Earth, Life & Social Sciences
Van Mourik Broekmanweg 6
2628 XE Delft
P.O. Box 49
2600 AA Delft
The Netherlands

www.tno.nl

T +31 88 866 30 00

TNO report

TNO 2016 R11227

Assessment of the strengths and weaknesses of the new Real Driving Emissions (RDE) test procedure

Date	27 September 2016
Author(s)	Rob F.A. Cuelenaere Norbert E. Ligterink
Copy no	2016-TL-RAP-0100300007
Number of pages	76
Number of appendices	-
Sponsor	Dutch Ministry of Infrastructure and the Environment PO Box 20901 2500 EX THE HAGUE The Netherlands
Project name	RDE Driving behaviour and boundary conditions
Project number	060.20448

Management samenvatting

Door *Dieselgate* is er hernieuwde aandacht voor de luchtverontreinigende uitlaatgassen van auto's, in het bijzonder voor de hoge NO_x praktijkemissies van moderne Euro-5 en Euro-6 personenauto's en bestelwagens. De ontwikkeling van nieuwe Europese **Real Driving Emissions (RDE)** wetgeving wordt gezien als de weg voorwaarts om in de komende jaren de praktijkemissies van nieuwe auto's te verlagen. Het Ministerie van Infrastructuur en Milieu heeft TNO opdracht gegeven om de Europese RDE wetgeving te beoordelen op haar sterktes en zwaktes.

In algemene zin kan geconcludeerd worden dat er met de 1ste en 2^{e} RDE pakketten en de aangekondigde aanvullingen in de 3^{e} en 4^{e} RDE pakketten een goede basis staat om de praktijkemissies van nieuwe auto's de komende jaren te verlagen.

Sterke punten RDE- wetgeving	**Opmerkingen**
RDE introduceert praktijkmetingen op de weg	Om lage praktijkemissies te realiseren zijn laboratorium tests alleen onvoldoende effectief
Emissies in stedelijk gebied worden apart beoordeeld	Voor luchtkwaliteit en gezondheid belangrijk dat praktijkemissies in stedelijk gebied worden beperkt
Testomstandigheden zijn voldoende ruim	De meeste omstandigheden die in Europa als normaal kunnen worden omschreven, zijn toegestaan bij het uitvoeren van RDE tests
Nauwkeurige PEMS meetapparatuur is beschikbaar	Er zijn geen (meet)technische belemmeringen om RDE tests uit te voeren
Koude start wordt meegenomen	Er zijn sterke aanwijzingen dat emissies tijdens de koude start op een goede wijze in het 3^{e} pakket worden opgenomen

Zwakke punten/Risico's RDE-wetgeving	**Opmerkingen**
Een goede handhavingsstructuur is bepalend voor de effectiviteit van de RDE wetgeving. Dit moet vorm krijgen in het 4^{e} pakket.	De uitwerking van het 4^{e} pakket moet nog starten.
Rekenmodellen EMROAD en CLEAR zijn onvoldoende transparant en geven verschillende resultaten. Fabrikanten kunnen het gunstigste model kiezen.	Door een gebrek aan informatie over en ervaring met de rekenmodellen is op dit moment geen oordeel te geven over de invloed van EMROAD en CLEAR op effectiviteit van de RDE wetgeving
De RDE wetgeving biedt de mogelijkheid om *Transfer functions* te introduceren	*Transfer functions* zijn overbodig en zouden een afzwakking betekenen
Conformity factors zouden nu al lager kunnen, omdat de meetnauwkeurigheid van PEMS apparatuur beter is dan verondersteld	De aangekondigde evaluatie van de PEMS meetnauwkeurigheid is nog niet gestart.
Discussie over inperken test-omstandigheden duurt voort	Er circuleren (aankondigingen van) voorstellen om de RDE testomstandigheden te beperken. Hierdoor bestaat het risico dat RDE in de toekomst minder effectief is in het beperken van praktijkemissies onder alle normale gebruiksomstandigheden.

Samenvatting

Door *Dieselgate* is er hernieuwde aandacht voor de luchtverontreinigende uitlaatgassen van auto's, in het bijzonder voor de hoge NO_x praktijkemissies van moderne Euro-5 en Euro-6 personenauto's en bestelwagens. De ontwikkeling van nieuwe Europese **Real Driving Emissions (RDE)** wetgeving wordt gezien als de weg voorwaarts om in de komende jaren de praktijkemissies van nieuwe auto's te verlagen. Het 1ste en 2^{e} RDE pakket zijn inmiddels gepubliceerd[1], het 3^{e} is momenteel in voorbereiding en een 4^{e} pakket is voorzien voor begin 2017.[2]

Het Ministerie van Infrastructuur en Milieu heeft TNO opdracht gegeven om de Europese RDE wetgeving te beoordelen op haar sterktes en zwaktes. Deze beoordeling moet beschikbaar zijn voordat de besluitvorming plaatsvindt over het 3^{e} en 4^{e} pakket, respectievelijk in november 2016 en het voorjaar van 2017.

Algemene conclusie
In algemene zin kan geconcludeerd worden dat er met de 1ste en 2^{e} RDE pakketten en de aangekondigde aanvullingen in de 3^{e} en 4^{e} RDE pakketten een goede basis staat om de praktijkemissies van nieuwe auto's de komende jaren te verlagen. Samengevat zijn de belangrijkste sterke punten van de RDE-wetgeving:

Sterke punten	**Opmerkingen**
RDE introduceert praktijkmetingen op de weg	Om lage praktijkemissies te realiseren zijn laboratorium tests alleen onvoldoende effectief
Emissies in stedelijk gebied worden apart beoordeeld	Voor luchtkwaliteit en gezondheid belangrijk dat praktijkemissies in stedelijk gebied worden beperkt
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[1] 1e pakket: http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32016R0427
2e pakket: http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32016R0646

[2] De RDE pakketten worden voorbesproken met stakeholders en lidstaten in de RDE-LDV expert groep. De uiteindelijke voorstellen worden door de Europese Commissie voor raadgevend advies in stemming gebracht in de TCMV.
De Nederlandse delegatie bestaat veelal uit vertegenwoordigers van de RDW (delegatieleider), het ministerie van Infrastructuur en Milieu en TNO.

De belangrijkste zwaktes en risico's van de RDE wetgeving zijn:

Zwakke punten/Risico's	**Opmerkingen**
Een goede handhavingsstructuur is bepalend voor de effectiviteit van de RDE wetgeving. Dit moet vorm krijgen in het 4^{e} pakket.	De uitwerking van het 4^{e} pakket moet nog starten.
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Introductie praktijktest
In de Europese Euro 5/6 verordening uit 2007 is reeds voorzien dat een puur op laboratorium tests gebaseerde typegoedkeuringssystematiek geen waarborg biedt voor lage uitstoot in de praktijk op de weg. Daarom wordt in Artikel 5(1) van de verordening het algemene principe geïntroduceerd, dat emissie beperkende technologie en de toepassing ervan zo ontworpen moet worden, dat deze effectief werkzaam is bij elk normaal gebruik van de auto. De Europese Commissie heeft in artikel 14(3) van de verordening een mandaat gekregen om, indien nodig, wetgeving voor testen op de weg te ontwikkelen.

De RDE wetgeving introduceert de verplichting bij de typegoedkeuring om de emissies van nieuwe personenauto's en bestelwagens te testen onder praktijkomstandigheden op de weg. De RDE test zal worden uitgevoerd met een auto uit een RDE-familie en wordt toegevoegd aan de bestaande test op de rollenbank in het laboratorium. De autofabrikant zal daarnaast moeten verklaren dat alle auto's uit de RDE-familie voor alle toegestane RDE tests onder de RDE emissielimiet blijven. Deze verklaring, die op verzoek van de Nederlandse delegatie in de typegoedkeuring is opgenomen, vormt de basis voor RDE handhaving die in het 4^{e} pakket vorm moet krijgen.

Op basis van de goede ervaringen met verplichte praktijktesten bij de typegoedkeuring van vrachtwagens, mag verwacht worden dat de introductie van RDE wetgeving bovenop de bestaande Euro-6 normen daadwerkelijk zal leiden tot een forse verlaging van de uitstoot door personenauto's en bestelwagens.

Als RDE effectief blijkt te zijn, dan zal de luchtkwaliteit, in het bijzonder de NO_2 concentraties in stedelijk gebied, op termijn sterk verbeteren.

Structuur RDE wetgeving
Idealiter zouden er geen grenzen gesteld moeten worden aan de praktijktests, zodat de uitstoot onder alle normale gebruiksomstandigheden van een auto laag zijn. De enige beperkingen komen dan voort uit snelheidsbeperkingen en het (motor)vermogen van de auto.

In de RDE wetgeving is niet voor die lijn gekozen, om te voorkomen dat autofabrikanten dure voorzieningen moeten aanbrengen voor situaties die bijna niet optreden. De condities waaronder een RDE rit moet worden gereden, zijn afgebakend. Tijdens een RDE rit worden de emissies gemeten met mobiele meetapparatuur (PEMS). Vervolgens worden verzamelde meetgegevens bewerkt en genormaliseerd naar een rit die qua zwaarte overeenkomt met de nieuwe WLTP laboratorium test. Uiteindelijk wordt de uitkomst van de databewerking afgezet tegen het emissiecriterium dat in de RDE wetgeving is vastgelegd.

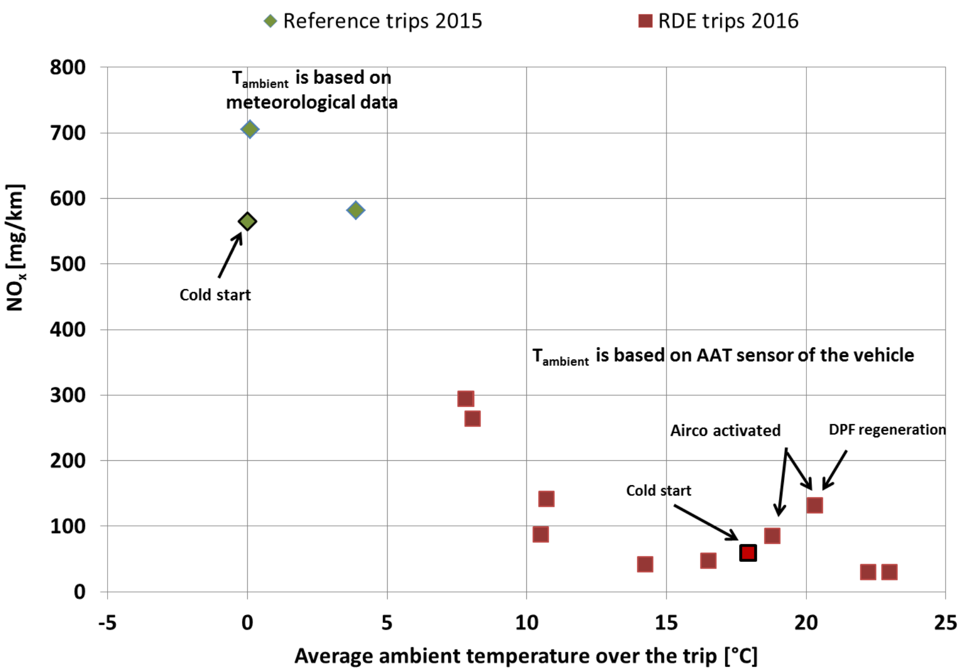
Dit betekent dat de nieuwe RDE testprocedure alleen effectief is, in de zin dat de test er voor gaat zorgen dat in de nabije toekomst de praktijkemissies van nieuwe auto's afnemen, als ten minste aan alle volgende voorwaarden is voldaan:
- Het emissie criterium moet streng genoeg zijn (*Conformity factor*);
- De toegestane rijomstandigheden voor een RDE rit, zoals rijgedrag en weersomstandigheden, moeten ruim genoeg zijn;
- Het rekenmodel, waarmee de meetgegevens van de uitgevoerde RDE rit worden bewerkt, normaliseert enkel voor de zwaarte van de RDE rit;
- Meetmomenten met een hoge uitstoot mogen niet worden weggelaten;
- Met het oog op verbetering van de stedelijke luchtkwaliteit dient de uitstoot tijdens stedelijk verkeer apart te worden beoordeeld, en niet worden uitgemiddeld met emissies tijdens delen van de rit op buitenweg en snelweg;
- Het moet mogelijk zijn dat onafhankelijke derde partijen controle testen uitvoeren.

***Conformity factor* NO_x**
De *Conformity factor* (CF) voor NO_x is vastgesteld in het 2^{e} RDE pakket en wordt geïntroduceerd in 2 stappen. In de uiteindelijke stap, die in januari 2021 voor alle nieuw verkochte personenauto's zal gelden, is de CF 1.0 met daarbovenop een marge die rekening houdt met de meetonnauwkeurigheid van PEMS apparatuur. De RDE limietwaarden zijn als volgt vastgesteld:

Dieselauto's	1ste stap RDE limietwaarde in mg NO_x per km (CF = 2,1)	2^{e} stap RDE limietwaarde in mg NO_x per km (CF=1 + marge 0,5)	Corresponderende Euro-6 limietwaarde in mg NO_x per km
Personenauto's en lichte bestelwagens N1, klasse I	168	120	80
Lichte bestelwagens N1, klasse II	220	158	105
Lichte bestelwagens N1, klasse III	263	188	125

In het 2e RDE pakket is tevens vastgelegd dat de emissies tijdens het rijden in stedelijk gebied apart moeten worden beoordeeld en ook aan de RDE emissielimietwaarden moeten voldoen. Dit is een heel positieve ontwikkeling. Beoordeling van alleen de emissies van een totale RDE rit heeft als risico dat hoge emissies in stedelijk gebied worden gecompenseerd door lage emissies op de buitenweg. Voor luchtkwaliteit en gezondheid zou dat tot ongewenste situaties kunnen leiden. De aparte beoordeling verzekert dat de praktijkemissies ook in het stedelijk gebied laag zullen zijn.

Beperkingen aan de testomstandigheden: de buitentemperatuur
Er is een breed besef, dat het van groot belang is dat de weersomstandigheden die zijn toegestaan voor het uitvoeren van een RDE test voldoende ruim zijn. Dit geldt in het bijzonder voor de buitentemperatuur. Bij moderne pre-RDE auto's is waargenomen dat de werking van de emissie reductie technologie sterk vermindert als de buitentemperatuur lager is dan de temperatuur waarbij de laboratorium tests worden uitgevoerd, dat wil zeggen tussen de 20 - 30°C (zie figuur NS1).



Figuur NS1 De NO_x emissie van een moderne Euro 6 dieselauto laat in een praktijkrit een sterke afhankelijkheid zien van de buitentemperatuur, Bron: TNO 2016 R11123 "Review into the relation between ambient temperature and NO_x emissions of a Euro 6 Mercedes C220 Bluetec with a diesel engine", Kadijk e.a.

Voor de Nederlandse situatie zijn de RDE grenzen voor de buitentemperatuur toereikend. Het RDE temperatuurbereik is 0 - 30°C (en in bijzondere gevallen zelfs tot -7°C en 35^{0}C). Er is nadrukkelijk geen ruimte om het temperatuurbereik in te perken: gemiddeld 8% van het jaar ligt de temperatuur tijdens de ochtendspits onder nul.

Een sterk element van de nieuwe RDE testprocedure is dat er geen eisen worden gesteld aan de omgevingscondities m.b.t. windsnelheid, luchtdruk, luchtvochtigheid, hellingsgraad van de weg of het soort wegdek (op voorwaarde dat de weg verhard is).

Eisen aan de samenstelling van een RDE rit
De RDE wetgeving bevat diverse redelijke eisen ten aanzien van de RDE rit die wordt gereden. Ze zijn nodig om de rit praktisch uitvoerbaar te maken, zorgen ervoor dat alle wegtypen aan bod komen en voorkomen dat extreem eenzijdige ritten worden gekozen.

Er wordt echter ook voorgeschreven dat een RDE rit in de vaste volgorde stad-buitenweg-snelweg moet worden gereden en dat periodes van stationair draaien (bijvoorbeeld voor een open brug) niet langer mogen duren dan 3 minuten. Dit introduceert het risico dat het voertuig herkent dat het aan een RDE test wordt onderworpen of dat de fabrikant het voertuig op RDE ritten optimaliseert. Omdat er nog geen auto's zijn die aan RDE voldoen, is het op dit moment niet mogelijk de omvang van dit risico op verhoogde praktijkemissies in te schatten.

Het risico kan in ieder geval worden beperkt door de maximale periode van stationair draaien te verlengen. Daarnaast is het van groot belang alert te blijven op toepassingen van ritherkenning of ritoptimalisatie en dat de wetgeving direct wordt aangepast, als daar aanleiding toe is.

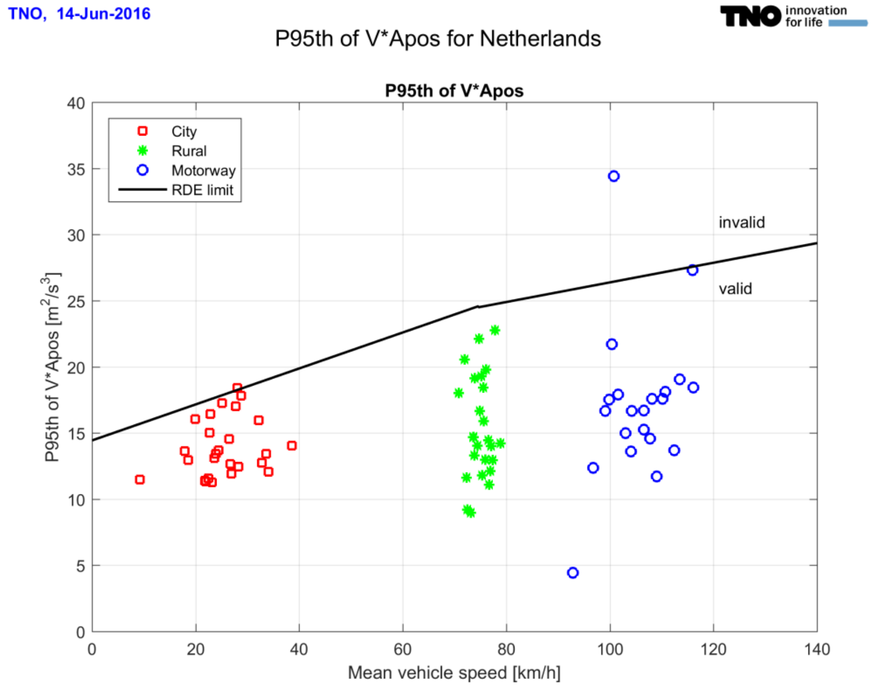
Beperkingen aan het rijgedrag tijdens de RDE rit
Rijgedrag, zoals acceleratie en rijsnelheid, hebben grote invloed op de NO_x uitstoot van moderne dieselauto's. Het is van groot belang dat rijsituaties met een hogere emissie in een RDE rit worden meegenomen, zeker als deze situaties onder 'normaal rijden' vallen. Het is echter alleszins redelijk dat wordt voorkomen dat auto's onder extreme rijomstandigheden worden getest, zoals voortdurend extreem hard accelereren of consequent extreem langzaam rijden. Daarom zijn in de RDE wetgeving grenzen gesteld aan het rijgedrag.

In een recent door TNO, in opdracht van het Ministerie van Infrastructuur en Milieu, uitgevoerd project is de bandbreedte van normaal rijgedrag in Noordwest-Europa bepaald. De uitkomsten zijn vergeleken met de grenzen die RDE stelt aan toegestaan rijgedrag. Voor het project zijn metingen uitgevoerd in Nederland, België, Frankrijk en Duitsland. Figuur NS2 toont de resultaten van Nederland en België.

