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TNO report

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Monitoring-based assessment of the NO_x-emissions of a Renault Talisman and a Volkswagen Caddy

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Samenvatting

Van emissiemetingen naar emissiemonitoring
Het belangrijkste doel van voertuigemissiemetingen zoals die voor het Ministerie van Infrastructuur en Waterstaat worden uitgevoerd, is het geven van informatie over de emissies van voertuigen op de weg en hoe deze emissies van invloed zijn op de luchtkwaliteit, de natuur en de gezondheid van de burgers. De vastgestelde gemiddelde emissies op de weg vormen de basis voor de Nederlandse emissiefactoren.

Nu voertuigtechnologieën steeds complexer worden en in het licht van dieselgate, zijn in de loop van de tijd nieuwe methoden ontwikkeld om de emissies van wegvoertuigen te bepalen. Vanuit de huidige methodologie (een relatief kort emissietestprogramma van drie dagen) is een verschuiving naar emissiemonitoring ontwikkeld om daarmee een breder gebied aan emissiegedrag van voertuigen te bestrijken. Emissiemonitoring is het meten van voertuigemissies over een langere periode om zo rekening te houden met langetermijneffecten zoals seizoensgebonden effecten en onderhoudsintervallen.

Dit rapport vergelijkt de huidige methodologie op basis van een kort meetprogramma met de nieuwe monitoringmethode en presenteert de emissieresultaten van twee voertuigen die over een periode van meer dan een jaar werden gemonitord. Elk voertuig heeft meer dan 20.000 km gereden, voornamelijk binnen Nederland. Deze twee voertuigen hebben dus het hele jaar door gereden onder typische Nederlandse weers- en weg-omstandigheden.

Monitoring bepaalt de uitstoot van voertuigen bij normaal, dagelijks gebruik.
Het verzamelen van gegevens van willekeurige voertuigen, gebruikt door hun eigenaren, levert een breed palet aan ongesorteerde informatie op. Dit rapport geeft ook inzicht in de manier waarop deze nieuwe emissiemonitoringgegevens worden gesorteerd en gepresenteerd voor verdere analyses.

Resultaten en conclusies
Uit de gepresenteerde resultaten blijkt dat emissiemonitoring een goede methode is om de gemiddelde emissies van voertuigen op de weg te bepalen. Lange termijn effecten zoals een onderhoudseffect, variatie in de bedrijfstoestand, het effect van korte ritten, seizoensgebonden effecten en prestaties van het nabehandelingssysteem kunnen niet worden verkregen via een testprogramma van enkele dagen.

Langetermijn emissiemonitoringgegevens bieden een uitgebreidere beoordeling van het emissieprofiel van het voertuig. De in dit rapport gepresenteerde analyse heeft het effect aangetoond van de variatie van de omgevingstemperatuur gedurende het jaar en het effect van nabehandelingssystemen op de NO_x-emissie.

Als voldoende monitoringgegevens van een voertuig beschikbaar zijn, kan het emissieprofiel van het voertuig en zijn gemiddelde emissie op de weg in detail worden weergegeven, hetgeen de berekening van de Nederlandse voertuigemissiefactoren sterk verrijkt.

Langdurige emissiemonitoring van een voertuig vereist echter meer uitgebreide data-analyses en het gebruik van betrouwbare meetsystemen met goed gekarakteriseerde sensoren die, zonder dat tussentijds onderhoud nodig is, in de voertuigen kunnen worden ingebouwd.

De kosten van monitoring kunnen hoger zijn in vergelijking met de kosten van een kort testprogramma. Daarom moeten zowel de data-analyses en de visuele presentatie van de resultaten op een sterk geautomatiseerde manier worden uitgevoerd. De hoeveelheid data neemt dramatisch toe met een verschuiving van testen naar monitoren. Het monitoren van een groter aantal voertuigen in regulier gebruik kan parallel aan elkaar worden gedaan, wat resulteert in veel meer data.

Ondanks de steeds lagere wettelijke limieten voor NO_x emissies van dieselauto's zijn de praktijkemissies in het verleden steeds hoger geworden (van Euro-4 in 2006, naar Euro-5 in 2009, en Euro-6 in 2014). Maar het begin van dieselgate in september 2015 heeft deze situatie veranderd en er lijkt een dalende trend ingezet voor praktijkemissies. De voertuigen die nu getest zijn, zijn de eerste die na dieselgate op de markt zijn gekomen. De Renault Talisman heeft nog steeds hoge emissies, maar wel lager dan de Renault Megane die is uitgerust met dezelfde motor, maar dan van voor dieselgate. De Renault Megane, gerapporteerd in TNO rapport R11177 uit 2016, had typische NO_x emissies van 700-1000 mg/km. De Renault Talisman stoot tussen de 400 en 800 mg/km uit. De Volkswagen Caddy is een voorbeeld van een dieselauto met lage NO_x emissies vooruitlopend op de nieuwe wettelijke eisen op basis van wegtesten. De Volkswagen Caddy heeft een NO_x uitstoot tussen 35 en 150 mg/km. De schoonste voertuigen komen nu in de buurt van de limiet van 80 mg/km op de NEDC typekeuringstest die voor al deze voertuigen geldt. Maar de spreiding in resultaten is zeer groot.

Aanbevelingen
Als er voldoende monitoringgegevens beschikbaar zijn, kan het emissieprofiel van een voertuig in detail worden weergegeven. Het is dan ook aan te bevelen om lange termijn monitoring van voertuigemissies, met gebruik van automotive sensoren, deel uit te laten maken van de toekomstige emissiewetgeving, dat wil zeggen in de post- Euro-6/VI-wetgeving zoals die momenteel in Brussel wordt besproken.

Uiteindelijk moet voertuigemissiewetgeving zorgen voor een lage uitstoot gedurende de levensduur van het voertuig. In het verleden lag de nadruk op de typegoedkeuring van nieuwe voertuigen en een beperkt aantal handelingen zoals vastgelegd in de typegoedkeuringstest. De verschuiving naar monitoring kan zorgen voor goede emissieprestaties tijdens de gehele levensduur van het voertuig. Dit is misschien niet allemaal de verantwoordelijkheid van de fabrikant, maar de fabrikant moet in de toekomst de controle van de emissieprestaties mogelijk maken.

Summary

From emission measurements towards emission monitoring
The main purpose of the vehicle emission measurements as performed for the Ministry of Infrastructure and Water Management is to provide information about on-road emissions of vehicles and how these emissions affect the air quality, nature, and the health of citizens. The average on-road emissions that are determined form the basis for the Dutch emission factors.

With vehicle technologies becoming more complex, and in the light of diesel-gate, new approaches to determine on-road vehicle emissions have developed over time. The current methodology consists of a relatively short emission test program of three days. To cover a wider range of emission behavior of vehicles a shift towards emission monitoring is explored. Monitoring emissions is measuring emissions over a longer period of time to incorporate long term effects like seasonal effects and maintenance intervals.

The results of this exploration are covered in this report by comparing the current methodology with the new monitoring methodology and showcasing two vehicles that were monitored over a period longer than one year. Each vehicle has driven over 20,000 km of distance and is driven mainly in the Netherlands. These two vehicles, therefore, have been driven through the typical weather and road conditions in the Netherlands, throughout the year.

Monitoring determines the emission of vehicles in normal, daily use. Collecting data from random vehicles, used by their owners will produce a wide palette of unsorted information. This report also provides insight in the way how this new emission monitoring data is sorted and presented for analyses.

Results and conclusions
The presented results show that emission monitoring turns out to be a sound methodology to determine the average on-road emissions of vehicles. Long term effects such as maintenance effect, variation of operating condition, short trips, seasonal effects, and aftertreatment performance are not captured in a test program of a few days.

Long term emission monitoring data offers a more comprehensive assessment of the vehicle emission profile. Analysis presented in this report have shown the effect of the variation of ambient temperature throughout the year and the effect of the after treatments towards NO_x emission.

With sufficient monitoring data of a vehicle being available, the emission profile of the vehicle and its average on-road emissions can be thoroughly represented, which enriches the calculation of the Dutch vehicle emission factors very much.

Long term emission monitoring of a vehicle requires more elaborate data analyses and use of reliable measurement systems with well characterized sensors that can be built in into the vehicles for a longer period of time without requiring maintenance. The associated costs, can be higher compared to the costs of a short test program. Therefore data analyses and visual presentation of the results must be done in a highly automated way.

The amount of data increases dramatically with a shift from testing to monitoring. Moreover, monitoring of a larger number of vehicles in regular use can be done in parallel resulting in much more data.

Despite the ever decreasing legal NO_x emission limits of diesel passenger cars, the average real-world emissions have increased (from Euro-4 in 2006, to Euro-5 in 2009, and Euro-6 in 2014). But with diesel gate a turn can be seen, and the real-world emission performance is improving. The vehicles monitored in this report are among the first vehicle available after diesel gate. The predecessor of the Renault Talisman with the same engine, was the Renault Megane, which was tested by TNO. In the report TNO report R11177 from 2016, the Megane had typical NO_x emissions between 700 and 1000 mg/km. The successor Renault Talisman has emissions between 400 and 800 mg/km. The Volkswagen Caddy has real-world NO_x emissions between 35 and 150 mg/km, and it performs much better. All three vehicles have to satisfy on the NEDC type-approval test a limit of 80 mg/km. The cleanest vehicles, prior to the RDE legislation are getting close to meeting the requirements as intended in Euro-5/6 legislation. But other vehicles, despite of diesel gate, still have very high emissions.

Recommendations
With sufficient monitoring data available, the emission profile of a vehicle can be thoroughly represented. As such, it is recommended that long term emission monitoring, with automotive sensors, be part of the future emission legislation, i.e., post Euro-6/VI legislation as currently discussed in Brussel.

Eventually, vehicle emission legislation should ensure low emissions over the lifetime of the vehicle. With the focus in the past on type-approval, the focus was on new vehicles and a limited range of operations as captured in the type-approval test. The shift towards monitoring may ensure a good lifetime emission performance. This may not all be the responsibility of the manufacturer. But the manufacturer should enable in the future the control of emission performance.

