 - "Alter"	Mean NOx measured[g/km]	NOx CLEAR [g/km] - Target-Power-Pattern	NOx CLEAR [g/km] - "WLTC"	NOx CLEAR [g/km] - "WLTC-Extended"	NOx CLEAR [g/km] - "Average_ECO"	NOx CLEAR [g/km] - "Average_NORM"	NOx CLEAR [g/km] - "Average_AGG"	NOx CLEAR [g/km] - "Average_ALL"
Average	1.206	1.192	1.025	1.397	1.299	1.222	1.099	1.203
Maximum value	1.531	1.699	1.441	1.860	1.759	1.662	1.470	1.637
Minimum value	0.503	0.650	0.497	0.606	0.497	0.436	0.302	0.413
Max/Min	3.044	2.613	2.901	3.068	3.538	3.808	4.869	3.967
Standard deviation	27.94%	25.68%	30.99%	29.26%	31.05%	32.15%	35.22%	32.73%

5.3 Normalisation results for CO for VW Bus T5

The normalisation results below contain the weighted emission results of the “Standard CLEAR method” in blue and the weighted emission results of the “Extended CLEAR method” in green. In red the measured CO-emissions of each trip are shown.



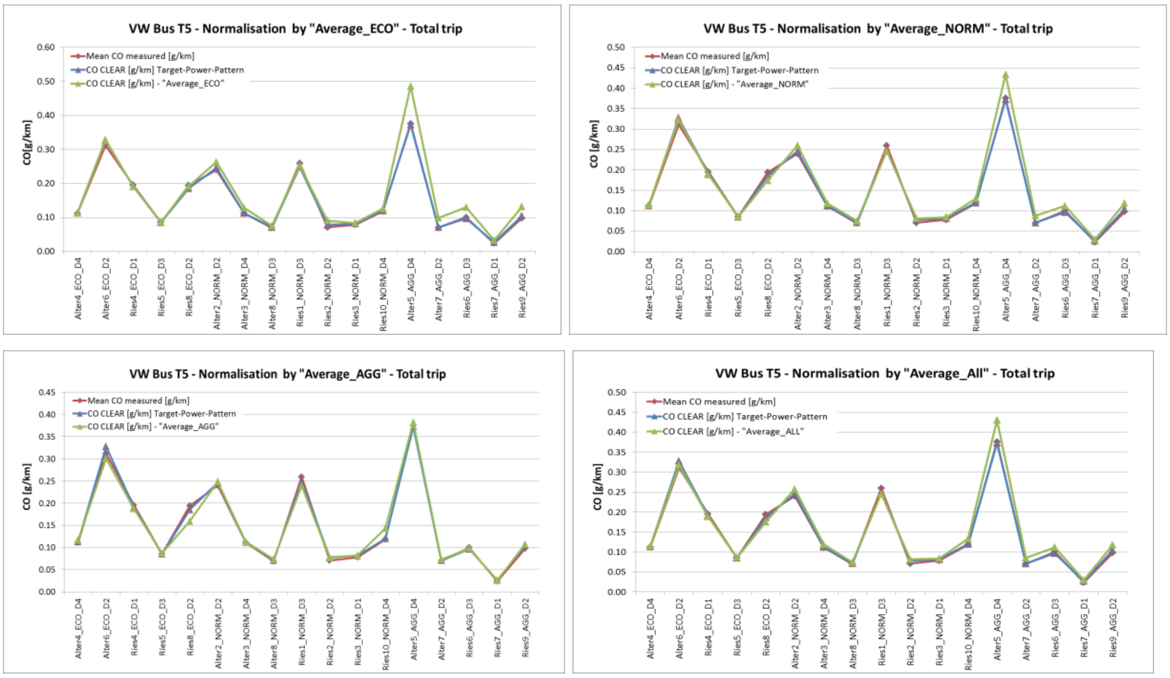


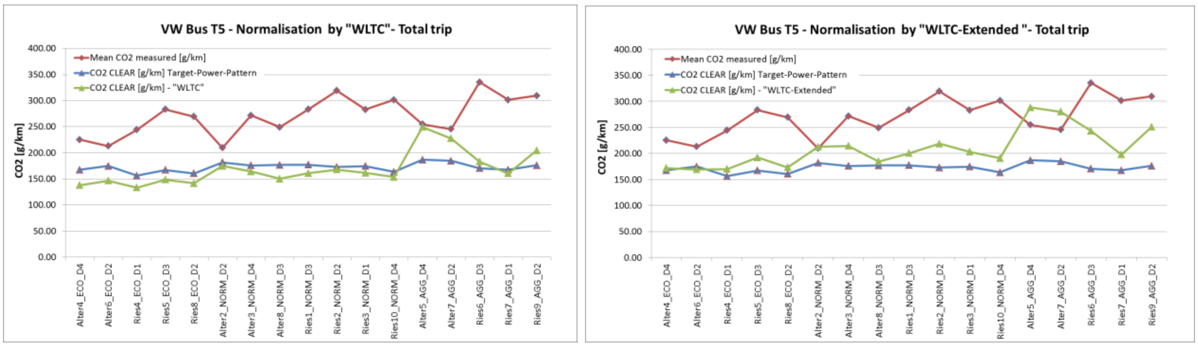
Figure 5-6: Normalisation results for CO for VW Bus T5 (red: measured trip emissions, blue: weighted CO with the "Standard CLEAR method", green: weighted CO by the "Extended CLEAR method")

Table 5-2: Max/min ratio and standard deviation of normalisation results

VW Bus T5	Mean CO measured[g/km]	CO CLEAR [g/km] - Target-Power-Pattern	CO CLEAR [g/km] - "WLTC"	CO CLEAR [g/km] - "WLTC-Extended"	CO CLEAR [g/km] - "Average_ECO"	COCLEAR [g/km] - "Average_NORM"	CO CLEAR [g/km] - "Average_AGG"	CO CLEAR [g/km] - "Average_ALL"
Average	0.148	0.149	0.171	0.169	0.165	0.157	0.148	0.156
Maximum value	0.376	0.373	0.541	0.523	0.486	0.434	0.382	0.431
Minimum value	0.024	0.026	0.036	0.032	0.033	0.030	0.026	0.029
Max/Min	15.934	14.084	15.107	16.327	14.866	14.675	14.833	14.772
Standard deviation	64.53%	63.86%	70.09%	69.38%	66.51%	64.85%	62.19%	64.49%

5.4 Normalisation results for CO_2 for VW Bus T5

Following figure shows the measured and normalised emissions by CLEAR. Red are the measured emissions, blue weighted emissions by the "Standard CLEAR method"(target-power-pattern) and green weighted emissions by the "Extended CLEAR method"(P-rpm-maps).