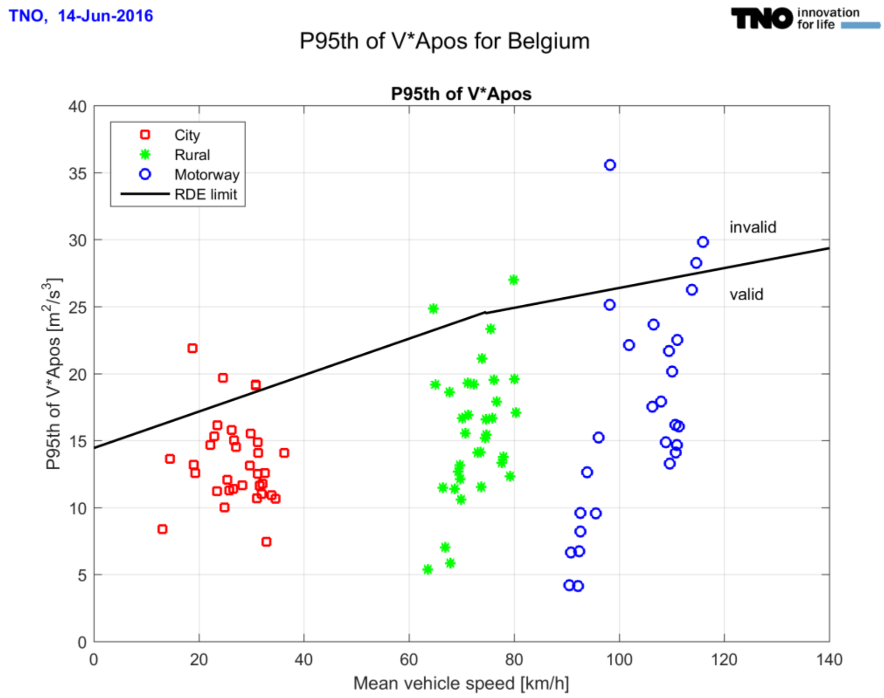
Het uitgevoerde onderzoek laat zien dat de in de RDE wetgeving gekozen grenzen voor rijgedrag in orde zijn. De grenzen zijn zodanig dat normaal rijgedrag in voldoende mate wordt afgedekt. Er is geen ruimte om de grenzen voor het rijgedrag te versoepelen (in het bijzonder de $v*a_{pos}$ limiet te verlagen), omdat dat zou leiden tot het buiten beschouwing laten van representatieve rijomstandigheden. De wetgeving zou daarmee slechts effectief zijn in een aantal EU-lidstaten en niet in de EU als geheel.

Eventueel kan worden overwogen om een extra grens op te nemen voor het rijgedrag voor lichte bestelwagens. De huidige grenzen staan voor bestelauto's namelijk extreem agressief rijgedrag toe. Nederland heeft hiertoe een eenvoudig voorstel ingediend bij de RDE-LDV expert groep. Het is nog onduidelijk of dit in het 3e of 4e pakket wordt opgepakt.

Nederland

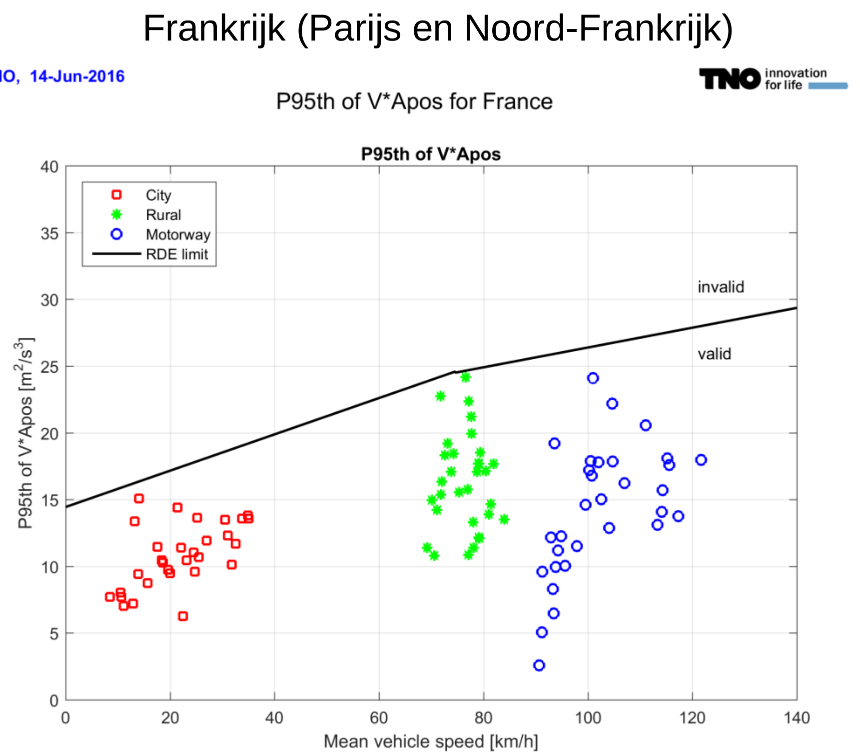


België



Figuur NS2 Rijgedrag in Nederland en België zoals waargenomen in een TNO project en afgezet tegen de RDE grens voor maximale rijdynamiek, uitgedrukt in $v*a_{pos}$. Bron: informatie door de Nederlandse delegatie beschikbaar gesteld aan de RDE-LDV expert groep.

Veelvuldig stoppen en weer optrekken is een verkeerssituatie die in dichtbevolkte stedelijke gebieden vaak voorkomt en veelal gepaard gaat met hoge emissies. In de nieuwe RDE procedure geldt een minimum gemiddelde snelheid van 15 km/u voor het stedelijke deel van de RDE rit. Het aantal keren stoppen en weer optrekken wordt hierdoor beperkt. Door de minimum gemiddelde snelheid te verlagen zouden meer situaties van normaal stedelijk rijden, zoals bijvoorbeeld waargenomen in Frankrijk (zie figuur NS3), binnen de eisen aan een RDE rit vallen. Er zijn geen voornemens om de minimum gemiddelde snelheid te verlagen.



Figuur NS3 In Frankrijk, in het bijzonder in en om Parijs, is de gemiddelde snelheid tijdens het stedelijke deel van een rit lager dan het in RDE vereiste minimum van 15 km/u Bron: Informatie door de Nederlandse delegatie beschikbaar gesteld aan de RDE-LDV expert groep.

Een sterk punt van de RDE wetgeving is dat er geen eisen of grenzen worden gesteld aan schakelgedrag.

Het testvoertuig

Niet alleen nieuwe, speciaal geprepareerde voertuigen moeten aan de RDE limietwaarden voldoen. De test kan worden uitgevoerd met een in gebruik zijnde, goed onderhouden auto en onder condities die daadwerkelijk overeenkomen met het mogelijke gebruik van de auto op de weg. Dit is van belang, omdat zo ruimte wordt geboden aan het uitvoeren van controle tests door onafhankelijke partijen.

Beschikbaarheid meetapparatuur

Betrouwbare PEMS meetapparatuur, die voldoet aan alle RDE eisen, is gewoon beschikbaar. Verschillende fabrikanten leveren systemen die aan de wettelijke eisen voldoen. De veronderstelde nauwkeurigheid van PEMS apparatuur is een belangrijk aandachtspunt, omdat het direct de hoogte van het emissie criterium voor NO_x bepaalt: de uiteindelijke *Conformity factor* is in het 2^e RDE pakket vastgesteld op 1,0 plus een marge van 0,5. Deze marge van 0,5 zou een afspiegeling moeten zijn van de (on)nauwkeurigheid van metingen met PEMS, maar is ruim vergeleken met de onnauwkeurigheid van de huidige generatie PEMS apparatuur, die beter is dan 0,3. Er is dus alle aanleiding om de aangekondigde jaarlijkse evaluatie van de marge al te starten onder het 4^{e} RDE pakket.

Er zijn mogelijkheden om de PEMS systemen en de meetvoorschriften verder te verbeteren. Door het opnemen van een taakstellende eis in de RDE wetgeving, kan de onnauwkeurigheid van PEMS - en daarmee de noodzakelijke geachte marge in de *Conformity factor* - verder afnemen.

Koude start

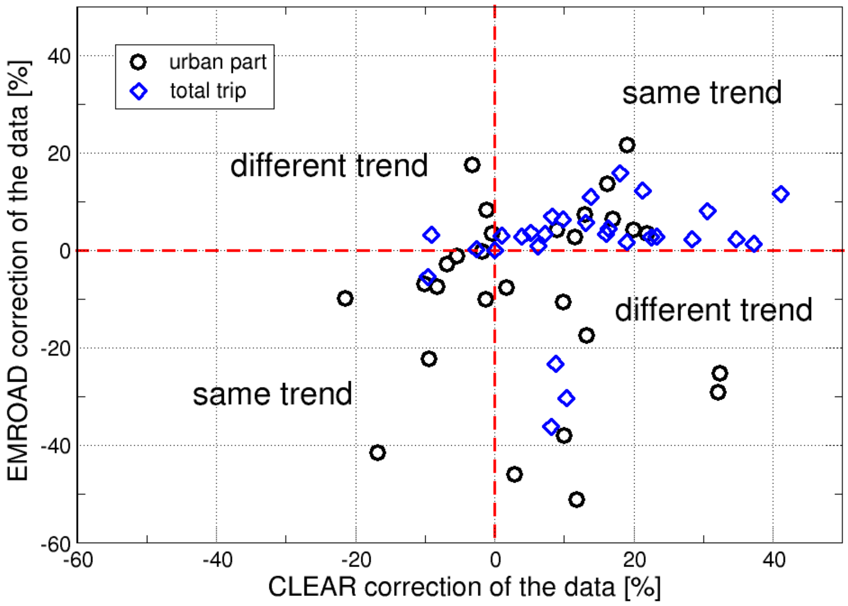
In de RDE wetgeving tot en met het 2^{e} pakket, is vastgelegd dat de emissies tijdens de opwarmingsfase van de motor wel worden gemeten, maar niet in de beoordeling worden meegenomen. Deze zogenoemde koude-start fase is gedefinieerd als de eerste 5 minuten na de eerste start van de motor.

Koude starts vinden vooral plaats in dichtbevolkte stedelijke gebieden. Als de emissies bij koude start niet worden gereguleerd, kan dit leiden tot een verdubbeling of verdrievoudiging van de gemiddelde NO_x uitstoot in stedelijk gebied van toekomstige auto's die aan RDE voldoen. Om reden van luchtkwaliteit is het daarom van groot belang dat de koude-start fase in de beoordeling wordt meegenomen. Dit kan in het 3^{e} RDE pakket eenvoudig – en zonder onaanvaard-bare lasten voor de auto-industrie - worden geregeld door de koude-start fase onder te brengen in de beoordeling van de uitstoot in stedelijk gebied. Op een voorstel van Nederland zullen de emissies van de koude start in het stedelijk deel van de RDE rit worden meegenomen en beoordeeld . Deze aanvulling wordt in het 3^{e} pakket opgenomen.

Rekenmodellen EMROAD en CLEAR

Iedere RDE rit zal in zwaarte verschillen en zal in zwaarte afwijken van de officiële typegoedkeuringstest op basis waarvan de Euro-6 limiet - van 80 mg/km voor personenauto's – is vastgesteld. In RDE zijn twee rekenmodellen (*evaluation tools*) EMROAD en CLEAR opgenomen, die ieder op een eigen wijze de zwaarte van RDE ritten normaliseren naar een typegoedkeuringstest. De fabrikanten mogen zelf kiezen of ze EMROAD of CLEAR willen gebruiken. EMROAD en CLEAR geven als uitkomst de genormaliseerde NO_x uitstoot op de gereden RDE rit en een oordeel of de auto aan het emissie criterium voldoet.

Bij toepassing op bestaande auto's is het effect van de normalisatie met EMROAD en CLEAR in veel gevallen beperkt tot een correctie binnen een bandbreedte van ±20%. Als echter bedacht wordt dat de meeste geanalyseerde ritten dicht in de buurt van gemiddeld Europees rijgedrag blijven, zijn dit al substantiële correcties. In sommige gevallen loopt de correctie door EMROAD voor geldige RDE ritten op tot een reductie van de uitstoot met 60% voor het stedelijke deel en 40% voor de hele rit. Daarbij moet worden opgemerkt, dat de uitstoot van de huidige geteste auto's veelal hoog, soms zelfs erg hoog is (tot wel tien maal de Euro-6 limiet) vergeleken met de *Conformity factor* van 2,1 in de 1^{e} RDE stap. De *evaluation tools* zouden andere resultaten kunnen geven als in de toekomst de resultaten van auto's met een lage uitstoot worden geanalyseerd.



Figuur NS4 Het effect van de *evaluation tools* EMROAD en CLEAR. De ruwe meetdata zijn vergeleken met de uitkomsten van de *tools*. De correctie van EMROAD en CLEAR is regelmatig in tegengestelde richting, vooral voor het stedelijk gedeelte. Samen met de correcties die in EMROAD kunnen oplopen tot 60% voor het stedelijke deel en 40% voor de hele RDE rit, roept het twijfels op over de werking van de *tools*. Bron: TNO 2016 R11177 "NO_x emissions of fifteen Euro 6 diesel cars: Results of the Dutch emission testing program 2016", Heijne e.a.

Op dit moment is het nog niet mogelijk een gedetailleerd oordeel te vellen over de *evaluation tools*. Daarvoor moeten eerst meetgegevens van moderne Euro-6 auto's op de nieuwe WLTP test beschikbaar komen.

De beoordeling van de *tools* wordt tevens bemoeilijkt door een gebrek aan transparantie over de werking ervan. Dat maakt het onmogelijk een inschatting te geven van hoe groot de correcties voor toekomstige RDE-*compliant* auto's zullen zijn. Tot op heden zijn nog geen resultaten beschikbaar gesteld van tests die zijn uitgevoerd in de RDE monitoringsfase, die op 20 april 2016 is gestart. Alleen als die resultaten aan partijen betrokken bij de RDE-LDV expert groep beschikbaar worden gesteld, kan een behoorlijke beoordeling worden gegeven.

Transfer function

De nieuwe RDE testprocedure bevat een stapeling van inperkingen aan de testcondities door 'testgrenzen' en 'normalisatie slagen' door toepassing van rekenmodellen (de *evaluation tools* EMROAD en CLEAR) die de testresultaten naar de condities op de rollenbanktest terug rekenen. Hiermee is ieder argument voor een uiteindelijke *Conformity factor* hoger dan 1,0, met een extra marge voor de daadwerkelijke onnauwkeurigheid van PEMS apparatuur, komen te vervallen.

Desalniettemin is in het 2e RDE pakket de mogelijkheid voor verdere normalisatie opgenomen om in een later stadium een gedifferentieerde *Transfer function* te introduceren. Het gaat hierbij om een 'verrekeningsfactor ' voor de emissieresultaten, die vooralsnog de waarde 1 heeft, maar waarvan op een later moment kan worden bepaald dat die op een nader vast te stellen manier moet worden berekend.

De introductie van een *Transfer function* is echter overbodig. Ondanks dat in het 2e pakket is gesteld dat er objectieve wetenschappelijke onderbouwing is vereist en dat de introductie niet mag leiden tot een afzwakking van de milieuwinst en de effectiviteit van de RDE wetgeving, kunnen wijzigingen richting een gedifferentieerde *Transfer function* – bovenop de al opgenomen beperkingen in de test omstandigheden en normalisatie met de *evaluation tools* – niet anders worden opgevat dan een poging om de effectiviteit van RDE af te zwakken.

Elementen van het 3e RDE pakket

De Europese Commissie bereidt momenteel het 3e RDE pakket voor. Naast het toevoegen van de koude-start fase, zal het 3e pakket ook wijzigingen bevatten om het testen van deeltjes aantallen (PN) met PEMS en het testen van hybrides mogelijk te maken en om de regels voor de regeneratie van roetfilter tijdens de RDE rit verduidelijken. Verder wordt aandacht geschonken aan typegoedkeuring van meerfase voertuigen[3], brandstofkwaliteit en kleine fabrikanten .

RDE test voor deeltjesaantallen

Naar verwachting zal de Europese Commissie in het 3e pakket voor PN een *Conformity factor* voorstellen van 1,5 voor zowel de 1e als 2e stap. Daarmee wordt een zelfde aanpak gevolgd als voor NO_x: de factor is 1,0 + een marge van 0,5 die rekening houdt met de meetonnauwkeurigheid van de PEMS apparatuur.

Bij de vaststelling van de PN-norm in Euro-6 was de inschatting dat benzineauto's met directe injectie (GDI's) alleen aan deze norm kunnen voldoen wanneer zij zijn uitgerust met een roetfilter (GPF). De aanwezigheid van een GPF heeft grote voordelen, omdat het de enige robuuste manier is om onder alle rij-omstandigheden een lage PN uitstoot van GDI's te garanderen. Bijkomend voordeel is dat een GPF naar verwachting ook effectief is voor deeltjes kleiner dan 23 nanometer, terwijl voor deze kleinere deeltjes op dit moment geen normen gelden. Dat komt omdat ten tijde van het vaststellen van de norm geen meetapparatuur beschikbaar was om deeltjes tussen 10 en 23 nm nauwkeurig te meten.

Met een conformiteitsfactor 1,5 is het onzeker dat op benzineauto's met directe injectie (GDI's) een GPF zal worden toegepast. Dat is alleen waarschijnlijk als de *Conformity factor* voor PN in het 3e pakket op 1,0 wordt vastgesteld <u>zonder</u> een additionele marge voor de PEMS meetonnauwkeurigheid en als tegelijkertijd de afkapgrens wordt verlaagd van 23 nm naar 10 nm op grond van technologische vooruitgang van de meetapparatuur <u>zonder</u> een verhoging van de Euro-6 PN limietwaarde. Het meenemen van deeltjes met een grootte vanaf 10 nm moet echter worden aangemerkt als een aanscherping van de emissienormen en valt daarmee buiten het mandaat dat is gegeven in de Euro-5/6 wetgeving.

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[3] multi-stage vehicles, (bestel)voertuigen die als chassis-cabine combinatie worden opgeleverd en waar door een derde partij een opbouw op gemaakt wordt.

Ondanks dat het onzeker is dat bij benzineauto’s met directe injectie een GPF moet worden toegepast om aan de PN norm te voldoen, hebben enkele fabrikanten aangekondigd (o.a. Volkswagen en Mercedes) dat ze GPF gefaseerd gaan introduceren op hun voertuigen.

RDE test voor hybrides
Hybride en plug-in hybride aandrijftechnologie zal in de nabije toekomst breed worden toegepast. Het is daarom van belang dat de nieuw RDE testprocedure de beoordeling van (plug-in) hybrides mogelijk maakt. De evaluatie *tools* moeten daarvoor worden aangepast. Alle betrokken partijen steunen het opnemen van hybrides in de RDE wetgeving.

Nederland heeft een eenvoudig en praktisch voorstel ingebracht, waarmee hybrides zonder beperkingen aan een RDE test kunnen worden onderworpen. De methode is gebaseerd op een door TNO ontwikkelde RDE evaluatie methode, die de NO_x- en de CO_2-uitstoot met elkaar vergelijkt. Het Nederlandse voorstel kent veel voordelen. De RDE tests kunnen zonder (aanvullende) beperkingen worden uitgevoerd, er hoeft geen nieuwe informatie te worden verzameld en er zijn geen signalen uit het motormanagement van de auto nodig. De evaluatie van de koude-start-fase kan eenvoudig worden toegevoegd, omdat de verbrandingsmotor niet per se aan het begin van de test hoeft te starten. Het Nederlandse voorstel zal in het 3^e pakket worden opgenomen.

In de RDE-LDV expert groep zijn ook ideeën besproken om de aanpak van regeneratie van roetfilters tijdens de RDE rit te verduidelijken, een uitzondering voor fabrikanten van kleine voertuigaantallen te introduceren en eisen aan de brandstofkwaliteit op te nemen. De Commissie is inmiddels met voorstellen daarvoor gekomen.

Het voorstel voor de regeneratie van roetfilters is een duidelijke verbetering van de RDE wetgeving. De voorstellen voor kleine fabrikanten en brandstofkwaliteit hebben een verwaarloosbaar milieueffect. Bij meerfase voertuigen wordt het criterium dat de RDE-familie voor één fabrikant geldt aangepast.

Het 4^e pakket: testen door onafhankelijke partijen
De focus van het 4^e RDE pakket zal liggen op het beschrijven van de handhavingsstructuur voor RDE en het mogelijk maken van onafhankelijke controle testen. Het 4^e pakket zal moeten garanderen dat RDE tests op de weg kunnen worden uitgevoerd door onafhankelijke derde partijen. Dit is belangrijk, zo niet bepalend, voor de effectiviteit van RDE.