Contents

1 Introduction

The main purpose of the vehicle emission testing for the Ministry of Infrastructure and Water Management is to provide information about on-road emissions of vehicles and how these emissions affect the air quality, nature, and the health of citizens. The average on-road emissions that are determined form the basis for the Dutch emission factors.

With vehicle technologies becoming more complex, and in the light of diesel-gate, new approaches have developed over time. Monitoring emissions is aimed at measuring emissions over a longer period of time to incorporate long term effects like seasonal effects and maintenance intervals. Monitoring is not yet used to determine the average emissions of light duty vehicles in the Netherlands.
The current methodology consists of a relatively short emission test program of three days. To cover a wider range of emission behaviour of vehicles and long term effect, a shift towards emission monitoring is explored. The results of this exploration are covered in this report by comparing the current methodology with the new monitoring methodology, and showcasing two vehicles that were monitored over the period of a year. Monitoring determines the emission of vehicles in normal, daily use. However, collecting data from random vehicles, used by their owners will produce a wide palette of unsorted information. This report also provides insight in the way how this new emission monitoring data is sorted and presented for analyses.

Current methodology: Three day emission measurement program
To cover the emissions in all normal traffic conditions in the Netherlands, an extended on-road test program was developed in 2016. This test program covers also a number of RDE (Real Driving Emission legislative) tests. RDE test are intended to provide boundary conditions such that tests fit in an European average with a combination of urban, rural and motorway driving, within certain limits to compare against the legal emission limits. However, for a more complete coverage of the Dutch traffic situations, more tests have been included. The final test program is designed in such a way that driving in urban, rural, and motorway with 3 different payload and different driving styles are included (in total 14 individual tests). In total three RDE tests are included.

The tests typically span 3 days to complete and the vehicle emission is aggregated to national emission factors using weighting factors.

The test programme, however, does not assess the effect of long term parameters to vehicle emission. For example, effect of changing ambient temperature in the Netherlands throughout the year is not captured in the 3 day test programme. Although some indication of temperature dependence can be deduced from comparing early morning and late afternoon tests. Furthermore modern vehicles have increasingly incorporated more complex technology to reduce emissions. The higher complexity results in difficulty in assessing its performance and emissions output in a single standardized test or a test program of a couple of days, which may not cover much of the variation observed in normal use.

New methodology: Emission monitoring for several months
To cover a wider range of emission behaviour and account for different parameters that affect emissions and getting a better understanding of the efficiency of technology to reduce emissions, emission monitoring as new methodology is explored. Long-term monitoring data can be used to offer a more complete representation of the vehicle emission. Effects of changing ambient temperature, aftertreatment, and maintenance to the vehicle emission can be investigated. Analysis of the monitoring data will also describe the emission trend of the vehicle regardless of driving behaviour and it can be further incorporated to the calculation of emission factors. However, monitoring data does not naturally cover all traffic conditions, as is to be relied on the typically vehicle usage of a normal car user. When a limited set of vehicles is monitored, the collected data has to be analysed to separate the effect of the use from the emission characteristics of the vehicle.

Towards emission monitoring based assessment
The report starts in Chapter 2 with the presentation of new visualisations, normalisations and detailed insights that are made possible by monitoring emission over a longer period of time. Chapter 3 is dedicated to compare the current methodology, the three day emission measurement program, with the new emission monitoring methodology. The comparison is made with data from a Volkswagen Caddy Diesel. In Chapter 4, the monitoring data of two light duty diesel vehicles, Renault Talisman Diesel and Volkswagen Caddy Diesel, are analysed.

SEMS: Smart Emission Measurement System
The data collection for the emission monitoring is carried out using the Smart Emissions Measurement System (SEMS). This system, developed by TNO, logs vehicle emissions such as NO_x and NH_3 as well as OBD signals of the vehicle. To measure the emissions, sensors are mounted in the exhaust of the vehicle, an example is shown below in Figure 1.1.

Figure 1.1: Example of sensors as used by SEMS, mounted in the exhaust of a vehicle.

All data is collected in the SEMS unit, a dedicated datalogger with enriched functionality such as a ‘can bus’ interface, GPS and wireless communication by 4G. Collected data is sent to a database after which further (automated) processing can be performed. The small SEMS datalogger unit is shown in Figure 1.2 .

Figure 1.2: The SEMS datalogger with cabling to/from sensors, GPS, OBD and power connections.

For further information on the SEMS system and its application, the reader is referred to the TNO methodology report [TNO2016a].

This report concludes with the current conclusions on the exploration of emission monitoring as possible replacement for the current methodology (the three day emission measurement program) to assess vehicle emissions as a basis for the Dutch emission factors.

The monitoring started from April 2018 and continued till late 2019. Each vehicle has driven over 20,000 km of distance and is driven mainly in the Netherlands. These two vehicles, therefore, have been driven through the typical weather and road conditions in the Netherlands, throughout the year.

2 Visualisation of normalised vehicle emission

With emission monitoring, new challenges arise on how to visualise the different set of data that is gathered. In this chapter the choice of visualisation and normalisation of emission data is motivated and explained.

By presenting emission data by vehicle operation points in so called emission maps, the emission characteristics of the vehicle are brought to the front. Emission maps are a common approach to present data. The right choice of variables in the emission maps will make the map more stable and independent against typical usage of vehicles and the variation of environmental conditions in which the data was collected. Normalisation of the data, to have a uniform presentation independent of the type of tests, is little more than the averaging over all the data for a given operation point, i.e., point in the map. The use of emission maps of NO_x emissions against velocity and CO_2 rate is central to this chapter, as it shows the main dependencies of NO_x emissions of modern diesel vehicles. The CO_2 emission rate is identical to the fuel consumption and an approximation of the power demand.

Only the absence of certain vehicle operations in normal use, and the absence of certain conditions, such as high or low ambient temperatures, should show up as blind spots.

2.1 Engine map of average NO_x emission flow rate

The two-dimensional map of average NO_x mass flow represents the distribution of NO_x emission trend depending on the two parameters vehicle velocity and CO_2 mass flow rate. The velocity is a central parameter to assess emissions in different traffic situations whereas CO_2 rate is a good proxy for the engine power demand. Engine power demand will vary with acceleration, payload, road slope, and wind. Figure 2.1 shows as an example the NO_x emission trend depending on vehicle speed and CO_2 emission.

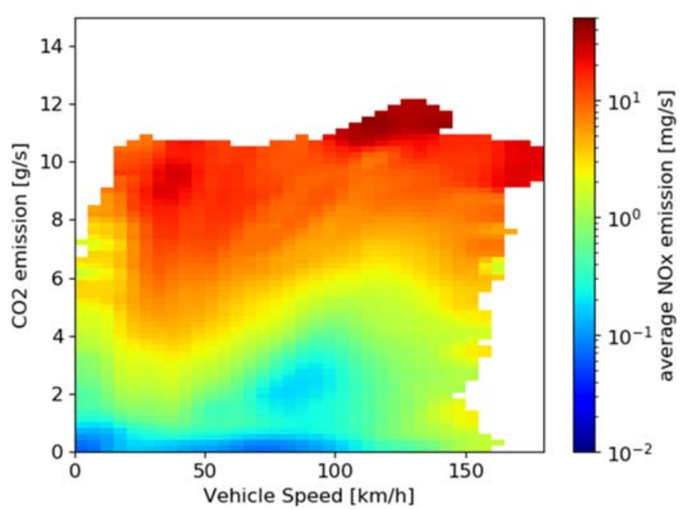

Figure 2.1: Two-dimensional-map of average NOx mass flow of a Volkswagen Caddy, based on a year of monitoring data.

In separate analyses in this report, the typical CO_2 rate for velocities is to be analysed. Emissions were previously plotted against velocity and acceleration, but acceleration is only one of the parameters that link to the engine operation, albeit an important one.

Analyses in the past, from the test programme, such the Euro-6 vans (TNO report 2017 R11473), has shown that each vehicle technology has its own particular emission map in terms of velocity and CO_2 rate showing the particular optimizations and weak spots in the emission control. In particular high engine load, and high CO_2 emissions rates, may lead to a disproportional increase in NO_x emissions. Also the effect of constant operation on the motorway between 80 - 100 km/h show up as an area of very low emissions in the emission map for many modern diesel vehicles, sold from 2016 onwards. At 100 km/h the CO_2 emission rate is about 2.5 g/s. In Figure 2.1. this operational point, NO_x emissions rates are in the order of 0.2-0.4 mg/s, leading to extremely low emissions, at a factor 10 below the limit of 80 mg/km. In the cases of higher dynamics at 80-100 km/h emissions are higher as CO_2 rate will vary outside the region 1-3 g/s.

On the other hand, the region with vehicle speed lower than 50 km/h and CO_2 emission higher than 3 g/s represents a highly dynamic driving within the city. Clearly, the dynamics, possibly in combination with the gear shifting is the poorest performance of this vehicle, which is still well below the type-approval limit for this vehicle.

2.2 Engine map of average NO_x/CO_2 ratio

It is only natural to assume that with higher engine loads, and CO_2 rates, the emissions increase as well. A disproportional increase in emissions, would be a much larger increase in NO_x emission than the increase in CO_2 emission.
To get a better understanding of the efficiency of the exhaust emission aftertreatment system, the NO_x/CO_2 ratio indicates how much NO_x [mg] is emitted per CO_2 unit [g]. Such a plot makes even more clear the low emissions at constant speed of 80 to 100 km/h. The NO_x emission can vary between 0.05 and 1 mg/g CO_2.

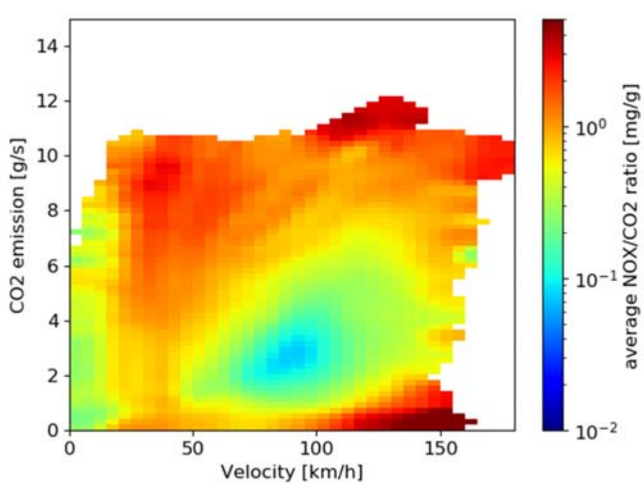

Figure 2.2: Two-dimensional-map of NO_x/CO_2 ratio of a Volkswagen Caddy.