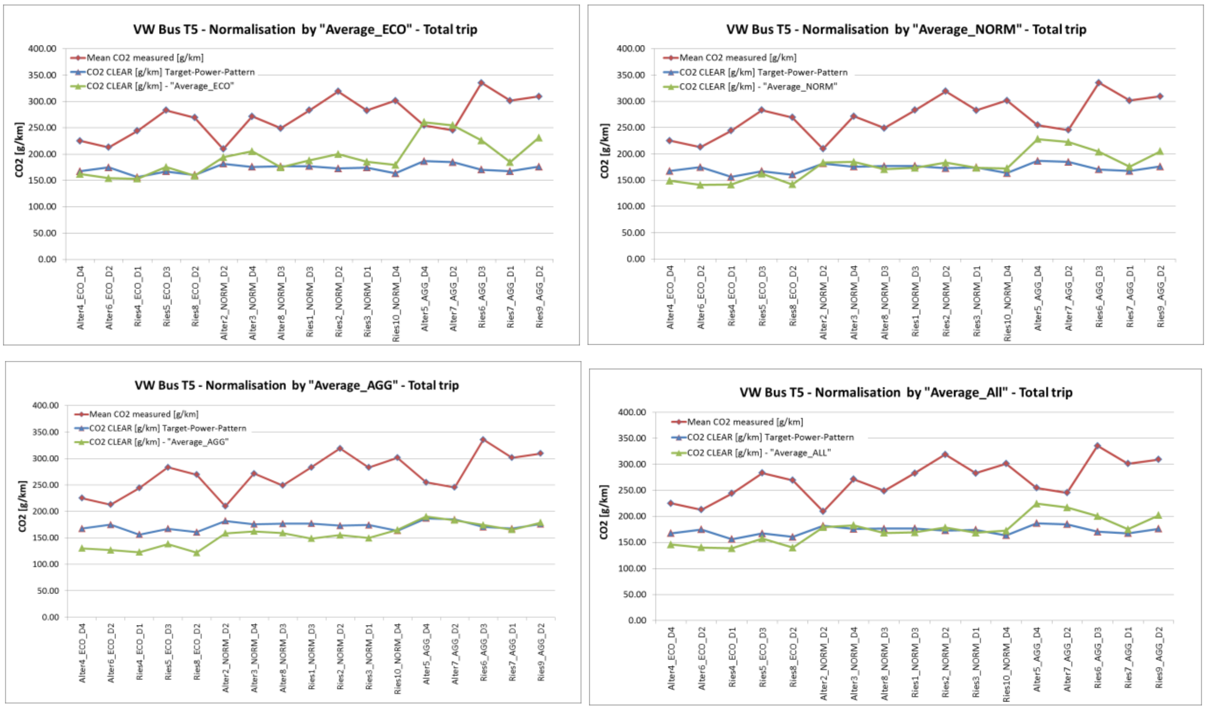


Figure 5-7: Normalisation results for CO_2 for VW Bus T5 (red: measured trip emissions, blue: weighted CO_2 with the "Standard CLEAR method", green: weighted CO_2 by the "Extended CLEAR method")

Table 5-3: Max/min ratio and standard deviation of normalisation results

VW Bus T5	Mean CO2 measured[g/km]	CO2 CLEAR [g/km] - Target-Power-Pattern	CO2 CLEAR [g/km] - "WLTC"	CO2 CLEAR [g/km] - "WLTC-Extended"	CO2 CLEAR [g/km] - "Average_ECO"	CO2 CLEAR [g/km] - "Average_NORM"	CO2 CLEAR [g/km] - "Average_AGG"	CO2 CLEAR [g/km] - "Average_ALL"
Average	264.105	172.631	168.574	209.430	193.429	177.233	154.710	174.235
Maximum value	335.515	186.860	249.476	288.429	260.784	228.190	190.206	224.533
Minimum value	209.643	156.220	133.373	169.236	153.273	140.882	121.850	138.664
Max/Min valid	1.600	1.196	1.871	1.704	1.701	1.620	1.561	1.619
Standard deviation	13.50%	4.62%	18.28%	17.05%	16.52%	14.49%	13.25%	14.42%

5.5 NO_x-emission maps

All NO_x-emission maps are trip specific. Y-axis represents the normalised power P_{norm} and x-axis normalised engine speed n_{norm} (normalised with P_{rated} and n_{rated}). Blue represents low NO_x-emissions and red high NO_x-emissions in [g/h]

5.5.1 Mazda CX5

Following figures show trip specific NO_x-emission maps of the Mazda CX5 for different driving styles for "ROUTE1". The trips cover an economic, normal and aggressive driving style.