Alleen onafhankelijke partijen kunnen er voor zorgen dat RDE tests ook de grenzen opzoeken van de rijomstandigheden en ritten die binnen RDE zijn toegestaan. Het is essentieel dat tests uitgevoerd door onafhankelijke partijen een status krijgen en dat resultaten uit die tests door typegoedkeuringsinstanties ontvankelijk worden verklaard en worden betrokken bij de beoordeling van auto’s die al op de Europese wegen zijn toegelaten. In het 4^e pakket moet worden geregeld hoe wordt opgetreden als fabrikanten of typegoedkeuringsinstanties onvoldoende actie ondernemen als een RDE test aantoont dat een auto niet aan RDE voldoet.

Alleen onafhankelijke RDE tests kunnen de informatie verschaffen die nodig is om de meetonnauwkeurigheid van PEMS apparatuur te volgen en te evalueren.
De Europese Commissie heeft een geannoteerde agenda opgesteld voor het 4^{e} RDE pakket. Daarin zijn alle essentiële onderdelen opgenomen. Het is op dit moment nog onduidelijk of het voorstel voor het 4^{e} pakket ook daadwerkelijk alle elementen zal bevatten. De Commissie had aangekondigd in september/oktober 2016 een voorstel met de expert groep te willen bespreken. Deze planning wordt waarschijnlijk niet gehaald.

Management summary

The *Volkswagen case* brought renewed attention to vehicle exhaust emissions, in particular to the high real-world NO_x emissions of modern Euro 5 and Euro 6 diesel passenger cars and light duty vans. The development of the new **Real Driving Emissions (RDE)** legislation is considered to be the way forward to secure low on-road emissions in the years to come. The Ministry of Infrastructure and the Environment in the Netherlands requested TNO to conduct an assessment of the strengths and weaknesses of the new European RDE test procedure.

In general the conclusion is justified that the 1st and 2nd RDE packages and the announced additions of the 3rd and 4th packages are a sound base for substantial reductions of on-road exhaust emissions of new vehicles in the near future.

Strengths RDE legislation	Comments
RDE will introduce on-road emission measurements	Relying solely on lab tests was ineffective in delivering low on-road emission levels
Emissions in urban areas will be assessed separately	For reasons of air quality and health it's important on-road emissions in densely populated urban areas will be reduced
Window of RDE test conditions is sufficiently broad	RDE legislation allows RDE test being conducted under almost all conditions that can be considered as 'normal' European conditions
Accurate PEMS equipment is available	There are no bottlenecks of technical nature that prevent the execution of valid RDE tests
Cold start will be included	It is expected that the 3rd package will contain adequate provisions to include emissions during cold start in the RDE data-evaluation

Weaknesses / Risks RDE legislation	Comments
The effectiveness of RDE strongly depends on adequate enforcement, to be developed under the 4th package.	The start of the 4th package development seems to be delayed.
Evaluation tools EMROAD and CLEAR lack transparency and give different results. Car manufacturers are free to choose the tool that gives favourable results.	A proper assessment of the impact of the evaluation tools on RDE's effectiveness can only be conducted if and only after test results, calculation results and experiences are exchanged in the RDE-LDV expert group
RDE legislation still contains the option of introduction of differentiated *Transfer functions*	*Transfer functions* are superfluous and can only be considered as an attempt to weaken RDE
The *Conformity factors* could already be reduced as the accuracy of PEMS equipment is better than assumed	Although announced, the process to reduce the *Conformity factors* has not yet been started.
Continued discussions on proposals to narrow the window of allowed test conditions	Constantly new ideas and proposals to narrow the window of RDE test conditions are brought to the RDE-LDV expert group. There is a risk that RDE in the future will become less effective in reducing on-road emissions under all conditions that can be considered 'normal' European driving.

Summary

The *Volkswagen case* brought renewed attention to vehicle exhaust emissions, in particular to the high real-world NO_x emissions of modern Euro 5 and Euro 6 diesel passenger cars and light duty vans. The development of the new **Real Driving Emissions (RDE)** legislation is considered to be the way forward to secure low on-road emissions in the years to come. RDE legislation is under development with the 1st and 2nd RDE packages being published[4], the 3rd package in preparation and the 4th package foreseen for early 2017.[5]

The Ministry of Infrastructure and the Environment in the Netherlands requested TNO to conduct an assessment of the strengths and weaknesses of the new European RDE test procedure and present the outcome well before final decisions are taken on the 3rd and 4th RDE legislative packages, due respectively in November 2016 and early 2017.

General conclusion
In general the conclusion is justified that the 1st and 2nd RDE packages and the announced additions of the 3rd and 4th packages are a sound base for substantial reductions of on-road exhaust emissions of new vehicles in the near future.
The strengthes of the RDE legislation can be summarized as:

Strength	Comments
RDE will introduce on-road emission measurements	Relying solely on lab tests was ineffective in delivering low on-road emission levels
Emissions in urban areas will be assessed separately	For reasons of air quality and health it's important on-road emissions in densely populated urban areas will be reduced
Window of RDE test conditions is sufficiently broad	RDE legislation allows RDE test being conducted under almost all conditions that can be considered as 'normal' European conditions
Accurate PEMS equipment is available	There are no bottlenecks of technical nature that prevent the execution of valid RDE tests
Cold start will be included	It is expected that the 3rd package will contain adequate provisions to include emissions during cold start in the RDE data-evaluation

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[4] 1st package: http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32016R0427
2nd package: http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32016R0646

[5] RDE packages are pre-discussed with stakeholders and Member States in the Commissions RDE-LDV expert groups. The European Commission brings the final proposals for a vote to TCMV.
The Netherlands delegation in general consists of delegates from RDW (head), the Ministry of Infrastructure and the Environment and TNO.

The weaknesses and risks of the RDE legislation can be summarized as:

Weakness / Risk	Comments
The effectiveness of RDE strongly depends on adequate enforcement, to be developed under the 4th package.	The start of the 4th package development seems to be delayed.
Evaluation tools EMROAD and CLEAR lack transparency and give different results. Car manufacturers are free to choose the tool that gives favourable results.	A proper assessment of the impact of the evaluation tools on RDE's effectiveness can only be conducted if and only after test results, calculation results and experiences are exchanged in the RDE-LDV expert group
RDE legislation still contains the option of introduction of differentiated *Transfer functions*	*Transfer functions* are superfluous and can only be considered as an attempt to weaken RDE
The *Conformity factors* could already be reduced as the accuracy of PEMS equipment is better than assumed when setting the margins in the Conformity factors.	Although announced, the process to reduce the *Conformity factors* has not yet been started.
Continued discussions on proposals to narrow the window of allowed test conditions	Constantly new ideas and proposals to narrow the window of RDE test conditions are brought to the RDE-LDV expert group. There is a risk that RDE in the future will become less effective in reducing on-road emissions under all conditions that can be considered 'normal' European driving.

Introduction of on-road emissions test

In the European Euro 5/6 regulation of 2007 it was already anticipated that the laboratory test for type-approval would not suffice to ensure low emissions on the road. Article 5(1) introduced the general principle that the effectiveness during normal use of the vehicle should be guiding in the design of emission control technology and emission control strategy. By the introduction of article 14(3) the European Commission was mandated to develop, if necessary, an on-road emission testing regulation.

The RDE legislation will introduce a mandatory on-road emissions test for passenger cars and light duty vans, on top of the normal type-approval test on a chassis dynamometer in a laboratory. In addition to the RDE test conducted with a vehicle representing an RDE-family, the car manufacturer will have to declare that all vehicles of the RDE-family comply under all possible RDE tests with the RDE emission criterion. This declaration, included in type-approval on the request of the Dutch delegation, will be the basis for the enforcement provisions in the announced 4th package.

The experiences with Heavy Duty vehicles in the past clearly show that a combination of stringent Euro 6 limit values and RDE-legislation offers a good perspective of a strong reduction in real-world NO_x emissions of diesel passenger cars and light duty vans.

If effective, RDE will have a major impact on urban air quality, in particular on NO_2 concentrations.

General design RDE legislation

Ideally, RDE testing is unbound, i.e., covering all normal conditions of use, only restricted by traffic regulations, such as speed limits, and the vehicle's capabilities. This is not the approach chosen in the RDE legislation as it might force car manufacturers to apply expensive technology for situations that hardly occur. An RDE test will consist of a trip driven on the road, with driving conditions within defined windows, emissions measurement with PEMS equipment mounted in or to the vehicle, a data processing step meant to normalize the severity of the RDE trip to the severity a standard WLTP type-approval test and finally a check against the RDE emission criterion. As a consequence it's essential for RDE's effectiveness in terms of reducing real-world emissions, that at least:

- The emission criterion is sufficiently stringent (Conformity Factors).
- A broad window of test conditions is covered (related to e.g. driving behaviour and ambient conditions).
- The evaluation method(s), used for translating the measurement results to a number to which the Conformity Factor is applied, only normalize for severity of the RDE trip and do not cover up events of high emissions.
- With respect to improving urban air quality emissions in urban traffic conditions are evaluated separately, in order to prevent for compensation of high urban emissions by low rural or motorway emissions.
- Independent validation tests are accommodated.

Conformity factor NO_x

For NO_x the conformity factor (CF) has been established in the 2nd package and will be introduced in two steps. In the final step, coming into force by January 2021 for all new cars sold, the CF will be 1.0 plus a margin currently set to 0.5 taking into account additional uncertainties introduced by PEMS measurement equipment.
The RDE NTE limit values are set accordingly:

Diesel vehicle class	1st step RDE limit values in mg NO_x per km (CF = 2.1)	2nd step RDE limit values in mg NO_x per km (CF = 1 + margin 0.5)	Corresponding Euro-6 limit value (mg/km)
Passenger cars and Light duty vehicles N1, class I	168	120	80
Light duty vehicles N1, class II	220	158	105
Light duty vehicles N1, class III	263	188	125

A positive development in the course of time was the introduction in the 2nd package of a separate evaluation of urban driving: emissions during urban driving will have to meet the RDE NTE limit values. An evaluation of only the total RDE trip would have enabled compensation of high urban emissions by low rural emissions; very undesirable from a perspective of air quality and human health. The separate urban evaluation ensures proper real-world emission in urban areas.

Limitations on the test conditions: ambient temperature

The importance of adequate RDE ambient boundary conditions, in particular the temperature window, is widely acknowledged. The effectiveness of the emission control of modern pre-RDE cars is strongly reduced if ambient temperatures are below the laboratory test window of 20 - 30°C.

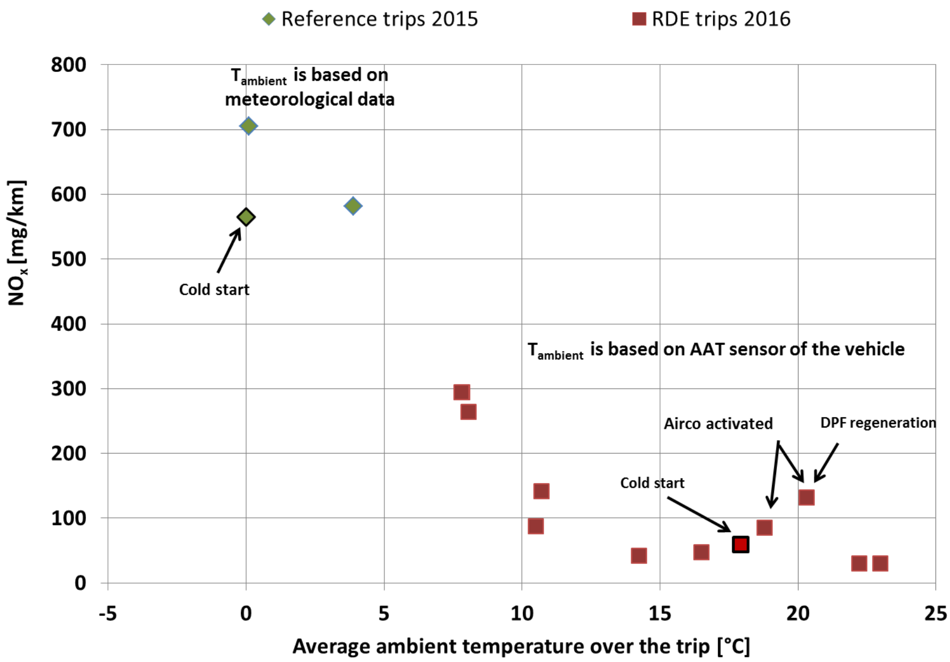


Figure S1 Real-world NO_x emissions of a modern Euro 6 diesel car strongly depend on the ambient temperature, Source: TNO 2016 R11123 "Review into the relation between ambient temperature and NO_x emissions of a Euro 6 Mercedes C220 Bluetec with a diesel engine", Kadijk et.al.

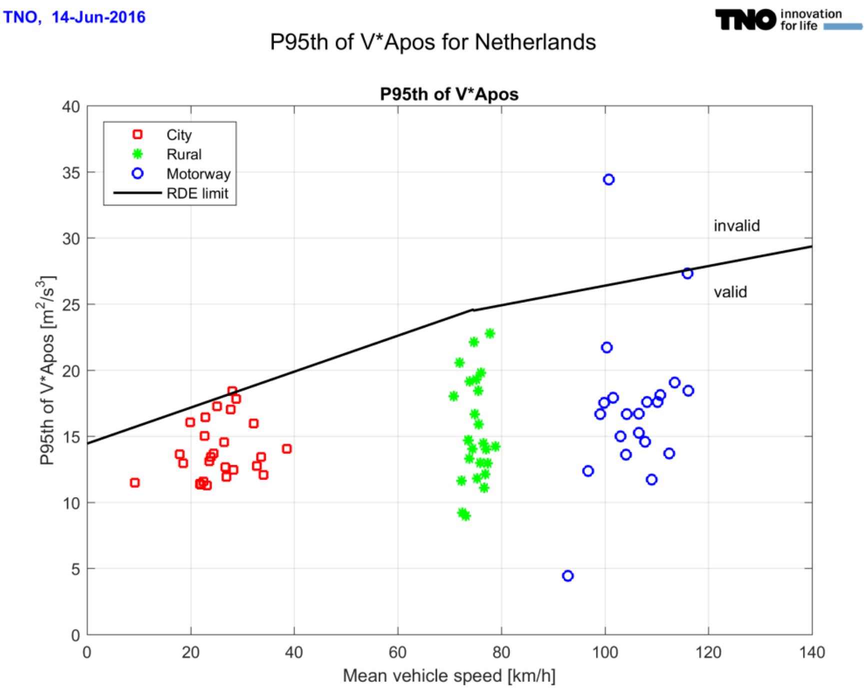
For the situation in The Netherlands the RDE temperature boundaries of 0 - 30°C (and even down to -7°C or up to 35°C for the extended boundaries) can be assessed as being adequate. There's no room to narrow the window: during on average 8% of morning rush hours temperatures in The Netherlands are below 0°C.

A strong aspect of the RDE requirements is that no restrictions are introduced to limit the window of ambient conditions with respect to wind speeds, air pressure, humidity, road inclines and surfaces (given that the road is paved).

Limitations on RDE trip composition
For practical reasons and in order to prevent for extremely biased situations and to guarantee the inclusion of all road sections, requirements for the composition of RDE trips have been introduced. Most requirements are assessed as being reasonable.

However, in particular the prescribed sequence of urban, rural and motorway driving and the restriction to a maximum of 3 minutes of idling might introduce a risk of trip recognition and/or trip optimization. This moment in time, with no RDE-compliant cars available, its possible impact on increased real-world emissions cannot be assessed. One option to reduce the risk is to extend the maximum period of idling. In addition it's essential that future testing programmes continuously investigate the application of trip recognition and optimization and, if appropriate, legislation is adapted accordingly.

The Netherlands



Belgium

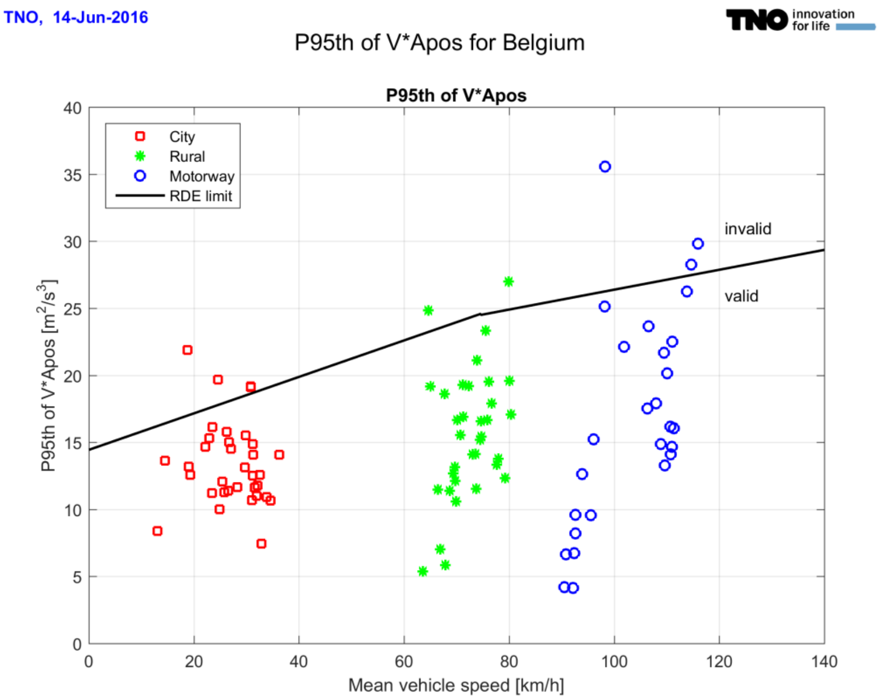


Figure S2 Driving behaviour in The Netherlands and Belgium observed in a research project conducted by TNO has been assessed against the RDE $v{*}a_{pos}$ limit value for driving dynamics. Source: information delivered by the Dutch delegation to the RDE-LDV expert group.

Limitation on driving behaviour

Driving behaviour, such as accelerations and driving speed, strongly impacts the NO_x emissions of modern diesel passenger cars. It's therefore most important that the events of high emissions are included in an RDE trip, in particular events that occur in what can be considered to be 'normal driving'. On the other hand, to prevent vehicles from being tested under extreme driving conditions, like excessively high dynamics or consistently slow driving, boundary conditions have been introduced in the RDE-legislation.

The RDE driving behaviour boundaries have been confronted with the outcome of a TNO project that established driving behaviour in North-West Europe. Measurements have been performed in Belgium, (the northern part of) France, (Ruhr area in) Germany and The Netherlands. The results of the Dutch and the Belgian measurements are shown in figure S2.

In general the RDE driving behaviour boundaries sufficiently cover normal driving. In order to prevent RDE legislation from being effective in some countries, but not throughout the EU as a whole, there is no room to tighten the boundaries (i.e. to lower the v*apos limit).

Nevertheless an additional driving behaviour boundary for delivery vans could be considered, as current boundaries allow for extremely aggressive driving of vans. It's unclear if a practical proposal to solve this problem suggested by the Dutch delegation to the RDE-LDV expert group will be included in the proposals for the 3rd or 4th package.