The two-dimensional-map of NO_x/CO_2 ratio represents the normalised NO_x emission regardless of the instantaneous fuel consumption. The visualised normalised NO_x emission therefore is independent from air flowrate at various engine speed and engine torque. The NO_x/CO_2 is somewhat independent of the details of the engine operation.

The lowest NO_x/CO_2 can be found in vehicle speed range of 80-100 km/h, with CO_2 emission 2-3 g/s. This represents the constant speed operation of the vehicle in the rural and motorway, which supports the low NO_x emission rate in Figure 2.1.

In contrast with Figure 2.1, NO_x/CO_2 is relatively high in vehicle speed range 30-50 km/h, with CO_2 emission 0-4 g/s. This may indicate that the low NO_x emission rate in Figure 2.1 in the same range is more correlated to the low CO_2 emission flow.

2.3 Average emission per binned parameter

Another representation of the data, is the average for each velocity. Data binned in this manner includes the typical dynamics of driving at each velocity. Whether this driving is representative for the average Dutch traffic remains unclear. As seen before, the low dynamics driving on the motorway, between 80 and 100 km/h leads to lower emissions, than higher dynamics, on, e.g., rural roads. The emission per velocity is an average of different dynamics. This average does indeed lead to the lowest mg/km NO_x emission at 90 km/h. Probably, because at this velocity there is less low dynamics in rural driving than at 80 km/h on the motorway were driving is generally very constant.

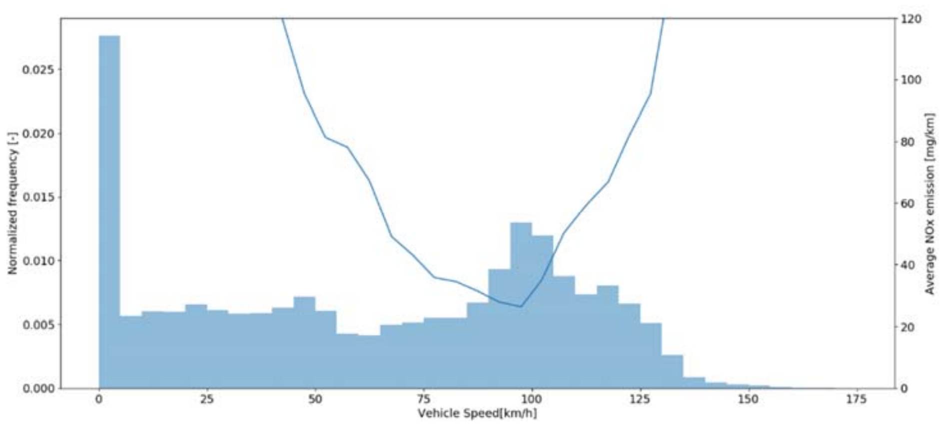

Figure 2.3: Average NOx emission [mg/km] per vehicle speed bins, showing the minimum average NO_x emission below 30 mg/km at 95 km/h.

Figure 2.3 shows the distribution of data per vehicle speed range and the blue line illustrates the average NO_x emission [mg/km] in each vehicle speed bin.
The distribution of the vehicle speed shows the quantity of data contained per bin to determine if the average NO_x emission is reliable. For example the high NO_x emission from vehicle speed higher than 150 km/h (from safe and legal driving in Germany) might be caused by the small quantity of the vehicle speed data rather than actually vehicle emission performance. The amount of data at each velocity, except maybe above 160 km/h, is sufficient to draw conclusions.

However, it is clear that velocities above 130 km/h are less likely for a vehicle based in the Netherlands. Moreover, this vehicle show the common pattern of a homogeneous distribution over velocities, with higher representation at motorway velocities.

3 Analysis of monitoring data of two Volkswagen Caddy vehicles

In this chapter the average emissions derived from a three day measurement program is compared with the emissions derived from emission monitoring. Initially, from 2016 onwards, vehicles were tested only over a period of 2 to 3 days. Only later, vehicle have been monitored over longer periods. The added value of monitoring vehicles over a longer period can been shown by comparing the two different approaches on the same vehicle model, i.e., the Volkswagen Caddy diesel Euro-6a.

3.1 Monitoring vs RDE tests and dedicated test data of Volkswagen Caddy

Two Volkswagen Caddy vehicles have been used for emission behaviour studies. The two vehicles, in this report marked as C1 and C2 are exactly the same type, variant and should have comparable emissions. The vehicle C1 was driven in test programme in May 2017 and its findings have been reported in [TNO 2017 R11473].

The vehicle C2 has been monitored since 6 April 2018 and was driven in the standard TNO test programme which includes 3 RDE tests in July 2018.

The vehicles specification sheet and summary of the tests of these two vehicles can be found in the Appendix.

In the following paragraphs the data of the three days test programme is compared with the data of the monitoring. The short period of the test programme covers only a part of the data in the monitoring programme.

3.2 Overview of monitoring data of Volkswagen Caddy C2

The monitoring data from the Volkswagen Caddy C2 is collected from 6 April 2018 to 28 May 2019 (so in total over more than one year), which covers around 23,800 km of driving and 400 hours of driving. The distance travelled over this period is shown on Figure 3.1. The vehicle is used by TNO employees for visits, moving equipment, and testing. The use, albeit not very intensive, could be considered normal but varied for a small van.

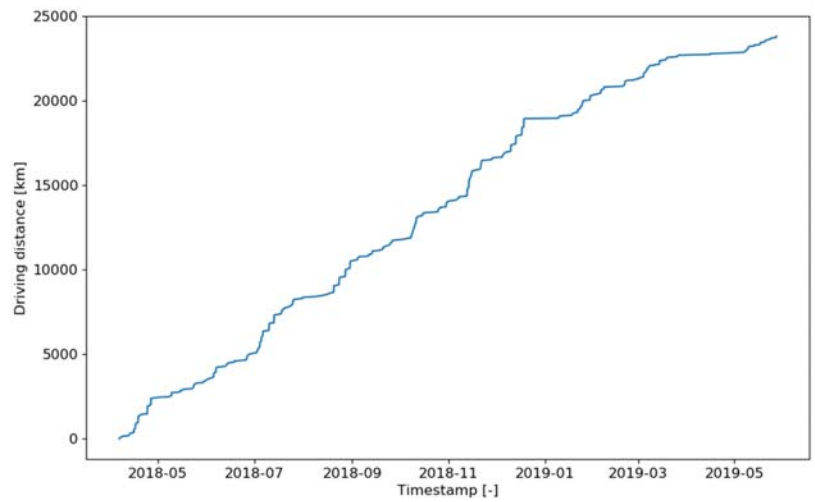

Figure 3.1: Driving usage of Volkswagen Caddy C2 for monitoring data analysis.

3.3 Representativeness of test data compared with monitoring data

The comparison of the monitoring data and test programme data are shown in Table 1. This table shows that the average NO_x and the CO_2 emission distracted from the monitoring data is higher than from the RDE test data (82% and 7% higher, respectively, for the Volkswagen Caddy C2).
Moreover, the test programme data from two vehicles of the same type have resulted in different average NO_x and CO_2 emissions

Table 1: Comparison of quantity of data from monitoring with RDE tests of two Volkswagen Caddy vehicles.

	Monitoring Data VW Caddy C2	RDE Test data VW Caddy C2	RDE Test Data VW Caddy C1
Total distance driven [km]	23,801	845	819
Average NO_x emission [mg/km]	71	39	70
Average CO_2 emission [g/km]	145	136	127

Figure 3.2 shows the normalized distribution of monitoring data and test programme data of Volkswagen Caddy C2. The monitoring data shows a more frequent driving in motorway, a larger range of ambient temperature, and larger range of exhaust gas temperature. The RDE test data shows more frequent driving in urban and rural ways, with a narrow range of ambient temperature and exhaust gas temperature.

The distribution of velocity times positive acceleration ($v*a_{pos}$) represents the change in specific power required to accelerate the vehicle. This parameter is used in RDE legislation to judge the aggressiveness of the driving behaviour in the RDE test. Simply said, the parameter presents the amount of hard acceleration in the test. There is minimal difference in distribution of $v*a_{pos}$ between the monitoring and test program data. The comparisons show the test programme covers only part of all driving, with slightly lower dynamics and lower velocity than in the monitoring programme.

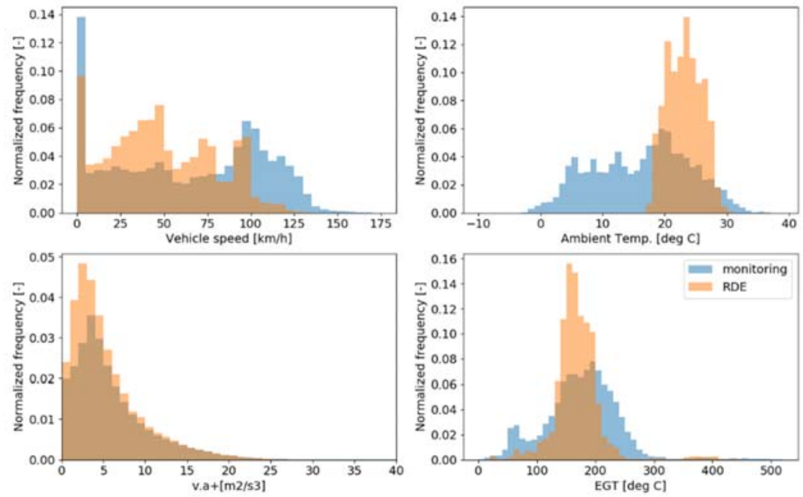

Figure 3.2. Comparison of monitoring data with test programme data for Volkswagen Caddy C2.