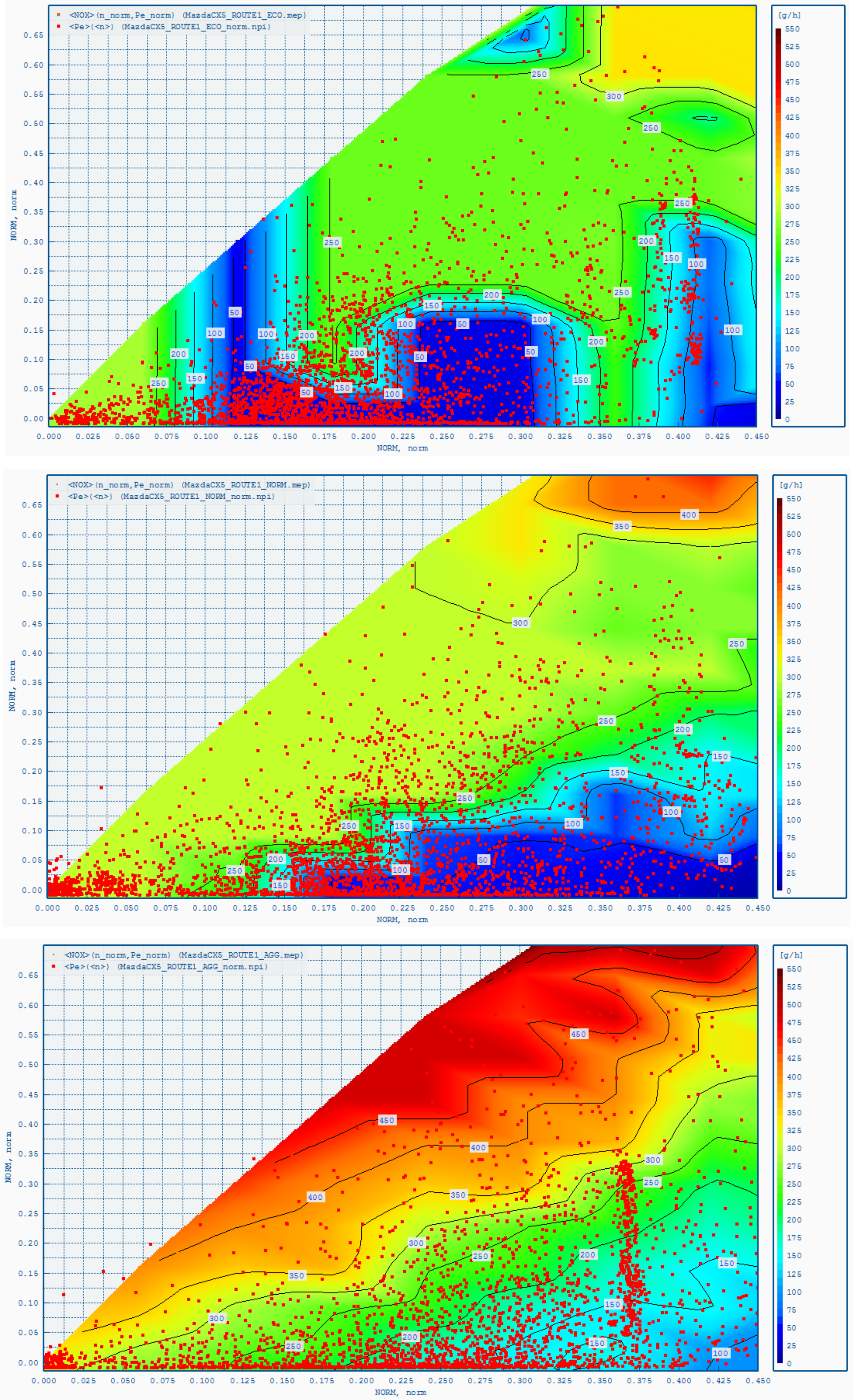


Figure 5-8: Trip specific NO_x-emission maps for Mazda CX5 for “ROUTE1“ driven with an economic, normal and aggressive driving style in [g/h]

5.5.2 VW Bus T5

Following figures show the NO_x emission maps of the VW Bus T5 for different driving styles on the “Ries”- and “Alternative”-route. Conspicuous is the gathering of some trip points of the economic driven route in mid load and mid to high engine speed areas (black encircled), which occurs for two different drivers. The maps are sorted by the driving style of the trip and the route.