France (Paris and to the north of Paris)

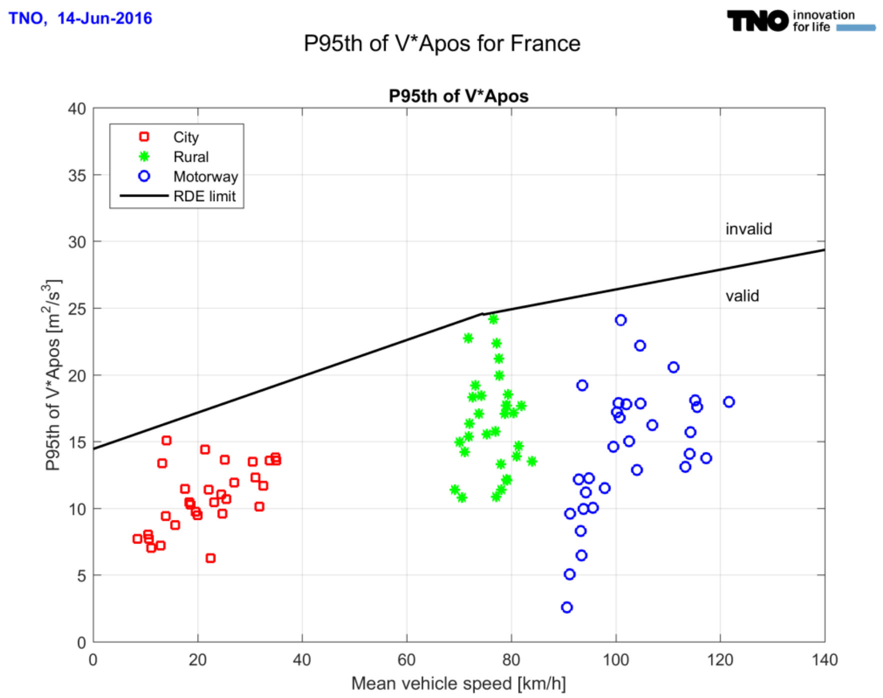


Figure S3 In France, particularly in and around Paris, the observed average speed of the urban part of trips is frequently below the required minimum speed of 15 km/h. Source: information delivered by the Dutch delegation to the RDE-LDV expert group.

In order to cover a wider range of urban driving throughout Europe, in particular stop and go traffic frequently observed in densely populated areas with high traffic density, it could be considered to lower the 15 km/h minimum average speed during urban driving of RDE trips. Stop and go urban traffic is generally associated with high emissions. No initiative has been reported to lower the minimum average speed.

A strong aspect of RDE is that no restrictions are introduced to prescribe gear selection.

Test vehicle
The obligation to meet the RDE requirements is not restricted to new specially prepared vehicles. The RDE test can be conducted with a proper in-use vehicle under conditions that actually correspond to possible use at real driving on the road. This wide range of vehicle conditions is particularly important to allow for independent testing.

Availability PEMS measurement equipment
Reliable PEMS measurement equipment fulfilling all RDE requirements is readily available, offered by several equipment suppliers. An important issue is the accuracy of PEMS equipment, as it directly impacts the NO_x conformity factor: the final CF will be 1.0 plus a margin set to 0.5 in the 2nd RDE package that takes into account the assumed uncertainties introduced by PEMS equipment. This margin of 0.5 is wide compared to the (in)accuracy of current generation PEMS of well within ±30%, giving reason to start the announced annual review procedure already under the 4th RDE package. Setting absolute demands on PEMS accuracy and measurement procedures could help to make sure that systems are further improved and the uncertainty margin in the Conformity Factors can be reduced.

Cold start
In RDE, up to the 2nd package included, the emissions during the warm-up of the engine - the so-called cold start period that covers the first 5 minutes after initial start of the vehicle engine - are measured by the PEMS system, but the collected data are excluded from the emissions evaluation. Cold start emissions predominantly occur in densely populated areas and – if uncontrolled – can double or triple average NO_x emissions under urban driving conditions of future RDE-compliant cars.

For reasons of air quality it’s very important that the cold start period will be included in the RDE data evaluation. This can easily be done in the 3rd RDE package - without unacceptable burden to the car industry - by the inclusion of the cold start in the evaluation of the urban part of the RDE trip. The 3rd package proposal will contain adequate provisions to include emissions during cold start in the RDE data-evaluation as proposed by the Dutch delegation.

Evaluation tools EMROAD and CLEAR
Individual RDE trips will vary in severity and may differ in severity from the type-approval test against which the Euro-6 limit values – 80 mg/km for diesel passenger cars – are established. To take into account these variations, two evaluation tools, EMROAD and CLEAR, have been introduced to normalize the RDE test results. It’s upon the choice of the manufacturer if they want to use EMROAD or CLEAR. In

addition to the normalised emissions EMROAD or CLEAR will also present a pass or fail result against the RDE emission criterion.

If applied to currently available vehicles the normalization corrections by EMROAD and CLEAR are in most cases within a bandwidth of ±20%; substantial corrections given the fact that the RDE trips driven are close to average European driving. In some cases the EMROAD tool showed corrections of up to 60% reduction in the urban part and 40% reduction in the total trip result for valid RDE trips. It should be noted that the emissions of most of the tested vehicles are high, often very high (up to ten times the Euro 6 limit values), compared to even the conformity factor 2.1 in the first RDE step. The results might be different if the evaluation tools were applied to data sets of low emitting cars.

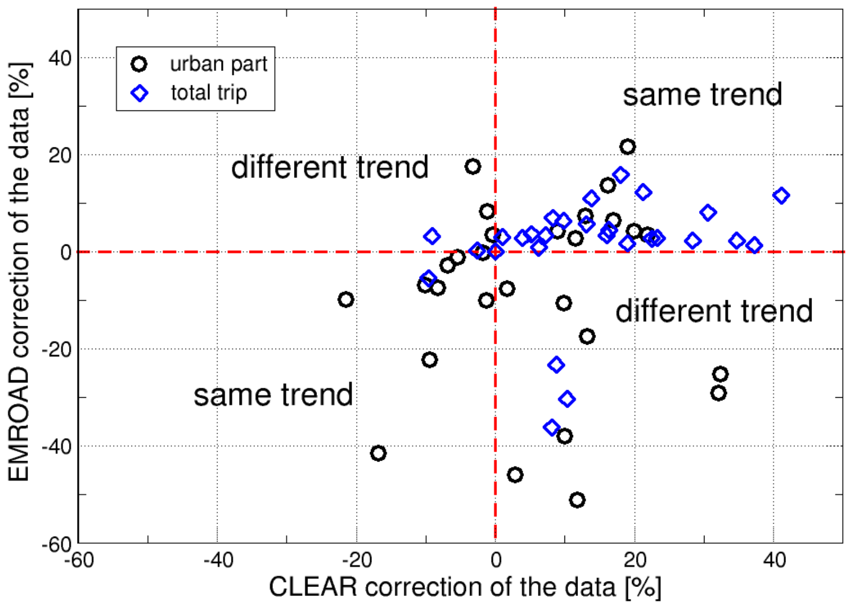


Figure S4 The impact of the RDE evaluation tools: The measurements, raw data, are compared with the calculated emissions after applying both EMROAD and CLEAR. CLEAR and EMROAD do often not follow the same trend in the normalization of the result, certainly not for the urban part. This together with the reduction of 60% on the urban test and 40% on the total trip of the measured average on valid RDE tests in EMROAD do raise concerns on the purpose of the tools. The tests performed are considered not extreme in any manner. Source: TNO 2016 R11177 "NO_x emissions of fifteen Euro 6 diesel cars: Results of the Dutch road vehicle emission testing program 2016", Heijne et.al.

At the moment it is not possible to do an evaluation of the tools in all its details, as required WLTP tests results of current Euro-6 vehicles are not widely available. The lack of transparency of what's happening inside the evaluation tools also complicates the assessment of the tools and the assessment of what the corrections would be for future RDE compliant vehicles. Test results from the RDE monitoring phase, that started from 20 April 2016, have not been made available so far. Only if the test results become available to parties involved in the RDE-LDV expert group a proper assessment of the evaluation tools can be conducted.

Transfer function

Given the pile of 'normalizations' and 'boundaries' included in RDE any argument to apply a conformity factor higher than 1.0, with only an additional margin for state of the art accuracy of PEMS equipment, in the final RDE phase has expired.

With the inclusion of a placeholder in the 2nd package, the option to introduce a differentiated Transfer function is still left open. This differentiation is meant to take account of the severity of emission control due to variations in RDE trips and should be justified by objective scientific reasons. As yet the value of the Transfer function is set to 1.0. An introduction of a differentiated Transfer function is superfluous. Even though it is stated in the 2nd RDE package that “if the transfer function is amended, this shall be done in a manner which is not detrimental to the environmental impact and the effectiveness of the RDE test procedures”, any amendment on top of all the RDE boundary conditions and evaluation tools already applied in the RDE legislation can only be considered as an attempt to weaken the effectiveness of RDE.

3rd package issues

The European Commission is currently preparing the 3rd RDE package and announced this package will comprise, on top of the inclusion of cold start coverage, Particle number (PN) PEMS testing and requirements for testing hybrid vehicles. The 3rd package will also cover clarification of particle filter regeneration provisions and new provisions for multi-stage vehicles, fuel quality and small volume manufacturers.

PN PEMS testing

It is expected that the European Commission will propose a PN Conformity factor of 1,5 in the 3rd package for both the 1st and 2nd RDE step, following a similar approach as for NO_x: a factor of 1.0 <u>plus</u> a margin expected to be set to 0.5 that reflects PEMS PN measurement (in)accuracy.

When set the Euro-6 PN limit value was expected to lead to the application of particle filters (GPF) on direct injection petrol vehicles (GDI). The application of GPF is the only robust technology to reduce PN emissions of GDI under all ‘normal’ European driving conditions with the added advantage that a GPF is also effective in reducing emissions of particles sized in the range of 10 to 23 nm, particles that currently are not regulated due to limitations in the measurement equipment at the time the Euro-6 limit was set.

Application of a GPF on all GDI’s will not be secured if the conformity factor for PN in the 3rd package is set at 1.5 (1.0 + 0.5 margin). Application on all GDI’s is expected to be secured only if the conformity factor is set at 1.0 without an additional margin for PEMS measurement (in)accuracy <u>and</u> the measurement cut-off size is reduced to 10 nm on grounds of technical progress of measurement equipment, without an increase of the Euro-6 PN limit values. However, the inclusion of particles in the 10-23 nm range can be considered being a strengthening of the emission values and as such outside the mandate given by the Euro5/6 legislation.

Even though a GPF might not be required to meet the RDE PN emission limit, several manufacturers have announced a phased-in introduction of GPFs on their petrol cars.

RDE tests for hybrid vehicles
Hybrids and plug-in hybrids will be a wide spread technology in the near future. Assessment of (plug-in) hybrids emissions requires modifications of the current RDE evaluation methods. All stakeholders support the inclusion of hybrids in the RDE legislation.

The Netherlands has proposed a practically applicable RDE test protocol without limitations for the manner in which the hybrids are tested. The method is based on a TNO RDE evaluation method of comparing the NO_x emissions with the CO_2 emissions. The advantages of the Dutch proposal are manifold. The RDE testing is unrestricted and it does not require additional information or signals. Since the engine does not need to start at the beginning of the trip, the cold start evaluation can be included, adding no or only limited complexity to any hybrid test. The Dutch proposal will be included in the 3rd package proposal.

In the RDE-LDV expert group proposals have been discussed to clarify the methodology to handle emissions during regeneration of particulate filters, to introduce an exemption for small volume manufacturers, to accommodate RDE testing for multi-stage vehicles and to include fuel quality requirements. The Commission recently came up with proposals.

The proposal dealing with particulate filter regeneration clearly is an improvement of the existing text. The proposals for small volume manufacturers and fuel quality have no or very limited environmental impacts. The current restriction that an RDE-family is only applicable to one manufacturer will be abolished for multi-stage vehicles.

The 4th package: independent testing
The focus of the 4th RDE package will be on the development of adequate enforcement provisions and on accommodating independent testing. The 4th package should adequately secure that independent on-road RDE testing can be performed by independent parties. The possibility of such independent surveillance testing is particularly important, if not decisive, for RDE's effectiveness, since only third party testing can ensure that RDE tests cover the full window of test conditions and a wide variety of trips. It's vital that independent tests get a proper status. The results of these tests need to be accepted as input for the type-approval process and review for vehicles already accepted on the European roads. Escalation and sanctioning of manufacturer and type-approval authority in case of insufficient actions on a non-compliant vehicle needs to be secured. And only by independent RDE testing information required to review the (in)accuracy margin of PEMS equipment can be delivered.

The annotated agenda of the 4th package outlined by the European Commission contains the vital elements. At this moment in time it's unclear if these elements will materialize in the 4th package proposal foreseen to be presented and discussed in an expert group September/October 2016. The start of the 4th package development seems to be delayed.

Contents

1 Introduction

The *Volkswagen case* brought renewed attention to vehicle exhaust emissions, in particular to the high real-world NO_x emissions of modern Euro-5 and Euro 6 diesel passenger cars and light duty vans. The development of the new **Real Driving Emissions (RDE)** legislation is considered to be the way forward to secure low on-road emissions in the years to come. RDE legislation is under development with the 1st and 2nd RDE packages being published[6], the 3rd package in preparation and its proposal expected to be published by the European Commission in autumn 2016 and the 4th package foreseen for early 2017.

The Ministry of Infrastructure and the Environment in the Netherlands requested TNO to conduct an assessment of the strengths and weaknesses of the new European RDE test procedure and present the outcome well before final decisions are taken on the 3rd and 4th RDE legislative packages, due respectively in November 2016 and early 2017.

In this report the outcome of this assessment will be presented. In the second and third chapter the importance of the development of RDE will be highlighted. It will underline that the design of the RDE legislation will make or break the business.

In the chapters 5 to 10 included, the details of the design of the RDE legislation will be assessed in respect of ambient and road conditions covered, RDE trip composition, driving behaviour, vehicle specifications, measuring equipment and evaluation methods.

Chapters 11 and 12 will assess the open issues expected to be dealt with in the 3rd and 4th legislative RDE package.

The focus of the assessment is on the contents of the RDE tests and test procedures. The dates of coming into force of RDE and the feasibility and availability of technology to meet the RDE requirements is outside its scope.

[6] 1st package: http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32016R0427
2nd package: http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32016R0646

2 RDE: from lab tests to on-road performance

RDE legislation is the natural consequence of the developments in the last twenty years in vehicle emission testing. With the increasing complexity of vehicle technology, the type-approval test became isolated from the normal variations in conditions on the road. Rather than simple physical principles guiding the emissions, as would be the case with a purely mechanical engine, the modern vehicle has complex electronic control which relies on input from many sensors. Recently, ambient, or air-inlet, temperature sensors received much attention, because many vehicles have reduced emission control at lower, yet normal European, temperatures, e.g., in the range 10 – 17°C, than the in the type-approval test, with a specified temperature range of 20 - 30°C. In designing a vehicle and developing an emission control strategy manufacturers seem to have restricted the robustness of the emission control strategy, as formally, in the type-approval test, emission-control robustness for normal use is not required.

In 2007 in European regulation 715/2007 (Euro-5/6) it was already anticipated that the laboratory test for type-approval would not suffice to ensure low emissions on the road. The general principle for on-road performance was set out in article 5(1) of the regulation:

> ***Article 5(1):*** *The manufacturer shall equip vehicles so that the components likely to affect emissions are designed, constructed and assembled so as to enable the vehicle, in normal use, to comply with this Regulation and its implementing measures.*

The normal use, rather than the specifics of the actual type-approval test should be guiding in the design of emission control technology and emission control strategy of the vehicle. The development of an on-road emission testing regulation as part of the Euro-6, if necessary, was mandated by article 14(3) of the same regulation:

> ***Article 14(3):****The Commission shall keep under review the procedures, tests and requirements referred to in Article 5(3) as well as the test cycles used to measure emissions. If the review finds that these are no longer adequate or no longer reflect real-world emissions, they shall be adapted so as to adequately reflect the emissions generated by real driving on the road. The necessary measures, which are designed to amend non-essential elements of this Regulation, by supplementing it, shall be adopted in accordance with the regulatory procedure with scrutiny referred to in Article 15(3).*

If Euro-5 vehicles, which entered the market in 2009 had delivered substantial emission reduction in real-world the need to invoke 14(3) would not have been necessary. But from very early on, it was clear that the more stringent NO_x emission limit from Euro-4 (250 mg/km) to Euro-5 (180 mg/km) did not deliver anything like the same reduction of NO_x emissions on the road.

Central to the gap between laboratory tests and on-road NO_x emissions of diesel vehicles is the strict specification and test protocol for comparable test results. Only in a small region around the conditions prescribed in the test procedure vehicles have low emissions. The desired robustness of emission control technology, functioning fully everywhere and all the time, at least in most conditions of normal use, goes against the grain of the lab-based type-approval test protocol, with its precise prescriptions. The robustness of emission control technologies requires both the responsibility of the manufacturer for the overall emission performance, and the freedom to test the emission performance of a vehicle in all normal on-road circumstances.

The use of a defeat device, or a hard switch, to reduce the emission control of a vehicle on-road, is a separate issue from the non-robustness of the emission control. In many cases no hard switch is needed to have limited performance of the emission control in normal vehicle use. Specific optimization of the emission control with the type-approval test protocol in hand is enough to have limited performance in most normal on-road conditions. Temperature, engine load and vehicle weight, running lights or air-conditioning are but a few of the aspects in which on-road conditions differ from the type-approval test. For all practical purposes, except the legal ones regarding defeat devices, the results are the same: high emissions on road.

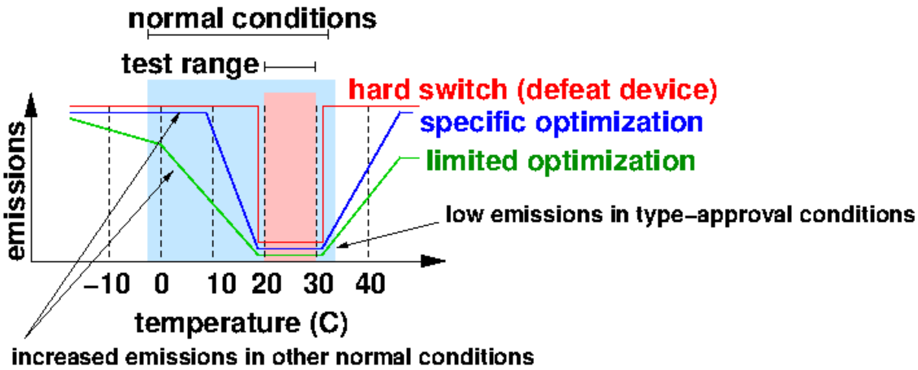


Figure 1 The temperature as an example of the emission control of modern diesel passenger cars. The control performs well under type-approval test conditions. High real-world emissions are observed if conditions deviate from type-approval conditions. The bandwidth of low emission conditions differs from vehicle to vehicle and strongly depends on the level of optimization applied by the manufacturer. Apart from this example of the temperature, small changes in test mass, running lights, etc. can all influence the emissions significantly.

Traditionally, with so-called mechanical engines and static engine maps, higher emissions were associated with high engine loads. These high engine loads, associated with accelerations and high velocities, were not covered by the type-approval tests. The need for the introduction of a new test cycle stems from these times. However, comparable tests require a test protocol suitable for the lowest powered vehicles, which excludes the higher engine loads. The engine load is nowadays only one of the many factors which influence the emission performance.

Normal use does span very large variations of multiple conditions: low temperatures in Northern-Europe, long stretches of uphill driving in mountainous areas, stop and go rush hour traffic in densely populated areas, etc. The only way to secure low real-world emissions under all conditions would be to introduce unbound testing, testing only restricted by vehicle capabilities. The approach chosen for RDE is to define ‘normal use’ by selecting average EU conditions surrounded by a broad, but nevertheless restricted, window of acceptable conditions.

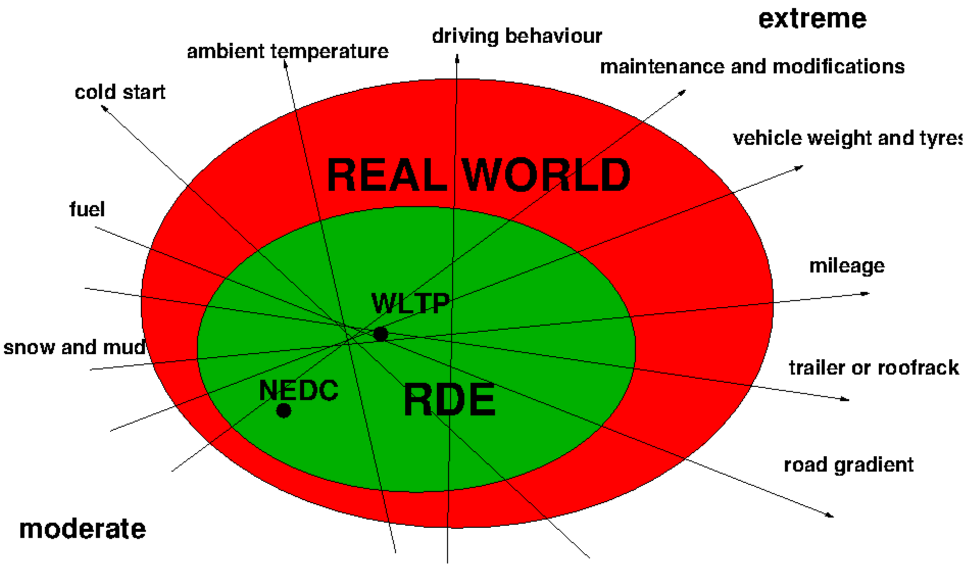


Figure 2 The introduction of the new WLTP test procedure as per 2017 will bring more realistic type-approval conditions, but the band width of testing conditions remains narrow compared to the full span of multiple conditions observed in Europe. A different approach is required to cover on-road conditions sufficiently.