Figure 3.3 shows the monthly average NO_x emission [mg/km] of the monitoring data and the test programme data for Volkswagen Caddy C2. The monitoring data shows variation of average NO_x emission [mg/km] throughout the year 2018 between 20 mg/km to 140 mg/km, whereas the test programme data only represents a small part of the emission trend.

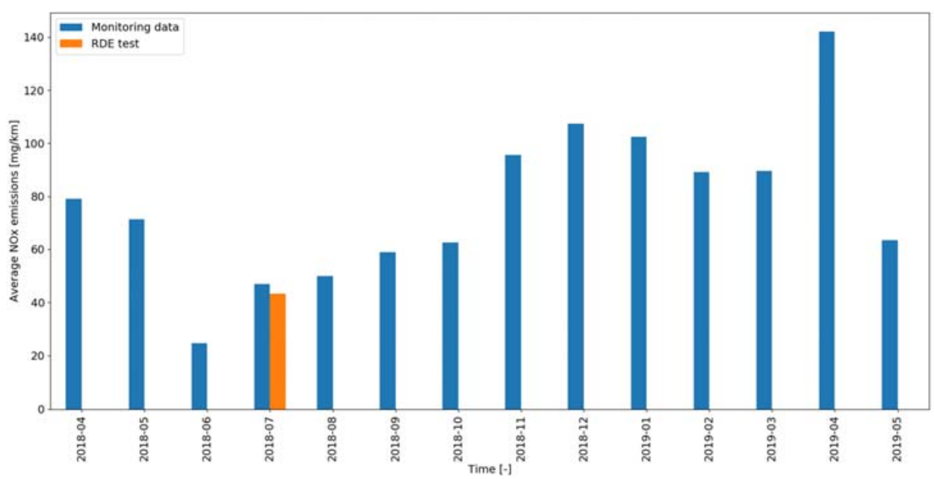

Figure 3.3: Monthly average NO_x emission [mg/km] between monitoring data and test data for Volkswagen Caddy C2.

This average NO_x emission [mg/km], however, is dependent on the amount of distance driven. In the month April 2019, with the highest emission, for example, the vehicle was only driven with 120 km distance for total of 3 hours. From the months with sufficient data the variations in emissions is still very large.
The seasonal variations seem dominant in the results.

3.4 Normalised NOx emission profile of Volkswagen Caddy C2

The normalised NO_x emission profile that is defined in Section 2 are plotted for general overview of performance of Volkswagen Caddy. Volkswagen Caddy C2 is chosen for analysis as it has been more extensively used for normal driving.

Figure 3.4 shows the average NO_x emission of the Volkswagen Caddy C2 as a function of vehicle speed bins. It is observed that the average NO_x emission decreases to the minimum of 26.2 mg/km at average vehicle speed around 90-100 km/h, before increasing again at higher velocities. This shows that this vehicle has the lowest the NO_x emission during motorway driving at 80-100 km/h.

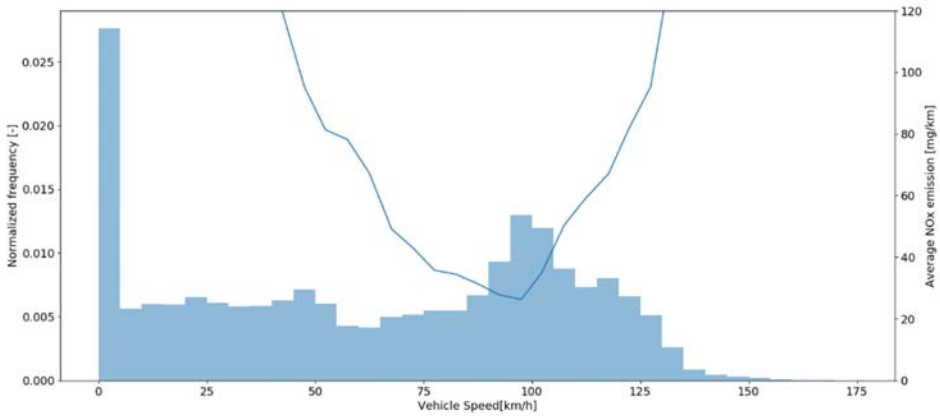

Figure 3.4: Average NO_x emission [mg/km] of Volkswagen C2 as a function of vehicle speed bin.

Figure 3.5 shows the two-dimensional-map of average NO_x flow of Volkswagen Caddy C2. As described in Section 2, NO_x emissions rates in 100 km/h with CO_2 rate of 2.5 g/s has the lowest average NO_x emission at the order of 0.2-0.4 mg/s. This low NO_x emission region correlates with the low NO_x emission shown in Figure 3.4.

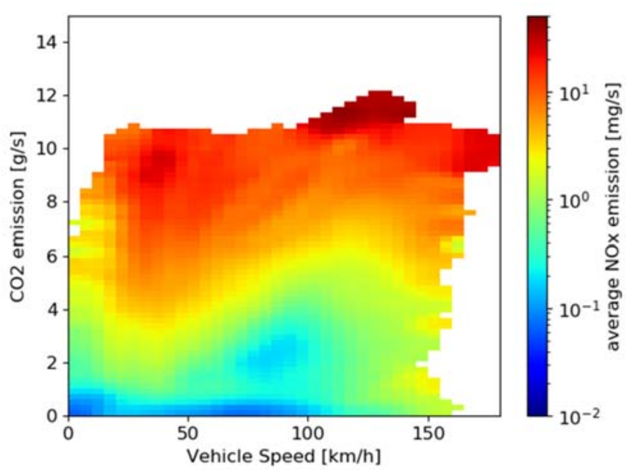

Figure 3.5: Two-dimensional-map of average NO_x mass flow of Volkswagen Caddy C2.

Figure 3.6 shows the two-dimensional-map of NO_x/CO_2 ratio of Volkswagen Caddy C2. As explained in Section 2, the lowest NO_x/CO_2 can be found in vehicle speed range of 80-100 km/h, with CO_2 emission 2-3 g/s. This represents the constant speed operation of the vehicle in the rural and motorway, which supports the low NO_x emission rate in Figure 3.5. However the NO_x/CO_2 ratio is high in vehicle speed range 30-50 km/h, with CO_2 rate 0-4 g/s. This may indicate that the low NO_x emission rate in Figure 3.5 in the same range is more correlated to the low CO_2 emission flow.

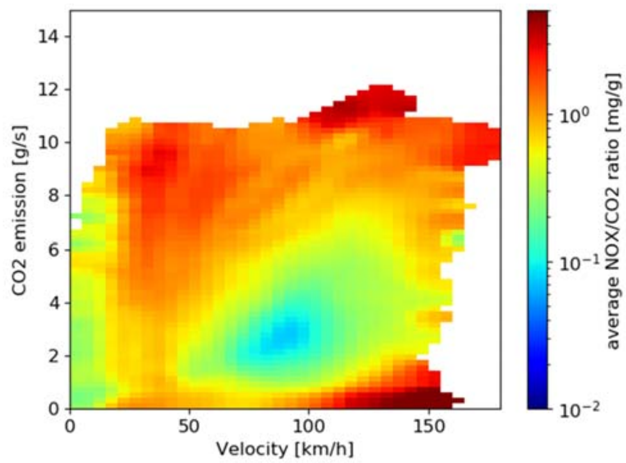

Figure 3.6: Two-dimensional-map of NO_x/CO_2 ratio of Volkswagen Caddy C2.

The CO_2 emission rate above 10.5 g/s, i.e., above the maximum power, is typically associated with DPF regenerations, which occur at accelerations above 80 km/h.

3.5 Identification of factors affecting NOx emission

Further studies on the monitoring data of Volkswagen Caddy C2 was carried out to learn the NO_x emission effects. The generic and average results are the main trends. However a large variation for a given velocity and dynamics remains. Further analyses is required in order to find the possible causes in conditions or vehicle use. In the following sections the different aspects like effect of dynamic driving, DPF regeneration and effect of ambient temperatures are further investigated.

3.5.1 Effect of dynamic driving in urban area

Figure 2.2 shows that in the vehicle speed ranging from 0-50 km/h, a high NO_x/CO_2 ratio occurs. Further investigation shows that the large NO_x/CO_2 ratio in this region is caused by the high dynamic driving.

Figure 3.7 shows the average NO_x emission [mg/km] per binned vehicle speed for all datasets and without acceleration (a < 0.5 m/s2). The amount of data that is reduced by this filtering is 14.4% (see Table 3) and the distribution graph shows that the quantity of data is sufficient for statistical analysis. This small fraction of total time does, however, represent half of the total NO_x emissions at low velocity.

It can be shown that the average NO_x emission with constant speed driving (orange line) is lower than the overall average until vehicle speed reaches 100 km/h.

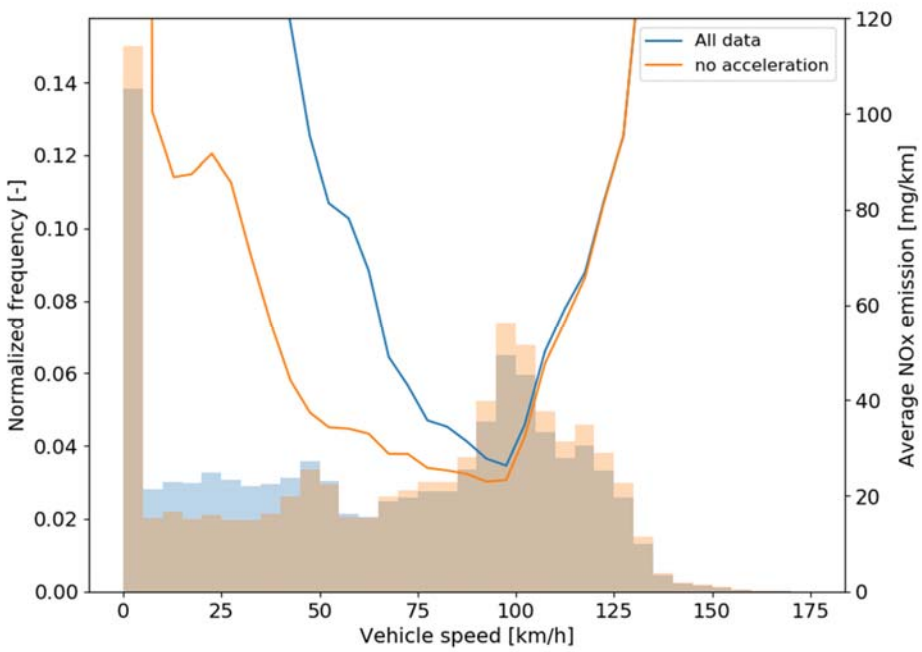

Figure 3.7: Average NO_x emission per vehicle speed bins. Original data is compared with data with no acceleration (a <0.5 m/s2 or a < 1.8 km/h per second).