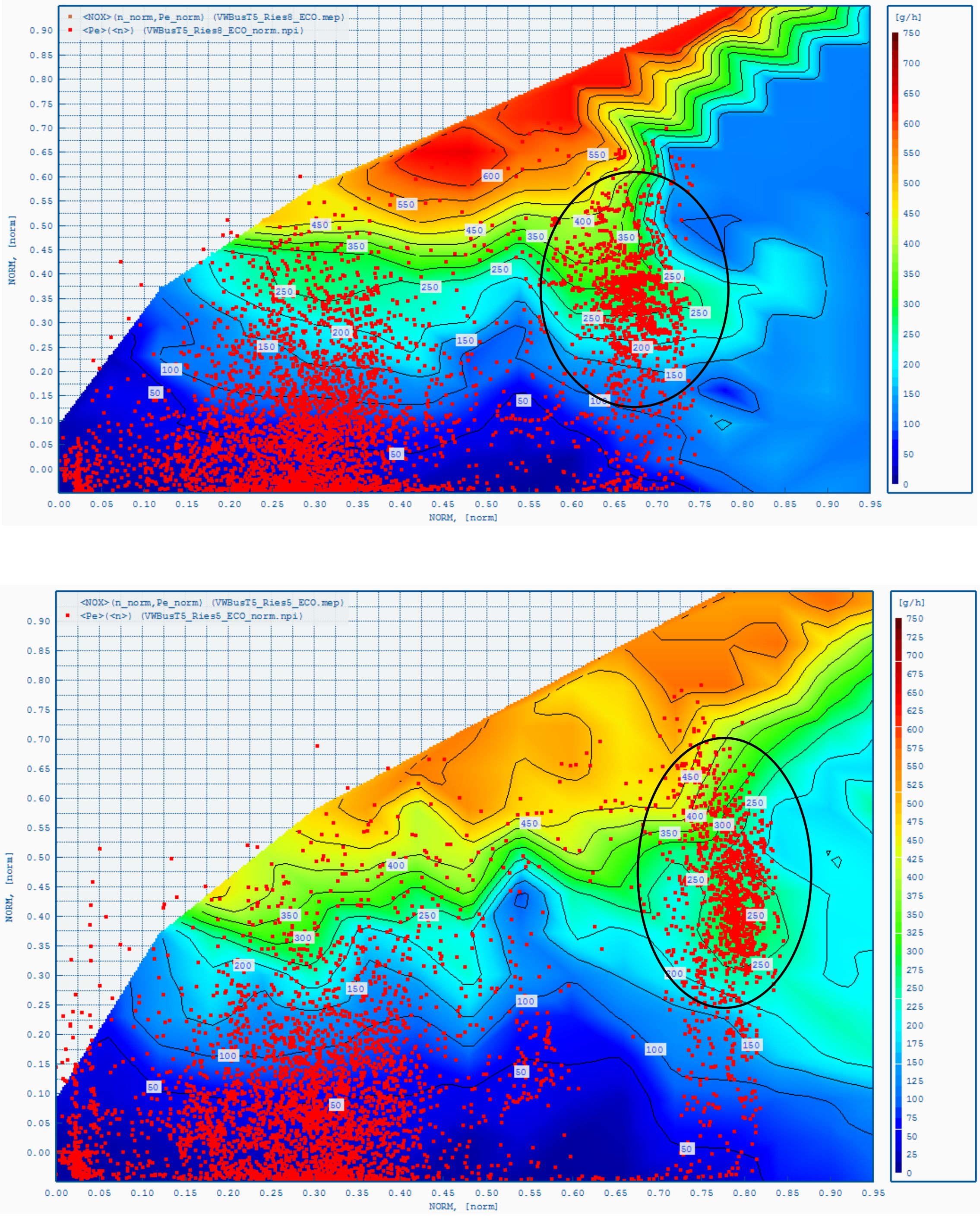


Figure 5-9: Trip specific NO_x-emission map for VW Bus T5 for “Ries8_ECO_D2“ and “Ries5_ECO_D3” in [g/h]