In the past the same phenomenon occurred for Heavy Duty (HD) vehicles. Over the years real-world NO_x emission remained high despite increasingly more stringent limit values. Only after the introduction of mandatory on-road testing with PEMS and more strict OBD requirements during Euro Vb and its full application under Euro VI real-world emissions of Heavy Duty trucks dropped dramatically.

The RDE legislation will introduce a mandatory on-road emissions test for passenger cars and light duty vans, on top of the normal type-approval test on a chassis dynamometer in a laboratory. The pre-RDE situation and the experiences with Heavy Duty vehicles in the past clearly show that a combination of stringent Euro 6 limit values and RDE-legislation offers a good perspective of a strong reduction in real-world NO_x emissions of diesel passenger cars and light duty vans.

3 General design of the RDE legislation

The approach followed in the RDE legislation contains four consecutive steps:

1. Execution of a valid RDE on-road trip.
A trip is valid if the driving conditions are within the windows defined in the legislation. The windows for ambient conditions, road conditions, trip composition, driving behaviour and vehicle conditions will be assessed in chapters 5 to 8 included.
2. Emissions measurement with PEMS equipment.
Emissions will be measured during the RDE trip with PEMS equipment mounted in or to the vehicle. The requirements for the measurement procedure and the PEMS equipment will be assessed in chapter 9.
3. Data processing.
The PEMS measurement data will be processed by evaluation tools, EMROAD and/or CLEAR, to take into account variations in severity of RDE trips and to normalize the RDE test results to the severity a standard WLTP type-approval test. Data processing will be assessed in paragraph 10.1 and 10.2 included.
4. Check against RDE emission criterion.
The result of the data processing step will have to fulfil the RDE emission criterion. The vehicle will have to fulfil the criterion not only on the complete RDE trip, but also on the urban part of the trip.

The general RDE emission criterion is:

> "Throughout the normal life of a vehicle type […] its emissions determined in accordance with the requirements of [the RDE legislation] and emitted at any possible RDE test performed in accordance with the requirements of [the RDE legislation], shall not be higher than the following not-to-exceed (NTE) values:
>
> $NTE_{pollutant} = CF_{pollutant} \times TF(p_1,\ldots, p_n) \times \text{EURO-6}$
>
> The [NTE value] shall be fulfilled for the urban part and the complete PEMS trip"

The RDE NO_x criteria are established with the 2nd package. The RDE fine particles (PN) criteria are expected to be introduced in the 3rd package (see chapter 11).

Where for **NO_x**:

EURO-6 is the Euro-6 NO_x emission limit:

Diesel vehicle class	Euro-6 limit value in mg NO_x per km
Passenger cars and Light duty vehicles N1, class I	80
Light duty vehicles N1, class II	105
Light duty vehicles N1, class III	125

TF, Transfer function, is currently set to 1, but may be differentiated in the future to reflect the severity of the RDE trip.

CF, Conformity factor, will be introduced in two steps:

	NO_x Conformity factor for passenger cars and light duty vehicles	New type approvals[1]	All registrations[1]
1st step	2.1	September 2017	September 2019
2nd step	1 + *margin*	January 2020	January 2021

1. The dates in the table apply to passenger cars and light duty vehicles of class I. The dates of coming into force for Class II and III light duty vehicles is 1 year after the given dates.

The *margin* is currently set to 0.5 and reflects PEMS (in)accuracy (see Chapter 9).

This will result in the following RDE NTE limit values:

Diesel vehicle class	1st step RDE limit values in mg NO_x per km	2nd step RDE limit values in mg NO_x per km
Passenger cars and Light duty vehicles N1, class I	168	120
Light duty vehicles N1, class II	220	158
Light duty vehicles N1, class III	263	188

4 Impact and effectiveness of RDE legislation

If RDE legislation is effective in reducing real-world NO_x emissions, the impact on urban air quality will be substantial. This can be deduced from analyses in The Netherlands that compared the current situation with the imaginary situation that real-world emissions would have followed the relative reductions in emission standards. “The NO_2 concentrations in the Netherlands would have been significantly lower if the emissions from passenger cars, light-duty, and heavy-duty vehicles would have been reduced as expected from the Euro-standards. At individual locations the local traffic contribution would have been about 30% lower than currently expected. This would be in addition to a lower expected large-scale contribution of a few $\mu g/m^3$. The total NO_2 concentrations at specific locations would have been 5 to 10 $\mu g/m^3$ lower than currently expected for 2015. As a result there would be practically no locations where the limit value would be exceeded in the Netherlands in 2015, compared to about 150 locations (or 15 km road length) in the current projection.”[7]

In chapter 2 it was concluded that RDE offers a good perspective of a strong reduction in real-world NO_x emissions of diesel passenger cars and light duty vans. It should be emphasized, however, that the effectiveness of RDE legislation does not only depend on the introduction of mandatory on-road testing, but also on the details of the design of the legislation.

Prior experience with Heavy Duty vehicles strongly supports the need of an adequate design. The design of the Heavy Duty PEMS-trips was tuned to the specifications and driving conditions of long-haul trucks. Typical urban driving conditions were insufficiently covered by the RDE design. As a result the real-world urban emissions of Euro VI distribution trucks and city buses are relatively high compared to long-haul trucks. The urban conditions with low velocity and low engine load still constitutes a risk of high emissions for heavy duty vehicles. These particular situations are often associated with air-quality problems, which are typically congested urban roads.

The importance of an adequate design can also be demonstrated by the emission map (specific NO_x emissions as a function of vehicle speed and acceleration) of modern Euro 6 diesel passenger cars and vans. High emissions occur under a limited span of normal driving conditions. Only if the events of high real-world emissions are included in the assessment RDE will bring low real-world emissions.

[7] Quote from: The Euro emission standards for cars and trucks in relation to NO2 limit value exceedances in the Netherlands; RIVM Letter Report 680363001/2013, G.J.M. Velders et al.

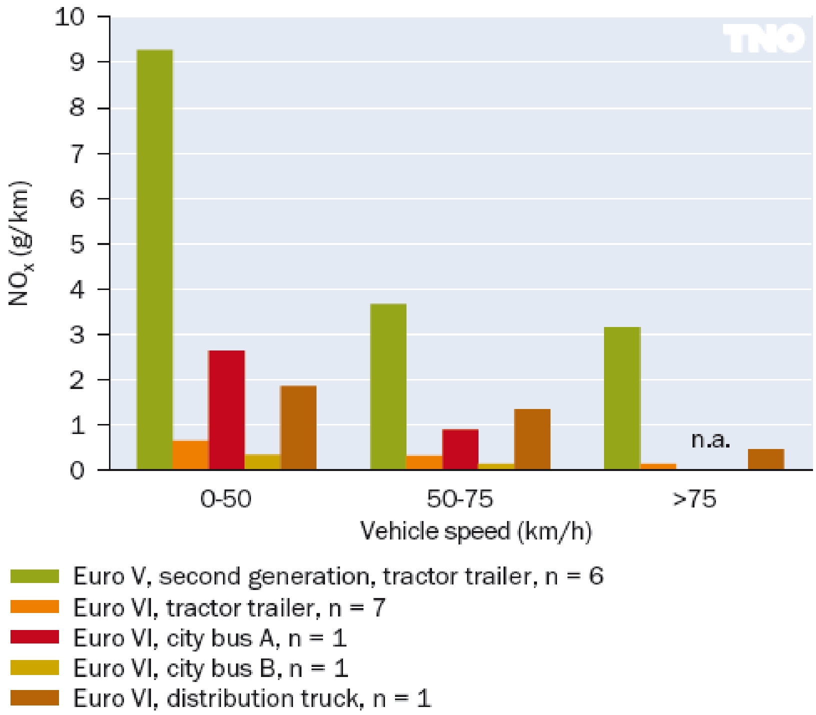


Figure 3 TNO tested two city buses and a distribution truck under conditions representative for these types of vehicles. In urban conditions, two of these Euro VI vehicles were still responsible for relatively high NO_x emissions in comparison to Euro VI long-haul trucks, although these emissions were significantly lower compared to Euro V vehicles. Euro VI buses produce widely differing emission levels: in urban conditions, bus A is not as clean as the Euro VI tractors that were measured, even though bus B shows that it is technically possible to achieve this. Source: Emissions of nitrogen oxides and particles of diesel vehicles, TNO, report TNO 2015 R10838, Kadijk et. al.

If effective, RDE will have a major impact on urban air quality, in particular on NO_2 concentrations. The effectiveness of the RDE legislation depends on a right balance between:

- The stringency of the limit values (Conformity Factors).
- A broad window of acceptable test conditions (related to e.g. driving behaviour and ambient conditions)
- Appropriate evaluation method(s), used for translating the measurement results to a number to which the Conformity Factor is applied.
- Essential for RDE’s effectiveness with respect to improving urban air quality is also the introduction of a separate evaluation of emissions in urban traffic conditions in order to prevent for compensation of high urban emissions by low rural or motorway emissions.
- The possibility of independent validation tests.

In the following chapters it will be assessed if the (current) RDE legislation strikes the right balance.

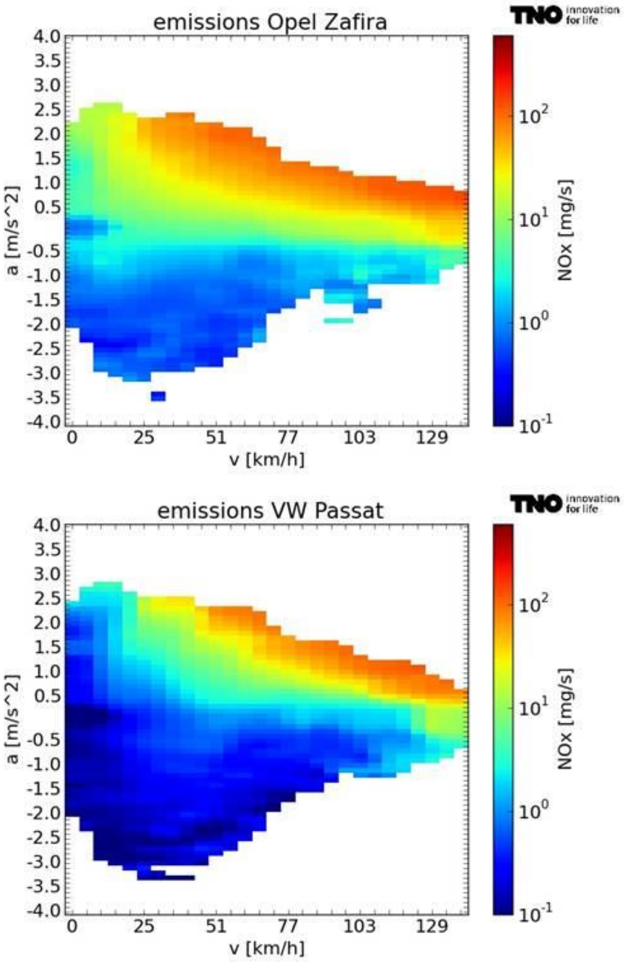


Figure 4 Typical emission map of two modern Euro 6 diesel passenger cars. Source: TNO 2016 R11177 "NO_x emissions of fifteen Euro 6 diesel cars: Results of the Dutch road vehicle emission testing program 2016", Heijne et.al.

5 Ambient temperature and road conditions

In the previous chapter it was concluded that to effectively reduce real-world emissions it's key that events of high emissions are included in RDE-trips. In this chapter the boundaries of 'normal' driving, in terms of ambient and road conditions contained in the RDE legislation are assessed.

5.1 Impact of ambient temperature on real-world NO_x emissions

The importance of adequate RDE ambient boundary conditions is widely acknowledged. The parameter that may have a major impact on NO_x emissions of diesel vehicles is the ambient temperature. In the current type-approval test procedure, the temperature of the test cell must be between 20 and 30 °C[8]. At around 12 °C, however, the average ambient temperature in most European countries is significantly lower. In its information note to the Transport Council Germany states: "One of the main reasons real driving emissions are significantly higher than on the dynamometer is that the manufacturers adapt the effectiveness of their emissions control systems to driving and/or environmental conditions in different ways. This is done primarily by means of the "temperature window", outside which the manufacturers reduce the effectiveness of the emissions abatement."[9] This is confirmed by recent on-road measurements performed by TNO and the UK.

In the TNO tests a vehicle that performed well with respect to on-road NO_x emissions at ambient temperatures of 15 °C and above, was also tested at lower temperatures and NO_x emissions turned out to be much higher. In 2015, the manufacturer explained that this is caused by a reduced operation of the applied emission control technologies to protect the engine when operated at lower temperatures. The recent tests confirm this behaviour, as they show a gradual but large increase of the emissions when the ambient temperature decreases from 20 °C to 0 °C. Given the average temperature in the Netherlands of 10 - 11 °C , the real-world emission performance in the Netherlands is incomparable with on-road test results above 20 °C as well as with the type-approval test results obtained in the lab.

[8] European type-approval also contains a low temperature test (Type VI test): a laboratory test performed at -7°C.
[9] http://data.consilium.europa.eu/doc/document/ST-9667-2016-INIT/en/pdf

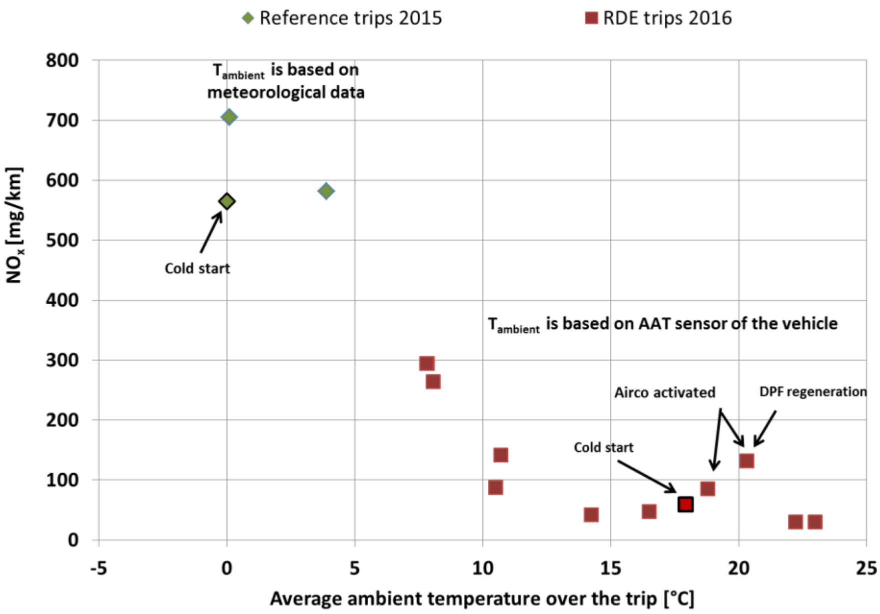


Figure 5 Real-world NO_x emissions of a modern Euro 6 diesel car strongly depend on the ambient temperature, Source: TNO 2016 R11123 “Review into the relation between ambient temperature and NO_x emissions of a Euro 6 Mercedes C220 Bluetec with a diesel engine”, Kadijk et.al.

In the report on the UK Vehicle testing programme[9] it was stated that “ambient temperature appears to be a significant factor influencing the emissions results obtained in both track and on-road testing. This influence of temperature is more immediately obvious when looking at the track test NO_x emissions results plotted in order of temperature. In general, vehicles that were tested at lower ambient temperatures tended to produce higher NO_x emissions than those which were tested at higher ambient temperatures.” The manufacturers justify the behaviour of the emission control by referring to protection of the engine, in particular prevention of condensation and clogging at low temperatures.

In its response to the EMIS hearing of the European Parliament[10] TNO states that no new technology is required to achieve low real-world NO_x emissions over the full range of normal driving conditions experienced in Europe, if existing components and control strategies are adapted. This may require some hardware changes, especially for proper thermal management and dimensioning of the systems. EGR problems related to low air inlet temperatures can be solved, as there is plenty of waste heat available in the engine to heat up the intake air. Switching-off of the LNT or SCR cannot be justified for reasons related to protection of the engine.

[10] http://www.emeeting.europarl.europa.eu/committees/agenda/201605/EMIS/EMIS(2016)0524_1/sitt-2493522

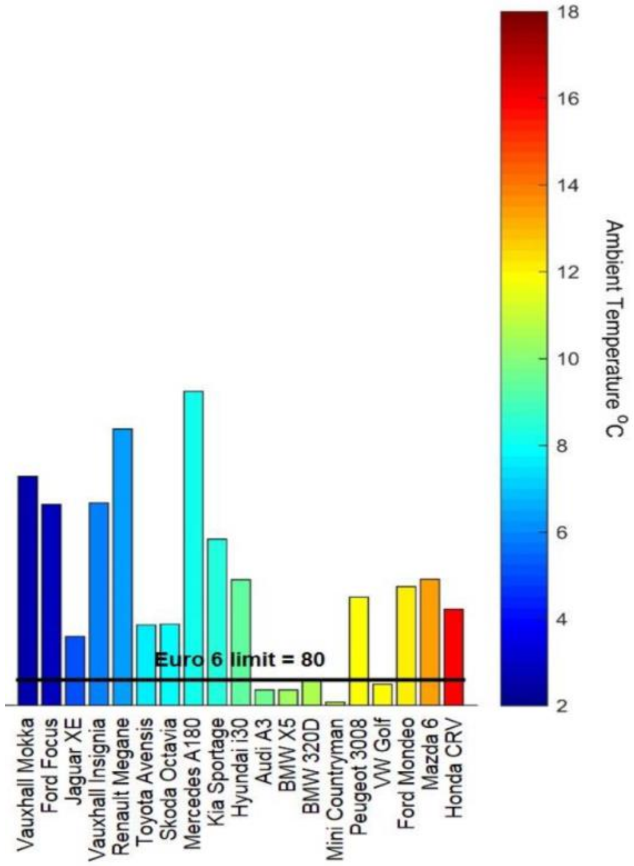


Figure 6. Results from the recently published UK Vehicle Testing Programme.[11] Track test results plotted in ambient temperature order.

5.2 Overview of RDE boundaries for ambient and road conditions

With the adoption of the 2nd RDE package the following ambient boundary and road conditions have been decided:

Condition	Boundary(ies)	
	Normal	Extended
Ambient temperature	0 - 30°C Temporary[12]: 3 - 30°C	-7 - 0°C and 30 - 35°C Temporary: -2 - 3°C and 30 - 35°C
Altitude	Maximum 700 m	Maximum 700 - 1300 m
Road surface	Paved road only	-
Road incline	Only indirectly restricted by maximum cumulative altitude gain over total RDE trip (see chapter 6)	-
(Head) wind, air pressure and air humidity	No restrictions	-

[11] http://www.unece.org/fileadmin/DAM/trans/doc/2015/wp29grpe/GRPE-73-03.pdf
[12] Temporary boundary conditions apply till 1 September 2019 for new type approvals and 1 September 2020 for all registrations.

An RDE trip executed within the normal and extended boundaries qualifies as being valid. Emissions measured during driving events under extended conditions will be divided by a factor of 1.6.

5.3 Strengths and weaknesses ambient and road conditions

Temperatures between 0 - 30°C by no means can be considered abnormal.
In The Netherlands the temperature window between 0 - 10°C is very relevant for normal driving conditions in major parts of the year, in particular during colder periods when commuters start their cars after a night of stand still. The extended temperature conditions will cover most occasions of temperatures below 0°C. The Netherlands has an annual average of 58 frost days, of which only a few below -7°C.