Table 2 and Table 3 show the overview of the effect of dynamic driving to average NO_x emission. In the urban roads, where vehicle speed ranges from 0-55 km/h, constant speed driving has reduced average NO_x emission by 50.0 %. Compared to the overall dataset, constant speed driving in all type of roads reduces average NO_x emission by 22.1 %.

Table 2: Average NO_x emission of Volkswagen Caddy C2 in vehicle speed 0-50 km/h (urban roads).

	Vehicle speed 0-55 km/h	Vehicle speed 0-55 km/h with no acceleration
Total distance driven [km]	3,605.3	2,454.1
Average NO_x emission [mg/km]	152.1	76.2

Table 3: Average NO_x emission of Volkswagen Caddy C2, showing the effect of acceleration to global average NO_x emission.

	All data	All data with no acceleration
Total distance driven [km]	23,800.9	21,685.8
Average NO_x emission [mg/km]	71.2	55.5

3.5.1.1 *Effect of DPF regeneration*

The Volkswagen Caddy is equipped with a DPF that has regeneration cycles to clean the diesel particulate filter. This mechanism results in 10-15 minutes period of high exhaust temperature (up to 600 °C). In the test programme of Volkswagen Caddy C2, the DPF regeneration only occurred 2 times. In the monitoring data, however, the DPF regeneration occurred up to 40 times, see Figure 3.8. As the exact moment and the time between regenerations varies, a better average effect of regeneration can be determined on the basis of a longer period like with monitoring.

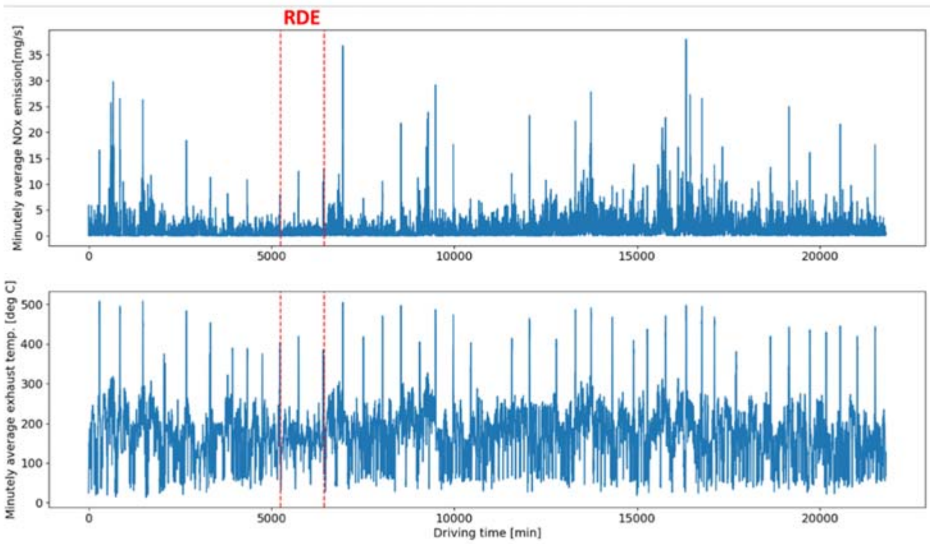

Figure 3.8: Time series of minutely average of NO_x emission and exhaust gas temperature from Volkswagen Caddy C2. Dashed red line visualizes the time period when a test programme was performed.

Based on the monitoring data, it is possible to investigate the average effect that the DPF regeneration has on the NO_x emission. The DPF regeneration period is identified when the exhaust gas temperature exceeds 320°C. Table 4 shows the average NO_x emission during and outside the DPF regeneration period, in comparison with the overall datasets.

Table 4: Average of NO_x emission [mg/km] during DPF regeneration.

	Total	during DPF regeneration	without DPF regeneration
Total distance driven [km]	23,801	524	23,276
Average NOx emission [mg/km]	71	370	65

While the DPF regeneration only represents 2% of the overall monitoring kilometres, it resulted in increase of 8% difference between overall monitoring data and vehicle operation without DPF regeneration.

3.5.2 *Effect of ambient temperature*

The density and ambient temperature of air changes over time according to the season. The slowly changing parameter is a factor that affects the vehicle performance and emission profile.

Figure 3.9 shows the hourly average of the NO_x emission and the ambient air temperature from the Volkswagen Caddy C2. Ambient temperatures during the RDE test only show small fluctuation between 20-25°C whereas the monitoring data covers a much larger temperature range of 0-30°C.

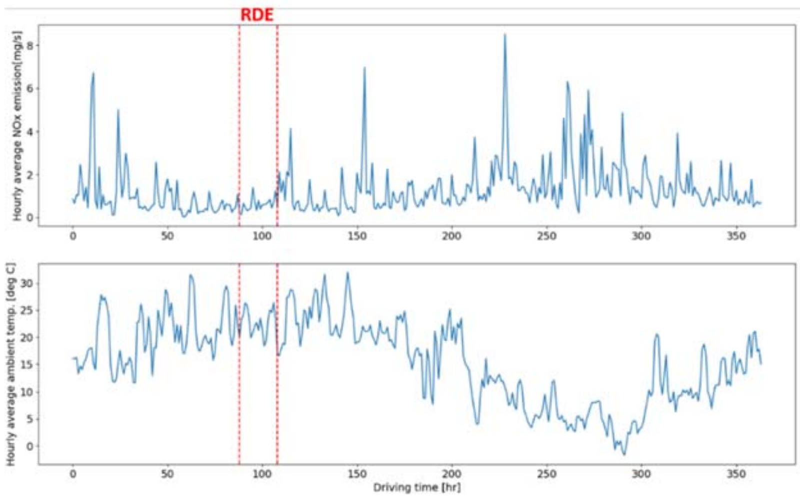

Figure 3.9: Time series of hourly average of NO_x emission and ambient temperature from Volkswagen Caddy C2. Dashed red line visualizes the period when the RDE tests was performed.

Around 300 driving hours (which is around December 2018), the hourly average NO_x flowrate shows more fluctuations than compared to the test period.
The effect of ambient temperature is further investigated by plotting the average NOx emission flowrate [mg/s] per binned ambient temperature range as shown in Figure 3.10. In the overlapping ambient temperature around 17-27°C, the monitoring data and the test programme data show similar average NO_x emission flow rate of around 0.8 mg/s. However, the monitoring data covers more ambient temperature range, and as the ambient temperature decreases towards 0°C, average NO_x emission flow rate increases up to 2 mg/s.

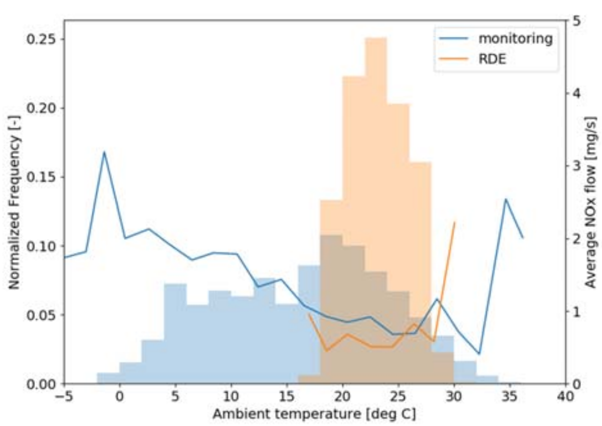

Figure 3.10: Normalised distribution of ambient temperature of monitoring data and RDE data, with corresponding average NOx emission flowrate [mg/s] of the Volkswagen Caddy C2.

4 Analysis of monitoring data of a Renault Talisman

The Renault Talisman is a second vehicle which TNO measured remotely for monitoring development. This vehicle is a lease vehicle. The data is made available by the driver for analyses in this study. The vehicle is also a Euro-6c, prior to RDE compliant vehicles. Hence, this vehicle does not have to satisfy on-road testing requirements. Unlike the Caddy, this vehicle has high to very high emissions compared to the type-approval, laboratory NO_x emission limit of 80 mg/km.

4.1 Overview of monitoring data

The Renault Talisman monitoring data is collected from 24 April 2018 to 8 March 2019, which covers around 21,750 km of driving distance and around 414 hours of driving, as shown in Figure 4.1.

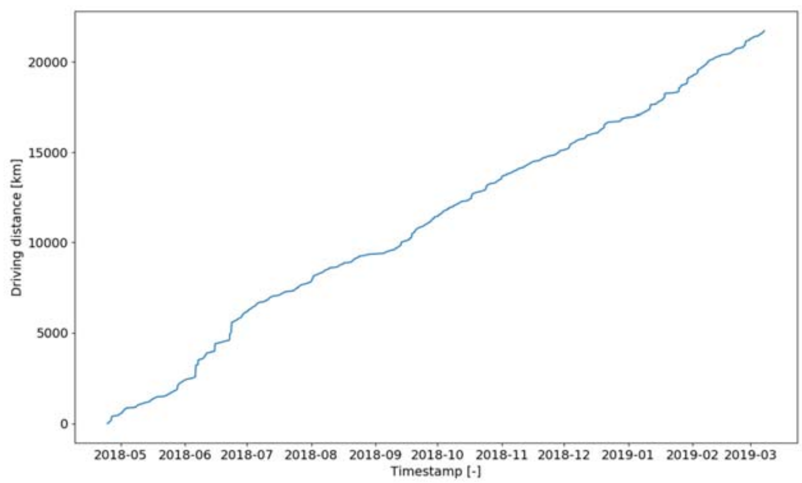

Figure 4.1: Driving usage of Renault Talisman for monitoring data analysis

4.2 Normalised NO_x emission profile of Renault Talisman

The overall average NO_x emission of Renault Talisman from the monitoring is 677 mg/km, and the average CO_2 emission is 137 g/km. To investigate the correlation of the high NO_x emission with vehicle usage, the normalised NO_x emission profiles are plotted.