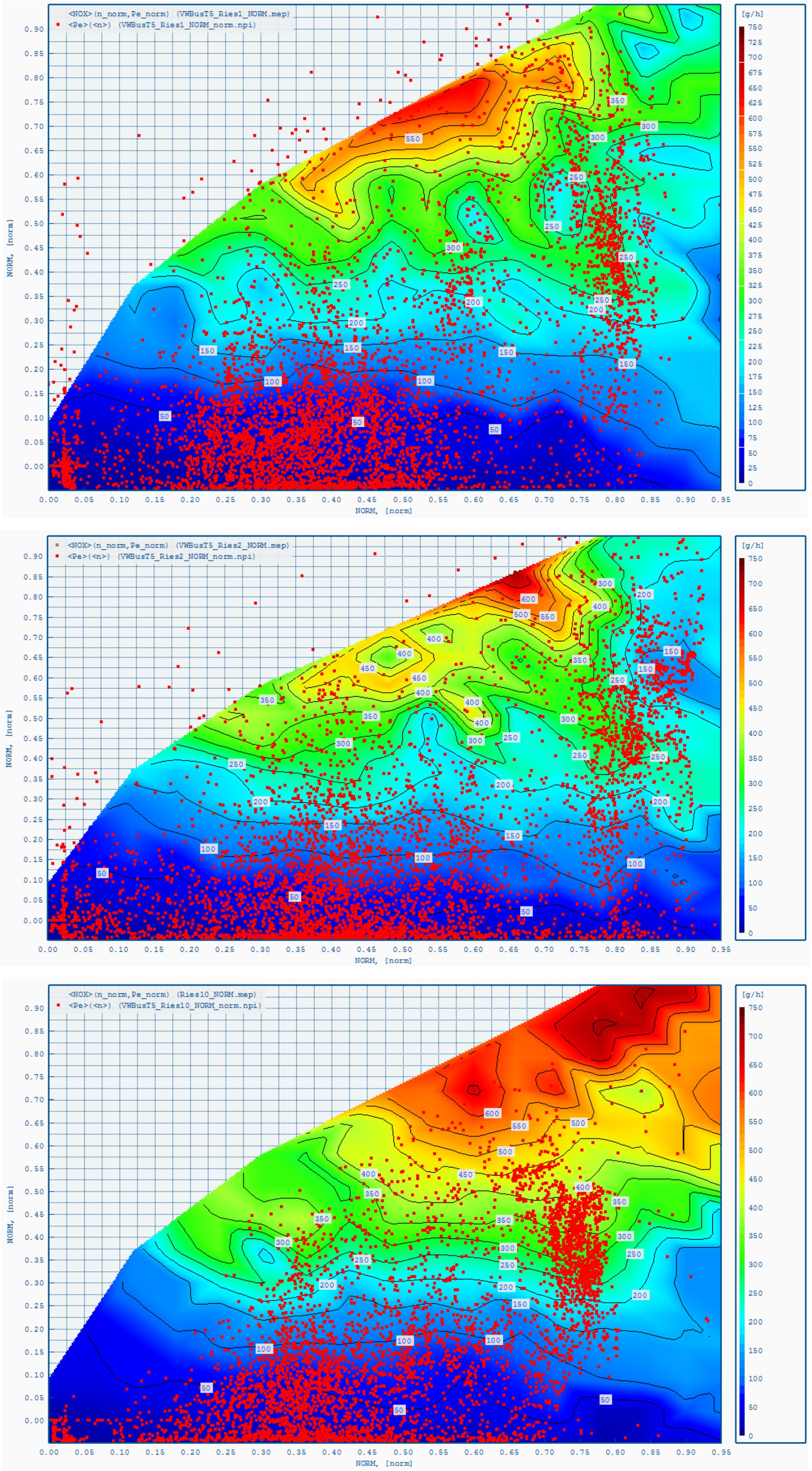


Figure 5-10: Trip specific NO_x-emission maps for VW Bus T5 for “Ries1_NORM_D3“, “Ries2_NORM_D2” and “Ries10_NORM_D4” in [g/h]