From 1990 till 2015, in the morning 8% of the days are below 0°C and 5% of the afternoons. Above 30°C occurs seldom in the Netherlands. In the morning 1% of these days are below -7°C. Given the typical distribution of traffic intensities over the day, the morning rush hour and the afternoon rush hour are dominant in the total distance travelled. In that case 7% of the data outside the normal RDE temperature range is still substantial and further limitations on ambient temperature on the test will reduce the effectiveness of RDE legislation for real-world emission reduction in the Netherlands.

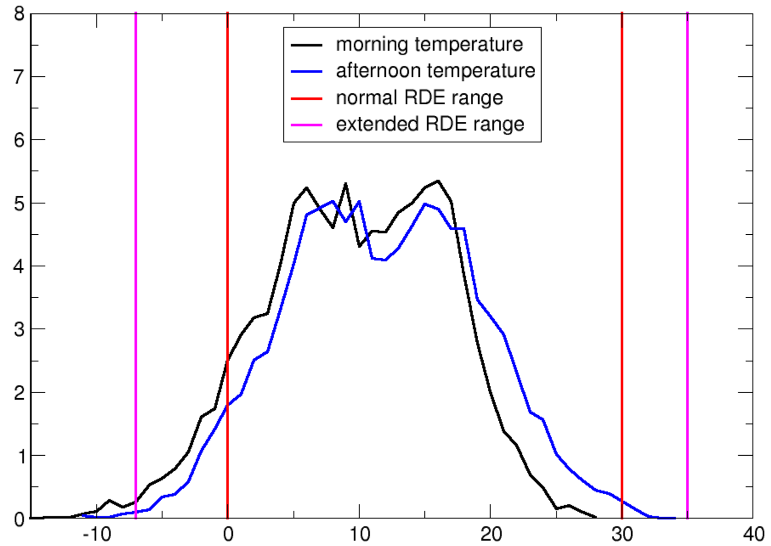


Figure 7 The distribution of temperatures in the Netherlands for the two main traffic periods in the morning (8:00) and the afternoon (17:00) based on KNMI data from De Bilt weather station. Below zero temperatures occurs in 8% and 5% of the days respectively.

For the situation in The Netherlands the temperature boundaries can be assessed as being adequate but not strict, with no room to narrow the window.

The situation in EU Member States with low(er) ambient winter temperatures might be a reason to even further extend the RDE temperature window.

The altitude boundary itself is not relevant for The Netherlands, but the requirement that the vehicle shall be RDE-compliant up to 700 m above sea level (or 1300 m under extended conditions) enlarges the window of operation of NO_x reduction technology and is expected to have a positive impact on on-road emissions in The Netherlands.

A strong aspect of the RDE requirements is that no restrictions are introduced to limit the window of wind speeds, air pressure, humidity, road inclines and surfaces (provided that the road is paved).

6 Trip composition

The RDE legislation contains several requirements for the composition of a valid RDE trip setting boundaries on the duration of the trip, the sequence of urban, rural and motorway driving, the minimum trip length and the number and duration of vehicle stops. In this chapter the boundaries of 'normal' driving, in terms of trip composition contained in the RDE legislation are assessed.

6.1 Impact of trip composition on real-world NO_x emissions

A modern diesel passenger car or van driving in an urban area emits typically twice the amount of NO_x (in g/km) of a car driving on rural roads. The differences tend to increase compared to previous Euro-classes. The emissions on motorways are somewhere in between and strongly depend on the speed limits in force. Due to the differences in emission performance, RDE legislation should require a balanced inclusion of all road types in a RDE trip.

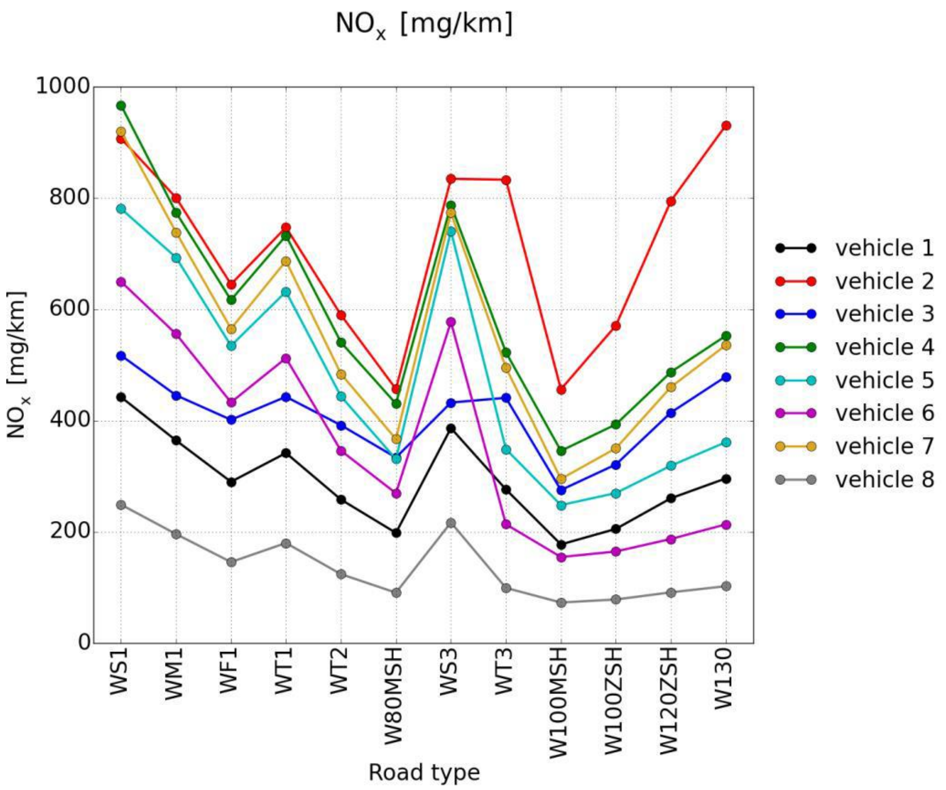


Figure 8 The emission performance of Euro-6 diesel passenger cars strongly depends on road type and driving conditions. The road type WS1 up to WT1 correspond to urban driving; WT2 and W80MSH to rural driving; WS3 up to W130 to motorway driving. Emissions during urban driving are substantially higher than those during rural driving. Source: "2016 Emission factors for diesel Euro-6 passenger cars, light commercial vehicles and Euro-VI trucks", TNO report TNO 2016 R10304v2, Heijne et.al.

This balanced inclusion of all road types is also justified by the variations in emission behaviour of different cars. Recent TNO measurements on a car that performs on average relatively good (compared to other Euro-6 diesel cars) show unexpectedly high emissions during rural driving.

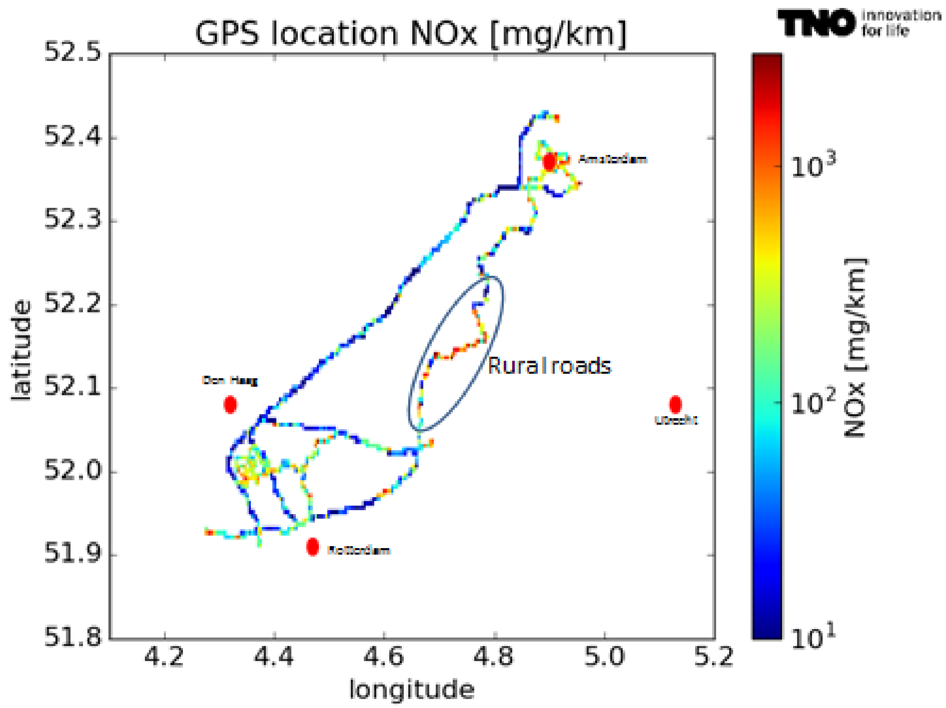


Figure 9 The emission measurements of a modern Euro-6 diesel passenger cars plotted on a real-world trip. The car showed good performance during driving on motorways with speed limits in force and expectedly higher emissions in urban areas. Emission performance during rural driving varied strongly. Source: information delivered by the Dutch delegation to the RDE-LDV expert group. Full results to be published.

6.2 Overview of boundaries for RDE trips

With the adoption of the 2nd RDE package the following boundaries of RDE trip composition have been decided. An RDE trip executed within these boundaries qualifies as being valid.

Condition	Boundary(ies)	Margins
Duration	90-120 minutes	-
Shares Urban (U), Rural (R) and Motorway (M) driving[13]	34%, 33%, 33% of trip distance	29% ≤ U ≤ 44% 23% ≤ R ≤ 43% 23% ≤ M ≤ 43%
Sequence is fixed: Urban driving followed by Rural and Motorway driving	-	-
Length of each section (U/R/M)	At least 16 km	-
Stops	Several stops ≥10s shall be included. Total stoppage time shall be 6-30% of time of urban driving. If a stop last over 180s, the emissions during 180s following the stop shall be excluded from the evaluation.	-
Total cumulative positive altitude gain	<1200 m per 100km RDE trip distance, calculated over the full RDE trip. Road incline as such is not regulated (see chapter 5)	-
Altitude start and end point	Shall not differ by more than 100 m.	-

6.3 Strengths and weaknesses RDE trip composition

Most RDE trip requirements are introduced for practical reasons – like a maximum trip duration of 2 hours - and are assessed as being reasonable. The development of a proper RDE-trip requires some settling-in with the numerous boundaries, but turns out to be feasible in practice and is not restricted to certain parts of Europe.

The shares of urban, rural and motorway driving, the minimum distances and stoppage time guarantee a balanced inclusion of all sections and driving conditions in the RDE trips.

The limitation of idling to a maximum of three minutes in the RDE test is a definite restriction of the test with respect to normal use. In the Netherlands, movable bridges where vehicles have to wait for the passage of ships often carry the sign “bridge open, engine off” for good reason. Many motorists keep the engine idling for long periods. Having a restriction of 3 minutes idling in the test would mean the

[13] Urban driving is defined as all events with vehicle speed up to 60 km/h included, rural driving by speeds between 60 and 90 km/h and motorway driving by speeds above 90 km/h.

emissions may go up afterwards to typical engine out levels. With a idling fuel consumption of 0.4 litres of diesel per hour, NO_x emissions may be as high as 3 mg/s, where in urban driving an average of about 0.5 mg/s is needed to pass an RDE test. Excluding idling and subsequent optimization of manufacturers to turn off emission control after 3 minutes of idling is a substantial risk for high local emissions, for example before an “open bridge”. A functioning stop-start system, widely applied as a result of European CO_2 standards, will solve this problem, but such systems may not engage without the correct operations by the driver, or, for example, while running the air-conditioning.

The risk of high local emissions due to occasionally long stops during urban driving can be removed by deletion of the requirement that 3 minutes of measurement data following a long stop will be excluded from the evaluation. Preferably, additionally the maximum duration of a stop is extended.

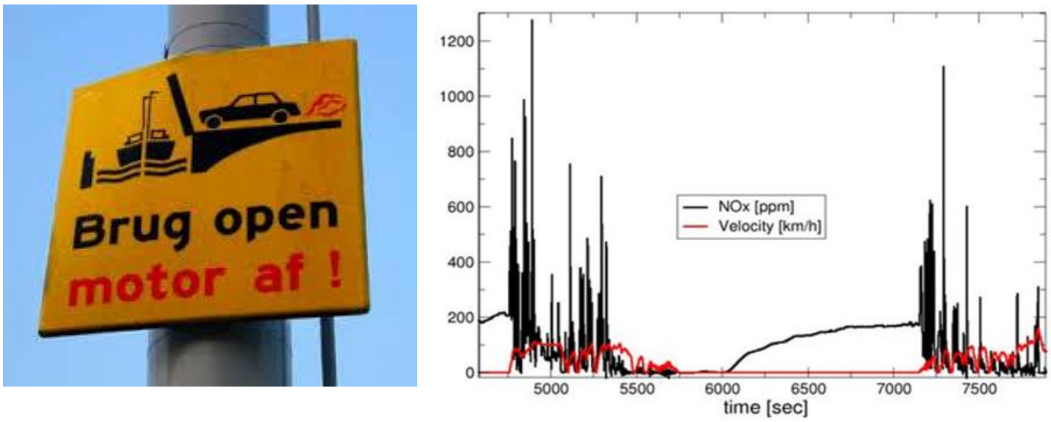


Figure 10 A typical Dutch situation of an open bridge where vehicles idle for longer periods. Some vehicles have increased emissions after a few minutes idling such as the Euro-6 diesel vehicle showing an increase in NO_x emissions after 4 minutes idling. The stop-start system was disabled by pressing the button on the dashboard.

The fixed sequence of urban driving, followed by rural and motorway driving might also give some room for RDE test recognition and/or optimization by the manufacturer. Persistent NO_2 hotspots are in general located in urban areas associated with high traffic density. Inclusion of cold start in the data evaluation and the separate evaluation of urban emissions (see Chapter 9) will guarantee low real-world emissions in all sections of the RDE trip, even in the situation in The Netherlands where a short duration of urban driving directly followed by motorway driving is common.

This moment in time, with no RDE-compliant cars available, the risk of increased real-world emissions due to trip recognition and/or trip optimization. Future testing programmes should keep the developments under review. Fundamentally, RDE testing should be unrestricted, except for some basic average properties and boundaries.

7 Driving behaviour

The RDE legislation contains several requirements for the driving behaviour to prevent a valid RDE trip from being driving consistently extremely aggressive or extremely smooth. In this chapter the boundaries of 'normal' driving, in terms of driving behaviour contained in the RDE legislation are assessed.

7.1 Impact of driving behaviour on real-world NO_x emissions

Driving behaviour, such as accelerations and driving speeds, strongly impacts the NO_x emissions of modern diesel passenger cars as was clearly shown in the emission maps of figure 4 in Chapter 4. It's therefore most important that the events of high emissions are included in a valid RDE trip, in particular events that occur in what can be considered to be 'normal driving'. The effectiveness of the NO_x emissions reduction technologies applied in diesel vehicles tends to be sensitive for higher driving dynamics and higher engine power. SCR-technology also requires sufficiently high engine temperature. Prolonged idling is a serious risk for high NO_x emissions with SCR.

On the other hand, to prevent vehicles from being tested under extreme driving conditions, like excessively high dynamics or consistently slow driving, boundary conditions have been introduced in the RDE-legislation.

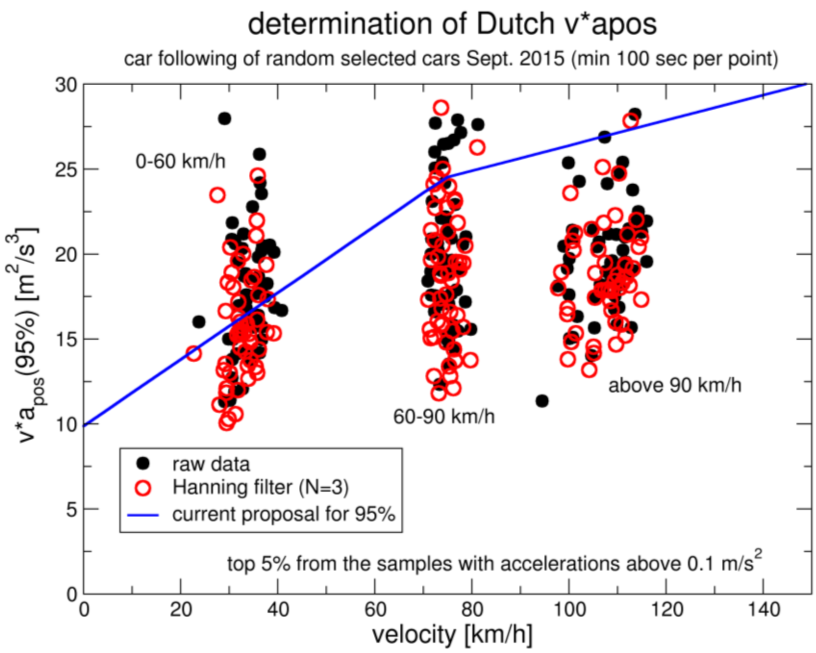


Figure 11 The first research project conducted by TNO to determine normal driving behaviour in The Netherland clearly showed that the original proposal (in the figure referred to as the "current proposal for 95%") to limit aggressive RDE driving – blue line in the figure – would have excluded a substantial amount of normal driving situations – dots above the blue line - from the RDE evaluation. Source: information delivered by the Dutch delegation to the RDE-LDV expert group.

$V*a_{pos}$, the product of vehicle speed and (positive) acceleration, is commonly used as an indicator for high(er) dynamics of a trip and RPA, the relative positive acceleration, as an indicator for the lack of dynamics in a trip.

The selection of the boundary conditions for driving behaviour is a very delicate process. If the limit for $v*a_{pos}$ is set too low, many events with high emissions that frequently occur under normal European driving are excluded from RDE testing. A limit set too high, will force car manufacturers to apply expensive technology for situations that hardly occur. Moreover, whether or not the driving boundaries were met, can only be checked afterwards, with the risk of invalidating RDE tests of up to two hours. This will generate a tendency to stay well away from the driving boundaries while testing. Therefore the mere existence of driving boundaries might put pressure on the test execution and might lead to more generic driving rather than a full span of normal driving behaviour.

7.2 Overview of boundaries for RDE driving behaviour

With the adoption of the 2nd RDE package the following boundaries for driving behaviour have been decided. An RDE trip driven within these boundaries qualifies as being valid.