Figure 4.2 shows the average NO_x emission per vehicle speed bin of the Renault Talisman. In general, high NO_x emission above 400 mg/km is observed in all speed category. Velocity bins above 130 km/hr refer to driving trips outside the Netherlands, i.e., Germany, thus showing low frequency distribution. The lowest NO_x average 434 mg/km at velocity bin 90-100 km/h, which is still well above the legislation limit of the 80 mg/km.

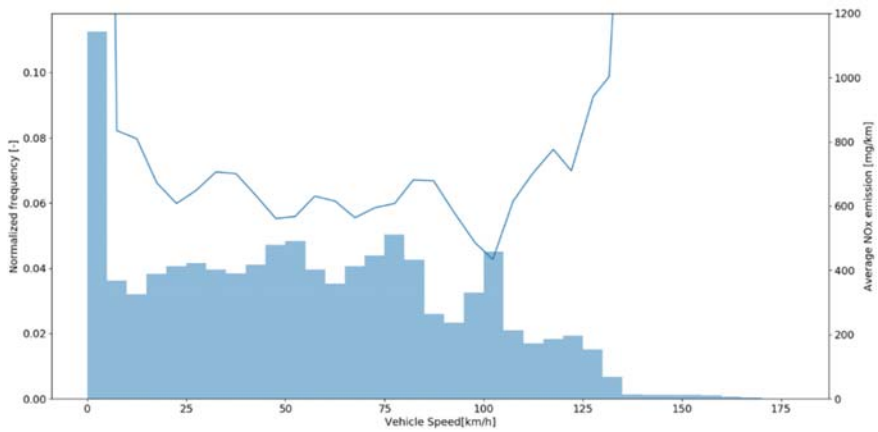

Figure 4.2: Average NO_x emission [mg/km] of Renault Talisman as a function of vehicle speed bin.

Figure 4.3 shows the two-dimensional-map of average NO_x emission for the Renault Talisman. Lowest average NO_x emission found at vehicle speed < 50 km/h at very low CO_2 emission (<1 g/s) which corresponds to low engine load. At motorway, where vehicle speed is around 100 km/h, the lowest average NO_x emission is 5-6 mg/s.

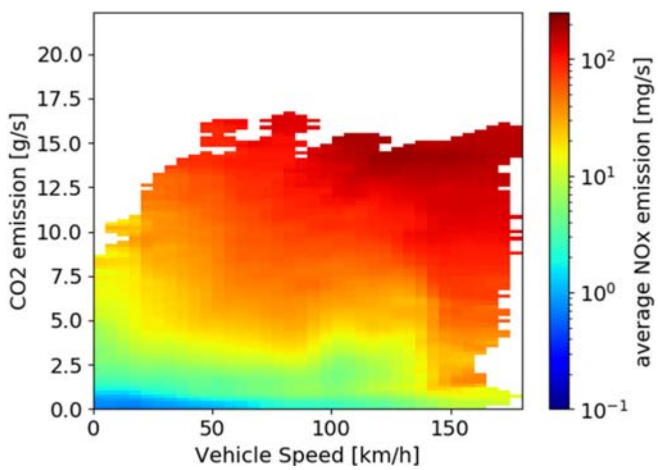

Figure 4.3: Two-dimensional-map of average NO_x mass flow of Renault Talisman

Figure 4.4 shows the average NO_x/CO_2 ratio of the Renault Talisman. Analysing the NO_x/CO_2 ratio around velocity 100 km/h confirms the low NO_x emission rate that is not biased by the CO_2 flow rate. Another low NO_x emission rate is observed at velocity around 50 km/h, at CO_2 emission around 2.5 g/s, which may be associated with constant driving around urban area.

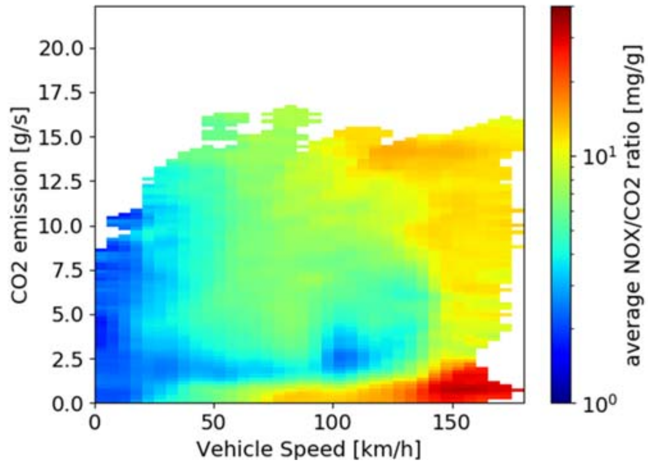

Figure 4.4: Two-dimensional-map of NOx/CO_2 ratio of the Renault Talisman.

The normalised emission plots do not show abnormal observations that may result in high average NO_x emission. A more detailed investigation into the NO_x emission will be explained in the next section.

4.3 Further investigation on high NO_x emission of Renault Talisman

For further investigation, the average raw NO_x concentration per minute is plotted in Figure 4.5. The figure shows fluctuations of NO_x emission [ppm] up to 2500 ppm.

This vehicle is equipped with an Lean NOx Trap catalyst (LNT), which injects periodically unburned fuel into the exhaust line to convert the stored NO_x to N_2 and O_2 The sensor used to measure NO_x is not capable to measure accurately in these fuel-rich conditions, which is a minor caveat in the conclusions on the emission behaviour of this vehicle. Part of the analyses deals with ways to handle this limitation. Based on the outcome of this study the processing of the signals is adapted for future vehicles. In particular, concentrations cannot be negative, but a negative O_2 signal indicates a fuel-rich exhaust gas. For reporting negative values are inappropriate, but the raw, negative signal are an indication of special circumstances for the sensor. Similar problems also occur for petrol vehicles.
An improved analyses and measurement technique is currently under investigation.

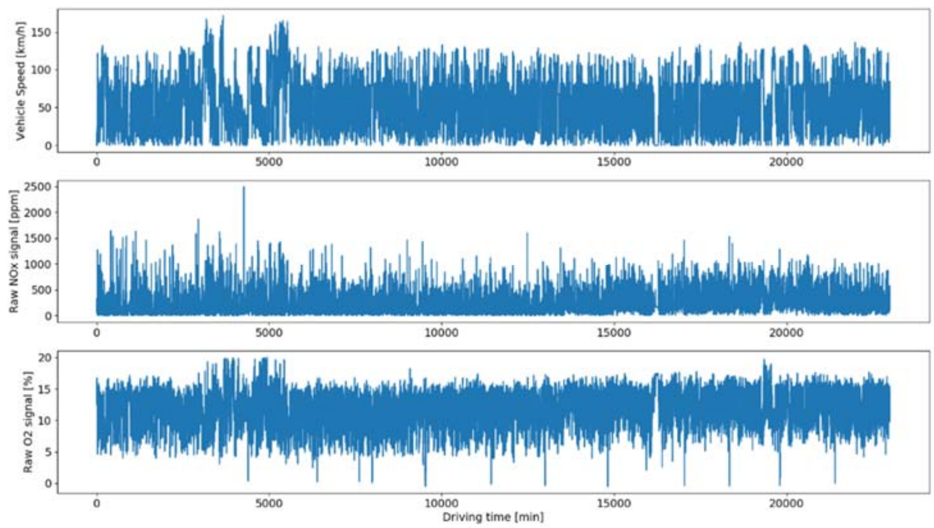

Figure 4.5: Time series of vehicle speed, raw NOx signal, and raw O_2 signal from monitoring data of the Renault Talisman.

Further analysis to the time series shows that the NO_x signal may reach 3000 ppm, which is the upper detection limit of the NO_x sensor installed in SEMS.

The measured raw O_2 concentration signal shows that the reading frequently goes below 0%. The raw O_2 signal is chosen because after the post-processing and calculations, any negative O_2 signal is normalised to 0%. The negative O_2 reading may be associated with the regeneration of the Lean NO_x Trap (LNT) that is installed in the Renault Talisman. The Continental NO_x sensor requires a little O_2 for its operation and vehicle operation that results in low O_2 in the tailpipe will affect the sensor performance.

To determine whether the high raw NO_x concentration is correlated to the low raw O_2 concentration, the average NO_x concentration per binned O_2 signal is plotted in Figure 4.6.

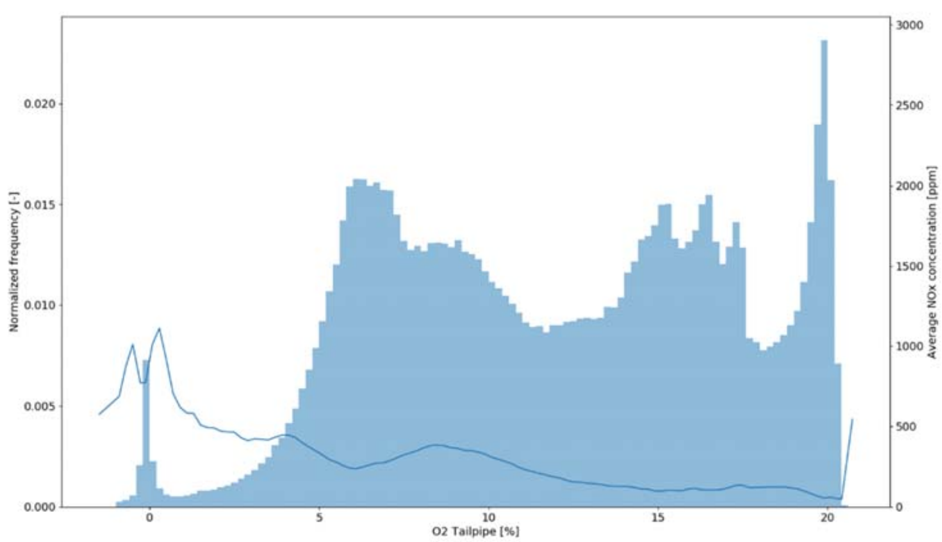

Figure 4.6: Average raw NO_x signal [ppm] per binned raw O_2 signal [%] of the Renault Talisman.