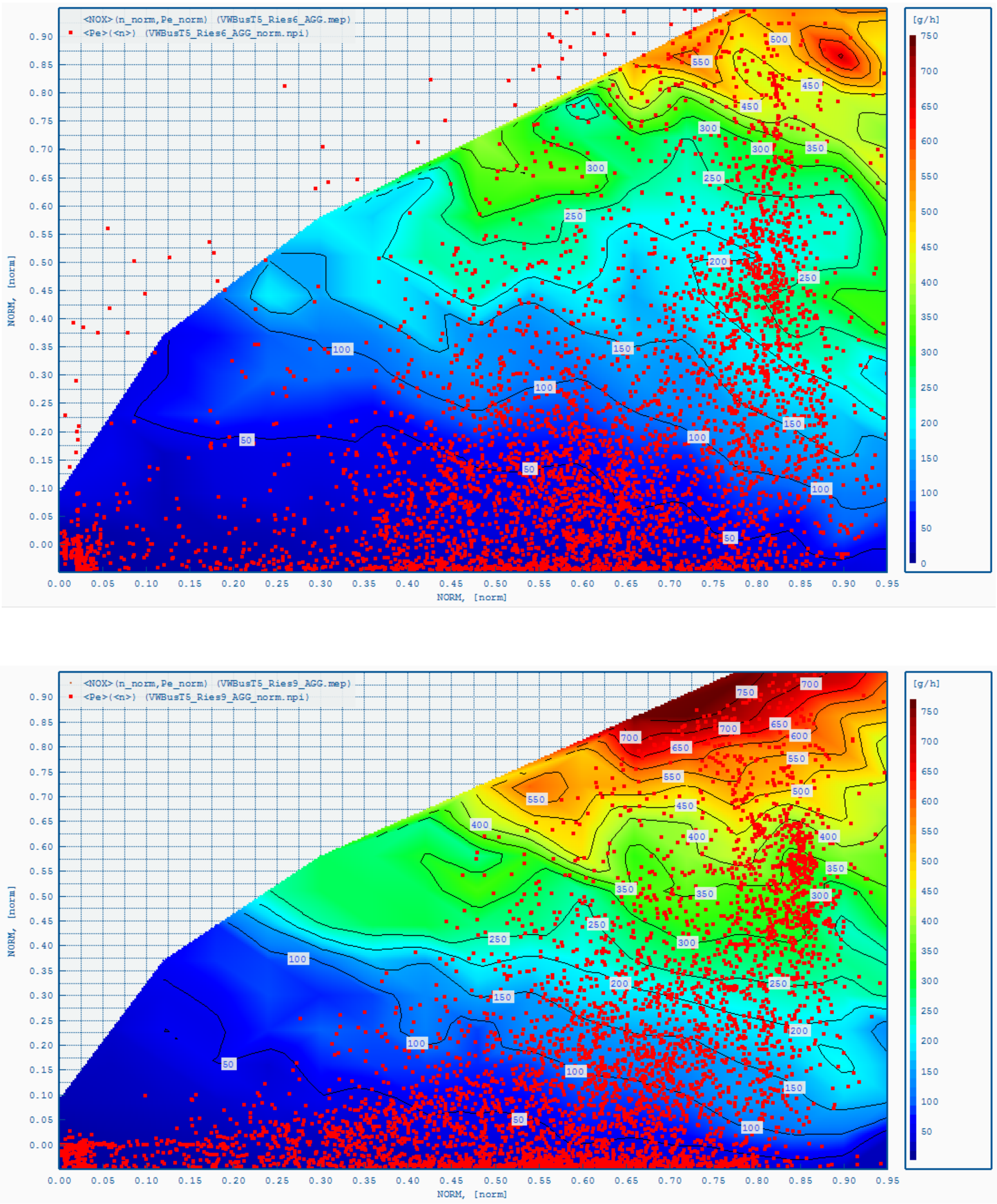


Figure 5-11: Trip specific NO_x-emission maps for VW Bus T5 for “Ries6_AGG_D3“ and “Ries9_AGG_D2” in [g/h]