Parameter	Boundary(ies)	Comment
$V*a_{pos}$	RDE trip is invalid if (per speed bin) $\bar{v}_k \leq 74.6\mathrm{km/h}$ and $(v \cdot a_{pos})_{k}\text{-}[95] > (0.136 \cdot \bar{v}_k + 14.44)$ or $\bar{v}_k > 74.6 km/h$ and $(v \cdot a_{pos})_{k}\text{-}[95] > (0.0742 \cdot \bar{v}_k + 18.966)$	To exclude extremely high dynamics
RPA	RDE trip is invalid if (per speed bin) $\bar{v}_k \leq 94.05\mathrm{km/h}$ and $RPA_k < (-0.0016 \cdot \bar{v}_k + 0.1755)$ or $\bar{v}_k > 94.05 km/h$ and $RPA_k < 0.025$	To include sufficient dynamics
Average speed during urban driving	15 km/h ≤ v_{avg_urban} ≤ 40 km/h	
Maximum speed	V_{max} ≤ 145 km/h	For no more than 3% of the duration of motorway driving speeds up to 160 km/h are allowed.
Speed range of motorway driving	Shall properly cover a range between 90 and at least 110 km/h. Speed shall be above 100 km/h for at least 5 minutes.	Vehicles with speed limitations have modified boundaries
Gear selection	No restrictions	

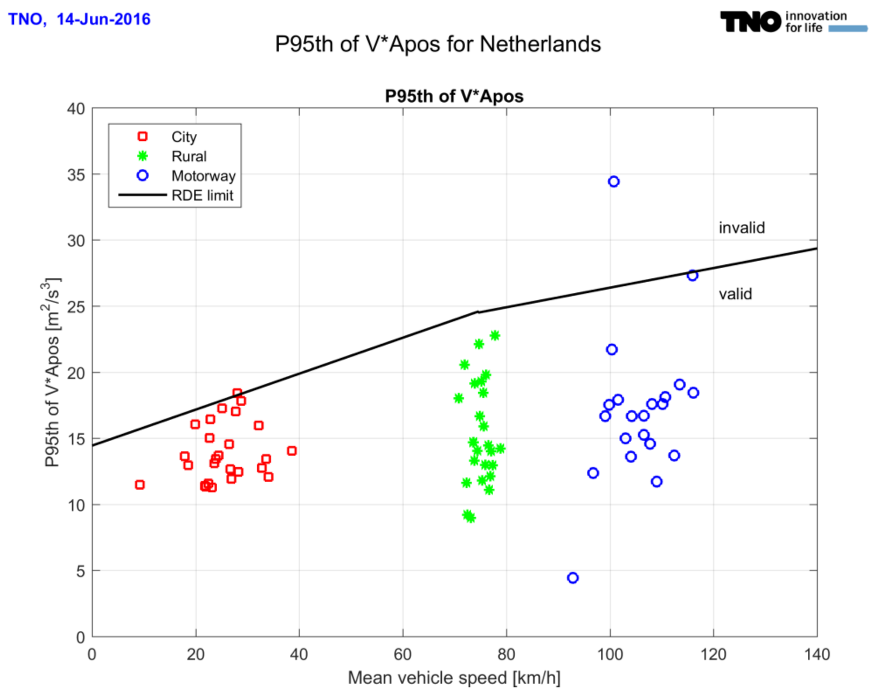
7.3 Strengths and weaknesses RDE driving behaviour

TNO conducted a research project to determine normal driving behaviour in The Netherlands. The results led to an adjustment of the boundaries, in particular the $v*a_{pos}$ limit, to the levels given in paragraph 7.2.

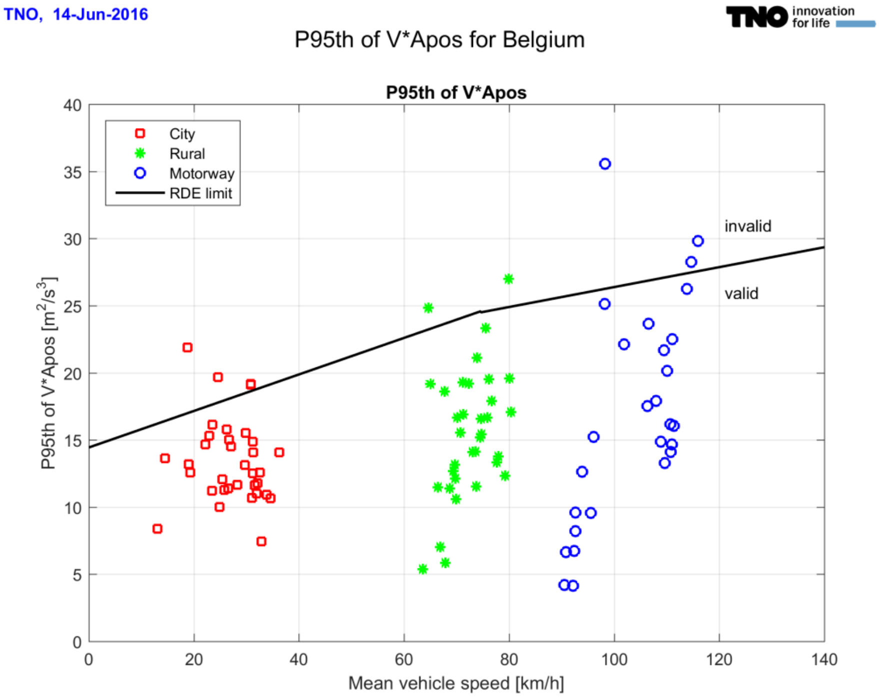
In a recent follow-up project normal driving behaviour driving in Belgium, (the northern part of) France and (Ruhr area in) Germany has been established and additional measurements in The Netherlands have been conducted.

The outcome of the project shows that no average driving exists; a broad range of driving behaviours has been observed. As a consequence RDE boundaries should allow for inclusion of this broad range in order to sufficiently cover ‘normal’ driving behaviour. Driving dynamics vary significantly among countries. The highest dynamics have been observed in Belgium. A significant number of Belgian trips was well above the $v*a_{pos}$ limit value. The average speed during urban driving was frequently below the lower limit of 15 km/h, most strikingly demonstrated in the Paris trips. This stop and go traffic is frequently observed in densely populated areas with high traffic density; typically situations with exceedances of NO_2 concentrations. Higher (or absence of) speed limits in a county are not necessarily reflected in high dynamics, as is the case for Germany.

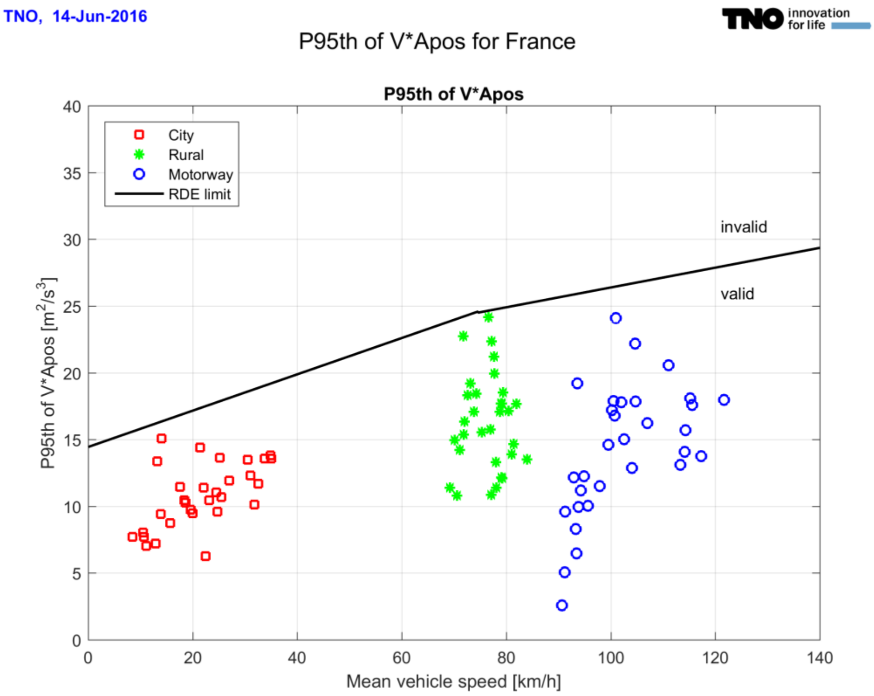
The Netherlands



Belgium



France (Paris and to the north of Paris)



Germany (Bonn and Ruhr)

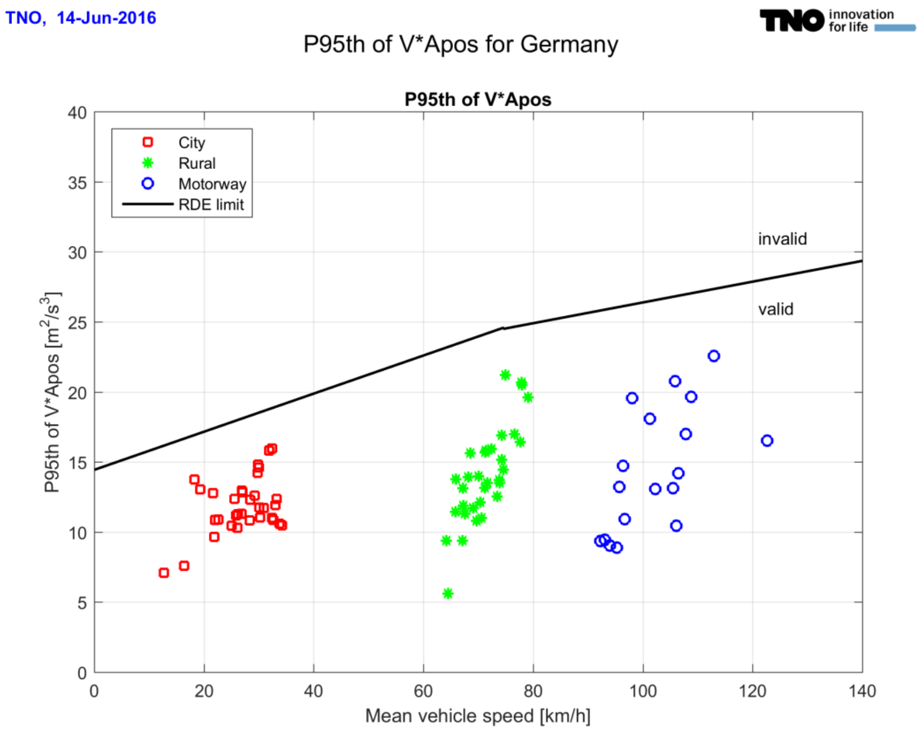


Figure 12 Driving behaviour in The Netherlands, Belgium, (the northern part of) France and (Ruhr area in) Germany observed in a research project conducted by TNO has been assessed against the RDE v*a_{pos} limit value for driving dynamics. Source: information delivered by the Dutch delegation to the RDE-LDV expert group.

If the RDE driving behaviour boundaries are confronted with the outcome of the TNO project the following conclusions can be drawn:

- In general the current RDE driving behaviour boundaries sufficiently cover normal driving behaviour.
- In order to prevent the RDE legislation from being effective in some countries, but not throughout the EU as a whole, there is no room to lower the v*a_{pos} limit.
- In order to cover a wider range of urban driving throughout Europe, in particular stop and go traffic frequently observed in densely populated areas with high traffic density, it could be considered to lower the limit of the average speed during urban driving of RDE trips. In any case there is no room to increase the current limit of 15 km/h as proposed by experts from the car industry. Stop and go urban traffic is generally associated with high emissions (see situation WS1 in figure 8 of chapter 6).

The requirements for motorway driving allow for RDE trips to be driven under typical traffic situations in The Netherlands, as long as the upper (v*a_{pos}) and lower (RPA) limits for dynamics are fulfilled. As maximum speeds of up to 145 km/h, and for a short duration even up to 160 km/h are allowed, the speed limits in The Netherlands of 100, 120 and 130 km/h are covered. RDE trips allow for the inclusion of 80 km/h highway stretches, but the emissions will be regarded as rural emissions rather than motorway emissions.

When the RDE legislation and it's boundary conditions were developed the main focus was on passenger cars. The light duty commercial vehicles, mainly delivery vans, have a power-to-mass ratio substantially lower than passenger cars. When fully loaded these vans cannot meet the RDE driving behaviour limit, not even when driven extremely "aggressive".

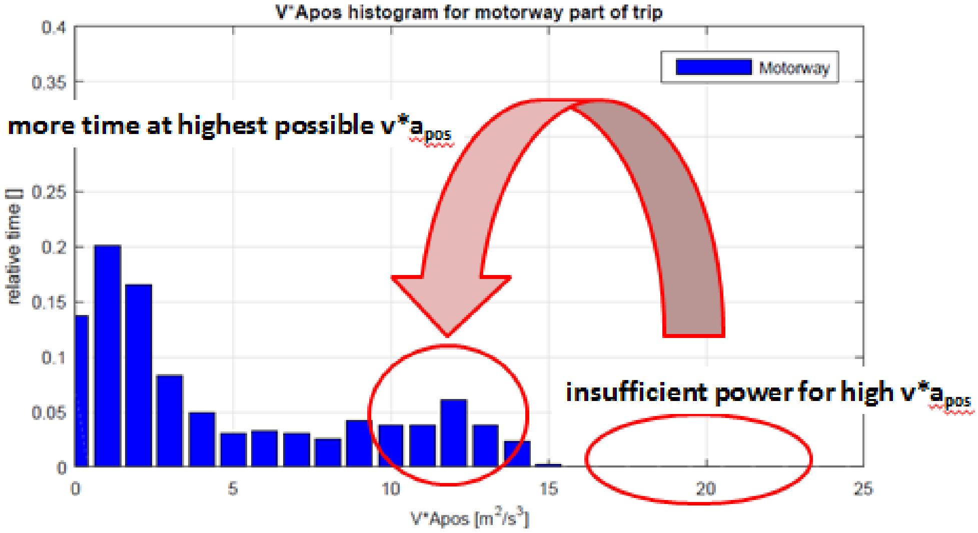
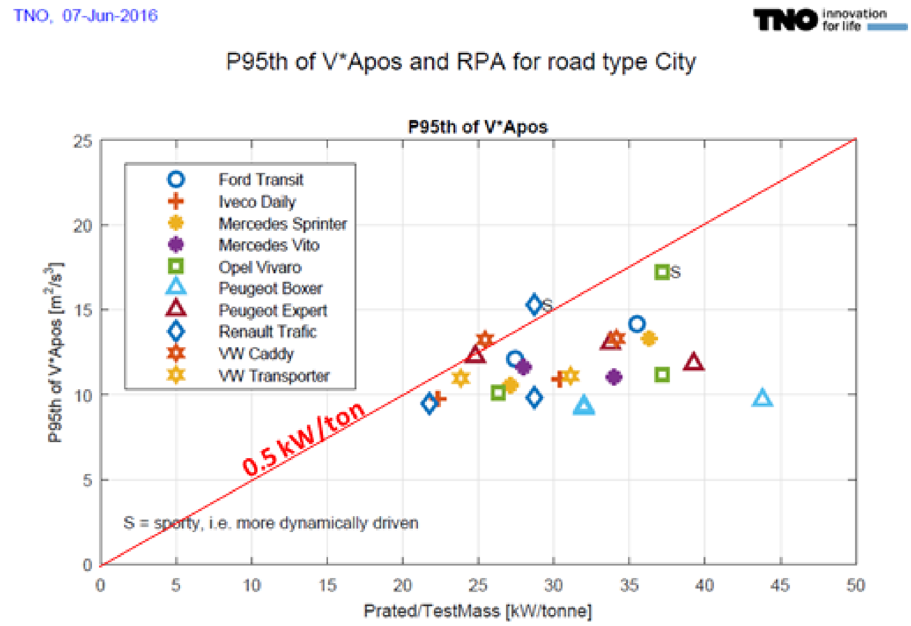


Figure 13 Dynamics of motorway driving of vans, expressed in terms of $v*a_{pos}$. Where passenger cars show monotonous decrease with $v*a_{pos}$, N1 vehicles show an atypical distribution. The elevation at levels between 10 and 15 m^2/s^3 reflects the events that loaded vans are driven at maximum power. Source: information delivered by the Dutch delegation to the RDE-LDV expert group.

Therefore van manufacturers request modification(s) of the driving behaviour boundaries to be included in the 3rd RDE package. In case this request is accepted, The Netherlands has put forward a simple proposal to introduce an additional restriction of the $v*a_{pos[95]}$ limit, based on the power-to-mass parameter.

There is a direct relation between maximum $v*a_{pos}$ and power-to-mass:

$v*a_{pos[95]} < 0.5 * W_{rated\_power}/kg_{vehicle\_testmass}$.



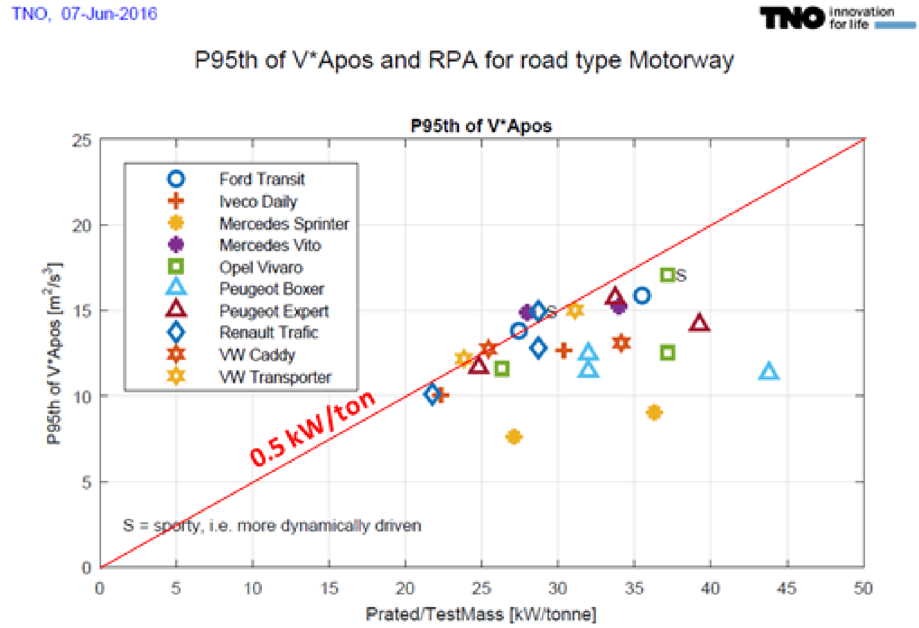


Figure 14 The relation between the driving dynamics and the power-to-mass of the light duty vans (N1 category) show a simple bound of $v^*a_{pos}(95\%) < 0.5^*P_{rated}$/testmass. This restriction can be implemented easily. An alternative approach of adding additional criteria, such as strict boundaries, may yield vehicle optimization, or may require new signal abd will increase testing complexity. Source: information delivered by the Dutch delegation to the RDE-LDV expert group.

The v^*a_{pos} boundary condition could be modified to:

"The RDE trip is invalid if (per speed bin)

$\bar{v}_k \leq 74.6\text{km/h}$ and

$(v \cdot a_{pos})_{k\text{-}}[95] > (0.136 \cdot \bar{v}_k + 14.44)$ **or** $\mathbf{(v \cdot a_{pos})_{k\_}[95] > \left(0.5 * \frac{W}{kg}\right)}$

or

$\bar{v}_k > 74.6 km/h$ and

$(v \cdot a_{pos})_{k\_}[95] > (0.0742 \cdot \bar{v}_k + 18.966)$ **or** $\mathbf{(v \cdot a_{pos})_{k\_}[95] > \left(0.5 * \frac{W}{kg}\right)}$"

This proposal is restricted to cases that the power-to-mass ratio of a vehicle is limited and will not have negative side effects of limiting the RDE driving conditions in all other cases.

Proposals for vans will not make it to the 3rd package. The van manufacturers consider to set up a special working group for dedicated issues on vans (and N2 and M2 category vehicles). The Netherlands has offered to participate in this working group.

A strong aspect of the RDE requirements is that no restrictions are introduced to prescribe gear selection allowing RDE tests to cover all gear shift strategies that may occur under normal driving conditions.

8 Vehicle conditions

The RDE legislation contains several requirements for the condition of the test vehicle prior to or during the RDE test. In this chapter these vehicle conditions are assessed.

8.1 Impact of RDE vehicle conditions

In real-world a wide variety of vehicle conditions can be observed. The vehicle's payload may range from carrying only the driver during commuter operation to fully packed for a family holiday. Fuel and lubricant quality may differ from the quality applied at type-approval test. It is key that RDE allows for the full range of vehicle conditions that can be characterized as being 'normal'.

8.2 Overview of RDE vehicle conditions

With the adoption of the 2nd RDE package the following requirements for vehicle test conditions have been decided. If the RDE trip is driven with a vehicle that fulfils these conditions, the RDE trip qualifies as being valid.

	Condition
Air conditioning systems and other auxiliary devices	Operation shall correspond to possible use by a consumer at real driving on the road
Fuels, lubricants and reagents	Within specifications issued by the manufacturer for vehicle operation by the customer
Payload	Besides the driver, a witness, test equipment and power supply, artificial payload may be added (up to 90% of the maximum payload)
Preconditioning	No requirements included (apart from ambient conditions described in Chapter 5)

8.3 Strengths and weaknesses RDE vehicle conditions

The RDE legislation requires no or only very limited vehicle preparations and allows for a wide range of vehicle conditions as long as the conditions can be characterized as being 'normal'. In this respect the adopted provisions match the objectives of the RDE legislation: the RDE test can be conducted with an in-use vehicle under conditions that actually correspond to possible use at real driving on the road. This wide range of vehicle conditions is particularly important to allow for independent testing (see Chapter 12).