The distribution of raw O_2 signal shows that as the O_2 signal decrease from 15% to 10%, the average NO_x concentration increases slowly from around 100 ppm to 390 ppm, before decreasing towards 240 ppm at 6%. When O_2 signal decreases further to 4%, the NO_x concentration increases again towards 450 ppm and peaks at 1100 ppm at O_2 around 0.5%.

The distribution of raw O_2 signals shows that the high NO_x concentration has already been measured in $O_2 > 0$ % reading. Further analysis can be done by looking into the overall average NOx emission without accounting the $O_2 < 0.5\%$, as shown in Table 5 and Figure 4.7.

Table 5: Average NO_x emission of Renault Talisman, comparing all datasets with data with raw O_2 > 0.5%.

	All data	Data with raw O2 >0.5%
Total distance driven [km]	21,749	20,895
Average NO_x emission [mg/km]	677	667

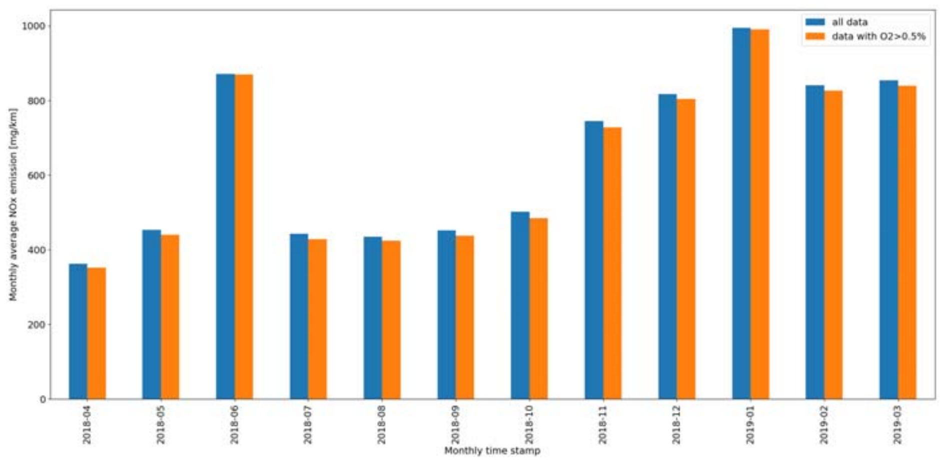

Figure 4.7: Monthly NO_x average [mg/km] of the Renault Talisman, comparing all datasets with data with raw O_2 signals > 0.5%.

Table 5 shows that the data with raw O_2 signals > 0.5% represents the 96% of all the datasets. Excluding the data where the O_2 signals ≤ 0.5% shows a decrease of 1.3% of average NO_x emission.

Figure 4.7 shows that excluding the data where the O_2 signals ≤ 0.5% reduces monthly average NO_x emission by up to 5.3%. The occurrence of the high NO_x reading in the low O_2 region therefore does not significantly affect the vehicle emission profile.

5 Conclusions and recommendations

Conclusions

- Emission monitoring: a sound methodology to determine the average on-road emissions of vehicles.
  - o The results as presented in this report show that emission monitoring turns out to be a sound methodology to determine the average on-road emissions of vehicles. While the current test program of three days is more representative than emission tests in the laboratory, the large variations in emissions in normal use are not fully covered by such a short test program. For example, long term effects such as maintenance effect [TNO 2019 R10541v2], variation of operating condition, short trips, seasonal effects, and aftertreatment performance are not captured in a test program of a few days.
  - o Long term emission monitoring data offers a more comprehensive assessment of the vehicle emission profile. For instance, the analysis in this report have shown the effect of the variation of ambient temperature throughout the year and the effect of the aftertreatments towards NOx emission.
  - o In different measurements the ambient temperature has been raised as an important parameter affecting the vehicle emissions.
    For instance, from indirect remote sensing effects up to 100% increase in emissions with a decrease in temperature has been put forward, source: [HBEFA].
    This will vary greatly from vehicle model to vehicle model. [TNO 2016 R11123].
  - o Furthermore, separating ambient temperature effects from other seasonal effects requires emission monitoring measurements over the different seasons.

- Emission monitoring: strong added value for calculation of the Dutch Emission factors.
  - o With sufficient monitoring data of a vehicle being available, the emission profile of the vehicle and its average on-road emissions can be thoroughly represented. This enriches the calculation of the Dutch vehicle emission factors very much, which is important in relation to calculating the effect of vehicle emissions on the air quality, nature, and the health of citizens. The current three days test program results in a much more limited data set.

- Emission monitoring:
  - o The advantages of emission monitoring above a short, three days, test program are mentioned above but what does it require/cost?
    - ▪ Long term emission monitoring of a vehicle requires more elaborate data analyses and availability of reliable measurement systems. These systems must be suited to be built in into vehicles for a longer period of time without requiring maintenance and equipped with reliable sensors that are well characterized.
    - ▪ The associated costs, can be higher compared to the costs of a short test program. Therefore data analyses and visual presentation of the results must be done in a highly automated way.

  - Is it worth the effort?
    - Yes. As discussed above, emission monitoring has some strong added values above short duration test programs. The amount of data increases dramatically with a shift from testing to monitoring. Moreover, monitoring of a larger number of vehicles in regular use can be done in parallel resulting in much more data. The significance of monitoring is also dependent on the total driving data recorded. Special circumstances, or driving styles, may require some additional testing, on top of the acquired monitoring data.
    - With legislative RDE testing on road, vehicles are optimized towards a short on-road measurement program. The difference with normal operation can only be shown by monitoring operation.

- Real world emission levels
  - Despite the ever decreasing legal NOx emission limits of diesel passenger cars, the average real-world emissions have increased (from Euro-4 in 2006, to Euro-5 in 2009, and Euro-6 in 2014). But with diesel gate a turn can be seen, and the real-world emission performance is improving.
  - The vehicles monitored in this report are among the first vehicle available after diesel gate. The predecessor of the Renault Talisman with the same engine, was the Renault Megane, which was tested by TNO. In the report TNO report R11177 from 2016, the Megane had typical NOx emissions between 700 and 1000 mg/km. The successor Renault Talisman has emissions between 400 and 800 mg/km. The Volkswagen Caddy has real-world NOx emissions between 35 and 150 mg/km, and it performs much better. All three vehicles have to satisfy on the NEDC type-approval test a limit of 80 mg/km. The cleanest vehicles, prior to the RDE legislation are getting close to meeting the requirements as intended in Euro-5/6 legislation. But other vehicles, despite of diesel gate, still have very high emissions.

<u>Recommendations</u>

- As stated, with sufficient monitoring data available, the emission profile of a vehicle can be thoroughly represented. As such, it is recommended that long term emission monitoring, with automotive sensors, be part of the future emission legislation, i.e., post Euro-6/VI legislation as currently discussed in Brussel.

Eventually, vehicle emission legislation should ensure low emissions over the lifetime of the vehicle. With the focus in the past on type-approval, the focus was on new vehicles and a limited range of operations as captured in the type-approval test. The shift towards monitoring may ensure the good lifetime emission performance. This may not all be the responsibility of the manufacturer. But the manufacturer should enable in the future the control of emission performance.

6 References

[TNO2016a]: TNO methodology report, J.S. Spreen et.al., October 2016.

[TNO 2016 R11123]: TNO report 'Review into the relation between ambient temperature and NOx emissions of a Euro 6 Mercedes C220 Bluetec with a diesel engine', Kadijk, Ligterink et.al., October 2016.

[TNO 2016 R11177] TNO report 'NOx emissions of fifteen Euro 6 diesel cars: Results of the Dutch LD road vehicle emission testing programme 2016, Veerle Heijne, Gerrit Kadijk, Norbert Ligterink, Peter van der Mark, Jordy Spreen, Uilke Stelwagen, October 2016.

[TNO 2017 R11473]: TNO report 'NOx-emissions of eighteen diesel Light Commercial Vehicles: Results of the Dutch Light-Duty road vehicle emission testing programme 2017', Kadijk, Vermeulen et.al. 2017

[TNO 2019 R10541v2]: TNO report 'Effects of a software update on NOx emissions and performance of a VW Polo', A.P. Indrajuana et.al., November 2019

[HBEFA]: 'HBEFA 4.1 development report', Benedikt Notter et al, August 2019.