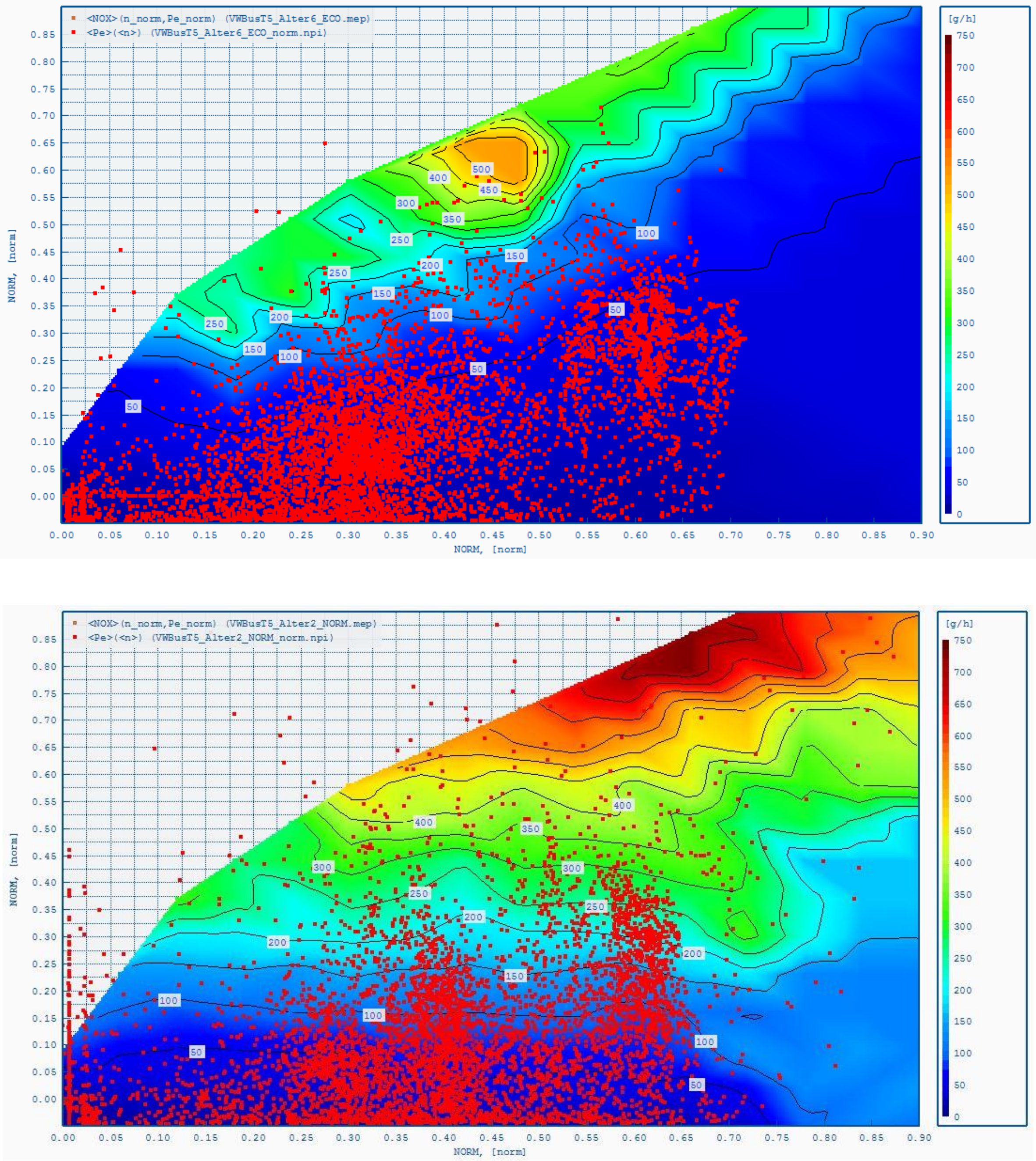


Figure 5-12: Trip specific NO$_x$-emission maps for VW Bus T5 for "Alter6_Eco_D2" and "Alter2_NORM_D2" in [g/h]

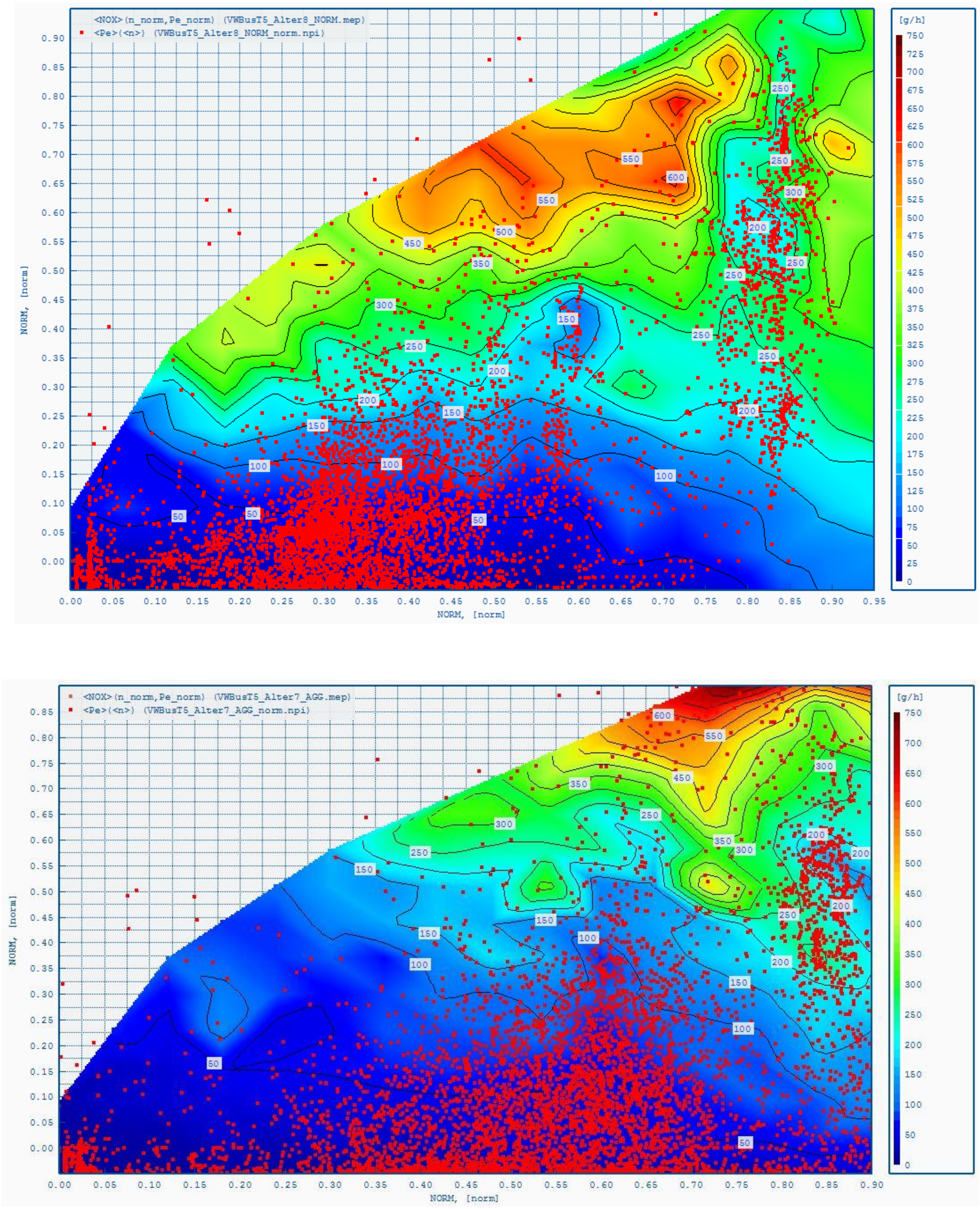


Figure 5-13: Trip specific NO_x-emission maps for VW Bus T5 for “Alter8_NORM_D3” and “Alter7_AGG_D2” in [g/h]

List of figures

List of tables

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