7 Signature

The Hague, 27 March 2020

TNO

Peter J. van der Mark
Projectleader

Armando P. Indrajuana
Author

A. Vehicle specifications and summary of RDE test results

Vehicle Specifications

Volkswagen Caddy C2

After treatment technology: low and high pressure EGR + oxicat + SCRF

Algemeen

J	Voertuigcategorie	Bedrijfsauto (N1)
	Carrosserietype	Bestelwagen (BB)
	Inrichting	gesloten opbouw
D.1	Merk	VOLKSWAGEN
D.2	Type	2KN
D.2	Variant	BBDFSFX0
D.2	Uitvoering	N0J2FM5FM5A4057N1SN2VR27MMG2NLL264
D.3	Handelsbenaming	CADDY
K	Typegoedkeuringsnummer	e1*2007/46*0217*28
	Plaats chassisnummer	In kofferruimte
	Aantal eigenaren privé / zakelijk	0 / 1

Vervaldata en historie

	Vervaldatum APK	20-03-2021
	Vervaldatum Tachograaf	Niet geregistreerd
B	Datum eerste toelating	20-03-2018
I	Datum tenaamstelling	20-03-2018
	Tijdstip tenaamstelling	09:17
	Datum eerste afgifte Nederland	20-03-2018

Terugroepacties

	Status terugroepactie(s)	Geen terugroepactie(s) geregistreerd

Motor		
P.1	Cilinderinhoud	1968 cm³
	Aantal cilinders	4
	Type gasinstallatie	Niet van toepassing

Milieuprestaties		
P.3	Brandstof	Diesel
	Brandstofverbruik stad	5.6 l/100km
	Brandstofverbruik buiten stad	4.2 l/100km
V.8	Brandstofverbruik gecombineerd	4.7 l/100km
U.1	Geluidsniveau stationair	72 dB(A)
U.2	Toerental geluidsniveau	2375 min-1
U.3	Geluidsniveau rijdend	73 dB(A)
P.2	Nettomaximumvermogen	55 kW
	Nominaal continu maximumvermogen	0 kW
V.5	Uitstoot deeltjes (licht)	0.00186 g/km
V.5	Uitstoot deeltjes (zwaar)	Niet geregistreerd
V.6	Roetuitstoot	0.5 m^{-1}
	Milieuclassificatie	Euro 6
V.7	CO2 uitstoot gewogen	Niet geregistreerd
V.7	CO2 uitstoot gecombineerd	124 g/km
V.9	Milieuklasse EG Goedkeuring (licht)	715/2007*2015/45X
V.9	Milieuklasse EG Goedkeuring (zwaar)	Niet geregistreerd

Volkswagen Caddy C1

After treatment technology: low and high pressure EGR + oxicat + SCRF

Algemeen		
J	Voertuigcategorie	Bedrijfsauto (N1)
	Carrosserietype	Bestelwagen (BB)
	Inrichting	gesloten opbouw
D.1	Merk	VOLKSWAGEN
D.2	Type	2KN
D.2	Variant	BBDFSFX0
D.2	Uitvoering	N0J2FM5FM5A4057N1SN2VR27MMG2NLL161
D.3	Handelsbenaming	CADDY
K	Typegoedkeuringsnummer	e1*2007/46*0217*25
	Plaats chassisnummer	In kofferruimte
	Aantal eigenaren privé / zakelijk	0 / 1

Vervaldata en historie		
	Vervaldatum APK	10-03-2020
	Vervaldatum Tachograaf	Niet geregistreerd
B	Datum eerste toelating	10-03-2017
I	Datum tenaamstelling	10-03-2017
	Tijdstip tenaamstelling	08:05
	Datum eerste afgifte Nederland	10-03-2017

Terugroepacties		
	Status terugroepactie(s)	Geen terugroepactie(s) geregistreerd

Motor		
P.1	Cilinderinhoud	1968 cm³
	Aantal cilinders	4
	Type gasinstallatie	Niet van toepassing

Milieuprestaties		
P.3	Brandstof	Diesel
	Brandstofverbruik stad	5.4 l/100km
	Brandstofverbruik buiten stad	4 l/100km
V.8	Brandstofverbruik gecombineerd	4.5 l/100km
U.1	Geluidsniveau stationair	72 dB(A)
U.2	Toerental geluidsniveau	2375 min-1
U.3	Geluidsniveau rijdend	73 dB(A)
P.2	Nettomaximumvermogen	55 kW
	Nominaal continu maximumvermogen	0 kW
V.5	Uitstoot deeltjes (licht)	0 g/km
V.5	Uitstoot deeltjes (zwaar)	Niet geregistreerd
V.6	Roetuitstoot	0.5 m^{-1}
	Milieuclassificatie	Euro 6
V.7	CO2 uitstoot gewogen	Niet geregistreerd
V.7	CO2 uitstoot gecombineerd	117 g/km
V.9	Milieuklasse EG Goedkeuring (licht)	715/2007*2015/45X
V.9	Milieuklasse EG Goedkeuring (zwaar)	Niet geregistreerd

Renault Talisman

After treatment technology: low and high pressure EGR + DPF+ LNT

Algemeen		
J	Voertuigcategorie	Personenauto (M1)
	Carrosserietype	Stationwagen (AC)
	Inrichting	stationwagen
D.1	Merk	RENAULT
D.2	Type	RFD
D.2	Variant	KH2
D.2	Uitvoering	A3661A110000
R	Kleur	Bruin
D.3	Handelsbenaming	TALISMAN
K	Typegoedkeuringsnummer	e11*2007/46*2969*07
	Plaats chassisnummer	Op rechts, rechter deurstijl
	Aantal eigenaren privé / zakelijk	0 / 1

Vervaldata en historie		
	Vervaldatum APK	30-03-2021
B	Datum eerste toelating	30-03-2018
I	Datum tenaamstelling	30-03-2018
	Tijdstip tenaamstelling	08:23
	Datum eerste afgifte Nederland	30-03-2018

Terugroepacties		
	Status terugroepactie(s)	Geen terugroepactie(s) geregistreerd

Motor

P.1	Cilinderinhoud	1461 cm³
	Aantal cilinders	4
	Type gasinstallatie	Niet van toepassing
	Zuinigheidslabel	B

Milieuprestaties

P.3	Brandstof	Diesel
	Brandstofverbruik stad	4.2 l/100km
	Brandstofverbruik buiten stad	3.5 l/100km
V.8	Brandstofverbruik gecombineerd	3.7 l/100km
U.1	Geluidsniveau stationair	77 dB(A)
U.2	Toerental geluidsniveau	3000 min-1
U.3	Geluidsniveau rijdend	71 dB(A)
P.2	Nettomaximumvermogen	81 kW
	Nominaal continu maximumvermogen	0 kW
V.5	Uitstoot deeltjes (licht)	0.00021 g/km
V.5	Uitstoot deeltjes (zwaar)	Niet geregistreerd
V.6	Roetuitstoot	0.51 m^{-1}
	Milieuclassificatie	Euro 6
V.7	CO2 uitstoot gewogen	Niet geregistreerd
V.7	CO2 uitstoot gecombineerd	98 g/km
V.9	Milieuklasse EG Goedkeuring (licht)	715/2007*2016/646W
V.9	Milieuklasse EG Goedkeuring (zwaar)	Niet geregistreerd

Summary of RDE Test Results

RDE Test result of Volkswagen Caddy C1

Table 3-8: Emission results per trip of a Volkswagen Caddy Euro 6 diesel.

No.	Trip ID + payload%	Date	Start time	Duration	Distance	Average velocity	Ambient temperature Avg/min/max			CO_2	NO_x	NH_3
				[s]	[km]	[km/h]	[°C]			[g/km]	[mg/km]	[mg/km]
1	RDE_C 28%	2017-5-11	8:25	5998	73.0	43.8	16	13	18	115	39	0.6
2	Motorway 28%	2017-5-8	10:49	3800	87.4	82.8	12	10	16	110	38	0.1
3	RDE_H 28%	2017-5-8	12:51	5690	72.7	46.0	15	14	17	120	57	0.2
4	Congest_H 28%	2017-5-8	15:01	6153	85.0	49.7	16	13	20	113	52	0.2
5	Congest_C 95%	2017-5-9	7:43	5736	82.9	52.0	12	9	13	113	48	0.2
6	City 95%	2017-5-9	9:28	4871	28.5	21.1	12	11	14	157	96	0.6
7	Rural 95%	2017-5-9	11:14	4813	64.6	48.3	13	12	15	113	45	0.3
8	RDE_H 95%	2017-5-9	12:56	6276	70.6	40.5	14	12	17	172	217	0.9
9	City to City 95%	2017-5-9	14:46	2672	21.5	28.9	15	13	18	140	101	2.4
10	RDE_C 55%	2017-5-10	7:54	6000	72.6	43.5	10	9	12	133*	70	1.1
11	Short trip 55%	2017-5-10	9:45	424	4.2	35.5	12	11	15	136	100	1.0
12	Delivery trip 55%	2017-5-10	10:05	1943	13.4	18.2	12	11	14	169	128	1.2
13	ISC_H 55%	2017-5-10	11:33	8107	121.0	53.7	15	13	20	114	38	0.4
14	City to City 55%	2017-5-10	13:53	2668	21.5	28.9	15	13	17	135	88	0.5
Total					818.9					127	70	0.5

RDE Test result of Volkswagen Caddy C2

Datum	Belading	Pay load	Rijstijl	Start-Stop	Type rit	Afstand	RDE pass/fail	avg speed	NOx	NH3 max	CO2
	[%]	[kg]				[km]		km/h	mg/km	ppm	g/km
4-7-2018											
4-7-2018	28	1579	Economy	Aan	RDE koude start	74.7	fail	45.6	12.6	8.8	123.4
4-7-2018			Normaal	Aan	Snelwegrit	89.5	nvt	78.5	9.9	3.2	120.5
4-7-2018			Normaal	Aan	RDE warme start	74.7		48.9	32.4	14.4	135.7
4-7-2018			Normaal	Aan	Avondspitsrit snelweg	84.3	nvt	47.3	21.7	8.6	130.4
4-7-2018											
4-7-2018											
4-7-2018											
5-7-2018	95	2089	Normaal	Aan	Morgenspitsrit snelweg	85.3	nvt	54.4	57.6	222.2	135.2
5-7-2018			Normaal	Aan	Stadsrit Amsterdam	27.8	nvt	26.4	90.8	10.1	173.5
5-7-2018			Normaal	Aan	Buitenweg naar Den Haag	64.6	nvt	50.9	30.6	4.6	130
5-7-2018			Normaal	Aan	RDE warme start	74.7		45.1	33.3	35.3	142
5-7-2018											
5-7-2018											
5-7-2018											
6-7-2018	55	1579	Normaal	Aan	RDE warme start	74.7		50.6	38	38.3	122.6
6-7-2018			Normaal	Aan	Delft - Den Haag	15.0	nvt	58.3	26.1	11.4	116.4
6-7-2018			Sportief	Uit	RDE warme start	74.7		44.2	72.8	21.8	158.4
6-7-2018			Sportief	Uit	Delft - Den Haag	15.0	nvt	46.5	43.9	3.3	146.3
6-7-2018			Economy	Aan	RDE warme start	74.7		48.3	40.2	218.6	132.4
6-7-2018			Economy	Aan	Delft - Den Haag	15.0	nvt				