RDE is developed in such a way that the RDE tests can be performed independent of the vehicle; no OBD- or ECU-signals from the vehicle are required. This limits the risk that the vehicle recognizes being RDE tested and is switched to a special engine control strategy.

The current RDE legislation fulfils the requirement that no link to the vehicle system is needed. A critical assessment of the 3rd package is required as proposals have been put forward that rely on information from the vehicle (see Chapter 11).

A typical Dutch situation, a family car pulling a caravan, will not be covered by the RDE legislation. The total mileage of this type of driving is limited. Not the vehicle conditions as such exclude pulling a caravan, but the boundaries for driving behaviour and the evaluation tools (see chapter 10) do. The motorway speed requirement, that the RDE trip shall properly cover a range between 90 and at least 110 km/h and shall be above 100 km/h for at least 5 minutes, cannot be met. The evaluation tools will simply exclude most events, because of the high CO_2 emissions.

The implicit exclusion of caravan pulling from the RDE legislation, will have no significant impact on the air quality in The Netherlands. The kilometres driven are limited, a large proportion is abroad and largely coincide with periods of low(er) traffic density in holiday periods.

9 PEMS - measurement equipment

The measurements during a RDE test will be performed by PEMS, portable emission measurement systems, that can operate fully independent of the vehicle. The RDE legislation contains a full description of the PEMS equipment, its quality and the measurement procedures. An important issue is the accuracy of PEMS equipment, as it directly impacts the NO_x conformity factor.

9.1 Impact of PEMS requirements and accuracy

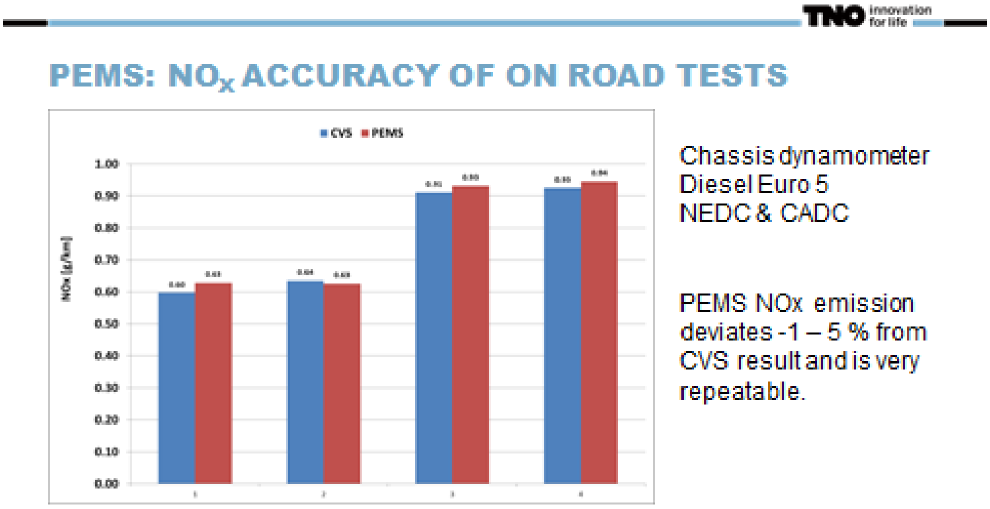
PEMS requirements could hamper - directly or indirectly – the possibility of independent tests, in the case that measurements can only be performed if vehicle data is available or assistance of the manufacturer is required. No such problems are foreseen with the requirements included in the 1st and 2nd RDE package (for more details see paragraphs 8.3 and 11.1).

The RDE legislation introduces in two subsequent steps quantitative limits for real-world emissions of passenger cars and vans (see conformity factors in Chapter 3). The second step requires full compliance with the Euro-6 emission limit value for NO_x of 80 mg/km plus a margin taking into account the additional measurement uncertainties related to the application of portable emission measurement systems (PEMS). In the 2nd RDE package the PEMS accuracy is assumed to be approximately 50% and as a consequence the margin is initially set at 0.5, is subject to an annual review and shall be revised as a result of the improved quality of the PEMS procedure or technical progress. If the actual PEMS accuracy is significantly better than the assumed 50%, the margin of 0.5 de facto is a weakening of the RDE legislation, allowing for higher real-world NO_x emissions.

9.2 Strengths and weaknesses PEMS requirements

Reliable PEMS equipment fulfilling all RDE requirements is readily available. PEMS equipment is well suited for performing on the road real-world emission tests, not only for assessment purposes but also in a legislative context such as RDE. The overall inaccuracy of NO_x-measurements with current generation PEMS equipment seem to be well within ±30%.[14] This results from a combination of variations in reproducibility of 20% and a direct measurement inaccuracy of 20%. Within the bounds of the prescribed PEMS accuracy for span, drift and offset of the concentration measurements the maximal deviation is estimated to be in the order of 20%.

[14] Upper limit of findings from TNO on-road test programmes. Confirmed by JRC in an assessment of their test programmes.



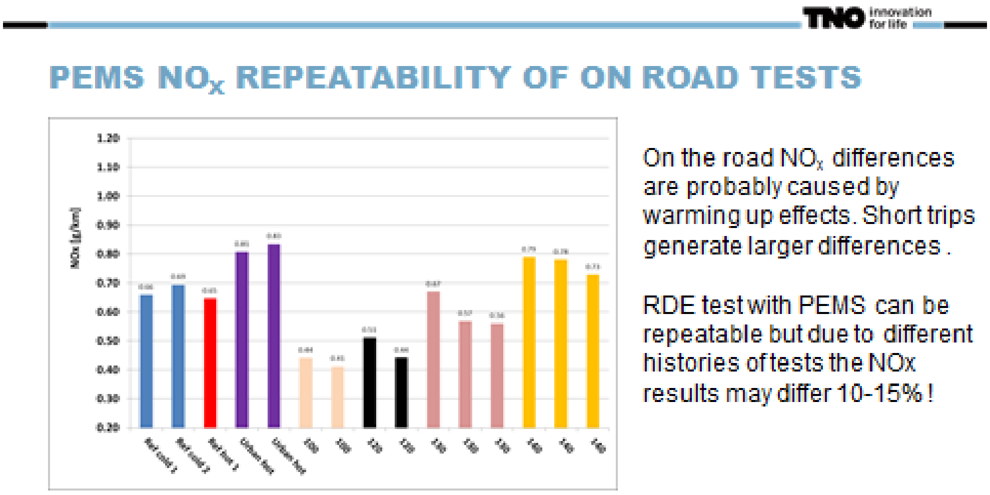


Figure 15 Recent findings of the TNO on-road test programme indicates PEMS overall accuracy to be better than 20%, the combined result of a high measurement accuracy (well below 10%) and good repeatability of the on-road tests (better than 15%). Source: TNO presentation “Real Driving Emission performance of Euro 6 Light-Duty diesel vehicles” at the 12th Integer Emissions Summit & AdBlue® Forum Europe, Gerrit Kadijk, Brussels, 6 June 2016

Second generation PEMS systems could be more accurate. The three main sources of inaccuracy are:

- the flow measurement used to translate measured concentrations to absolute emissions.
- inaccuracy in span, drift and offset of the concentration measurement, which has improved with the second generation PEMS equipment. Retaining a stable environment, for example, by keeping the PEMS equipment powered on overnight, shows further improvement of the accuracy. This inaccuracy is important especially at low concentrations observed in well-performing vehicles.
- poor operation practice and mounting of PEMS equipment in harsh and vibrating conditions.

The largest measurement errors are caused by inaccuracies in the exhaust flow measurement. There is a tendency of PEMS manufacturers to apply cheaper and less accurate flow meters. In addition exhaust systems with multiple tailpipes increase this inaccuracy further.

Furthermore the reliability of PEMS measurements is affected by (variations in) the ambient conditions to which the PEMS unit is subjected. Proper system conditioning is essential. Mounting the PEMs inside the vehicle (e.g. in the trunk) provides more constant operating conditions than mounting outside the vehicle and also increases reliability of the measurements.

The margin of 0.5 set in the 2nd RDE package is wide compared to the current PEMS (in)accuracy, giving reason to start the review procedure already under the 4th RDE package. Setting absolute demands on PEMS accuracy could help to make sure that systems are further improved and the uncertainty margin in the Conformity Factors can be reduced.

10 Data processing and data evaluation

After execution of a valid RDE trip, the PEMS measurements will be processed in order to evaluate if the vehicle fulfils the RDE emission criterion.

The data processing established under the 2nd package consists of two steps:
- Removal of the first 5 minutes of measurements (cold start)
- Data normalization by running the evaluation tools Moving average window (MAW, EMROAD) and Power binning (CLEAR).

In this chapter the following issues will be assessed:
- Cold start
- Evaluation tool EMROAD
- Evaluation tool CLEAR
- CF, Conformity factors
- TF, Transfer functions

10.1 Cold start

In RDE, up to the 2nd package included, the emissions during the cold start period are measured by the PEMS system, but the collected data are excluded from the emission evaluation.

10.1.1 Impact of RDE cold start processing

The cold start covers the first 5 minutes after initial start of the vehicle engine[15] and reflects the warm-up period of the engine. The warm-up of emission after-treatment systems might be longer; periods of up to 15 minutes have been observed for SCR equipped vehicles. This cold-start provision is independent of the requirements of ambient temperature.

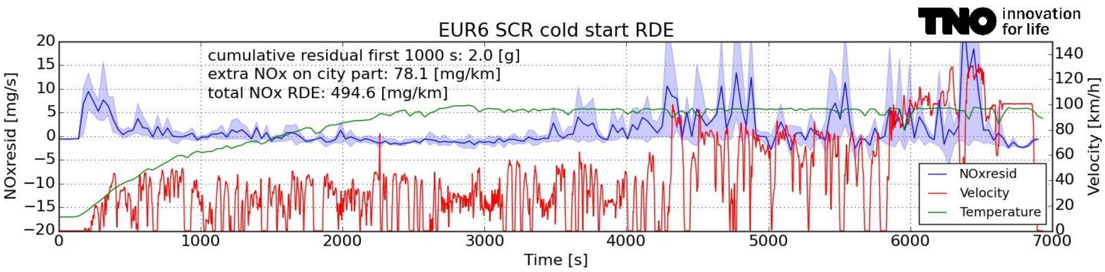


Figure 16 Typical cold start behaviour of a SCR equipped vehicle. During the first 10 minutes of cold start operation emissions are higher than might have been expected from emissions during similar hot operation. The difference is expressed as residual NO_x. Source: information delivered by the Dutch delegation to the RDE-LDV expert group.

[15] The cold start period can be shorter than 5 minutes if the engine coolant temperature can be reliably determined and has reached 70 °C.

Cold start emissions predominantly occur in densely populated areas and – if uncontrolled – can add up to 200 mg/km[16] to the average NO_x emission under urban driving conditions.

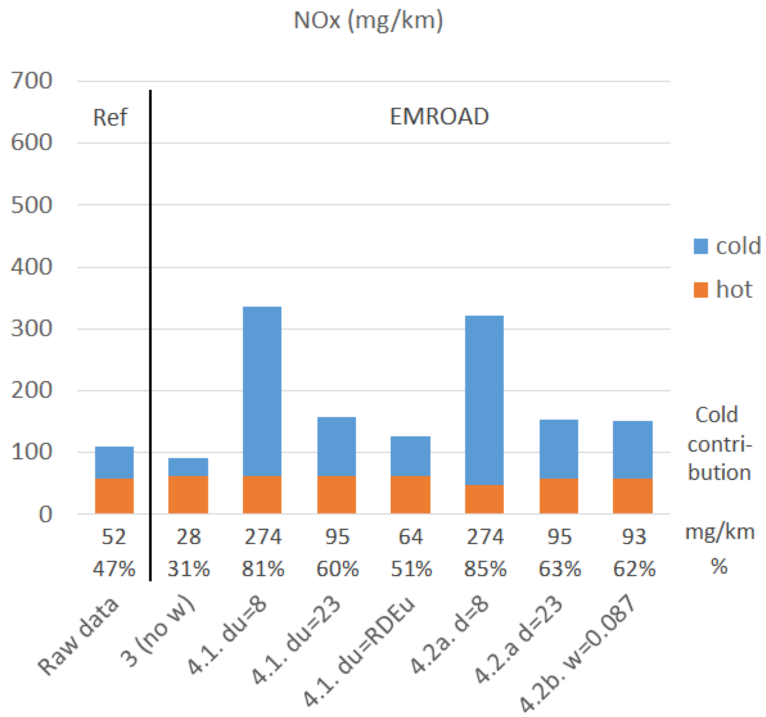


Figure 17 In a test programme of AECC, results were measured indicating that emissions during the cold start period added 50% to the total NO_x emissions during urban driving (raw data). Depending on the evaluation method applied the cold start period added 28-274 mg/km to the evaluated RDE-result. Source: Presentation 'The importance of tackling cold-start RDE, Dr Joachim Demuynck, AECC, at the AECC Technical Seminar on Real-Driving Emissions, Brussels 4 July 2016.

10.1.2 Strengths and weaknesses of cold start processing

The current exclusion of the cold start period - in the 2nd legislative package the first 5 minutes of the test are excluded - means that the RDE tests is always conducted with a warm engine and as such conflicts the general RDE principle that RDE tests must cover the conditions of normal use of the vehicle. The cold start period of 5 minutes typically covers 1-3 km of driving, whereas the average urban distance after a cold start is approximately 8-15 km.

The main reason for the exclusion is not of a technical nature, but because an additional separate evaluation had to be developed in order not to underrepresent the cold start emission s in the current evaluation tools. The European Commission announced a 3rd RDE package proposal to include the cold start period in the data evaluation.

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16 Whereas the limit value for the urban part of the RDE trip for passenger cars is 168 mg/km in the 1st step and 120 mg/km in the 2nd step.

For reasons of air quality it's very important that the cold start period (first 5 minutes) will be included in the RDE data evaluation. This can easily be done in the 3rd RDE package - without unacceptable burden to the car industry - by the inclusion of the cold start in the evaluation of the urban part of the RDE trip. The Netherlands has put forward a proposal accordingly.

10.2 Evaluation tools

Individual RDE trips will vary in severity and may differ in severity to the NEDC against which the Euro-6 limit values – 80 mg/km for diesel passenger cars – are established. To take into account these variations, two evaluation tools, EMROAD and CLEAR, have been introduced to normalize the RDE test results to a standard WLTP trip. It's upon the choice of the manufacturer if they want to use EMROAD or CLEAR. The outcome of the evaluation with EMROAD or CLEAR will be a pass or fail against the RDE emission criterion.

10.2.1 EMROAD

EMROAD is an evaluation tool developed by the Joint Research Centre (JRC) of the European Commission and is based on the Moving Average Windows (MAW) approach. The first step in EMROAD is that emissions are averaged over windows. The duration of a window is the amount of kilometres travelled until the vehicle has emitted a cumulative mass of CO_2 equivalent to the amount of CO_2 emitted during a WLTP test cycle. All consecutive windows move in increments of the sampling period (i.e. 1 second).

In a second step the validity of a trip is assessed by comparing the CO_2 emission of a window against CO_2 emission of a 'normal' window with the same average speed. The 'normal' level of CO_2 emissions, the so called vehicle CO_2 characteristic curve, is derived from the results of driving the type-approval WLTP test. A trip is valid if, for every section (urban/rural/motorway), at least 50% of the windows is within 25% of the vehicle characteristic CO_2 curve (the area between the green lines in figure 18).

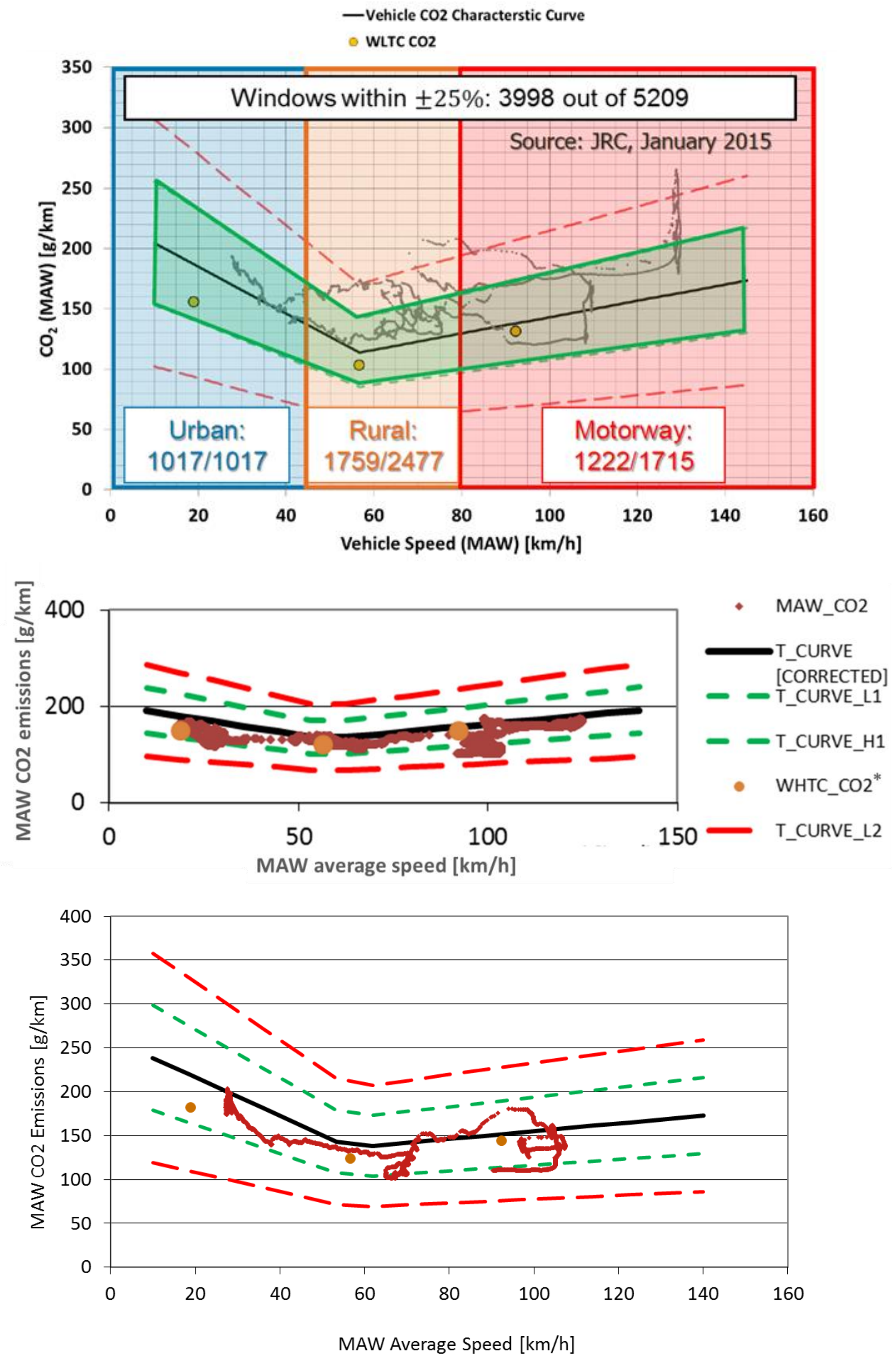


Figure 18. Typical plots of the CO_2 emission of moving average windows of RDE trips. The black line represents the vehicle CO_2 characteristic curve derived from the results of driving the type-approval WLTP test. The green lines and red lines represent a 25% respectively 50% deviation from the black line. A trip is valid if, for every section (urban/rural/motorway), at least 50% of the windows is in between the green lines. Sources: JRC presentation to the RDE-LDV expert group; information delivered by the Dutch delegation to the RDE-LDV expert group; presentation 'AECC project on real-world GDI PN Emissions', Dr Joachim Demuynck, AECC, at the AECC Technical Seminar on Real-Driving Emissions, Brussels 4 July 2016.
*) In output of EMROAD these points are incorrectly labelled. The correct label is WLTC_CO2.

The final emission result of a valid RDE trip is obtained by a weighted average of the individual windows. The weight given to a window depends on the distance to the vehicle characteristic CO_2 curve. If the windows falls within the green lines in figure 18, the window gets full weight. The weight dimishes in the areas between the green and red lines in figure 18, from 100% for windows on the green line to 0% for windows on the red lines (see figure 19).

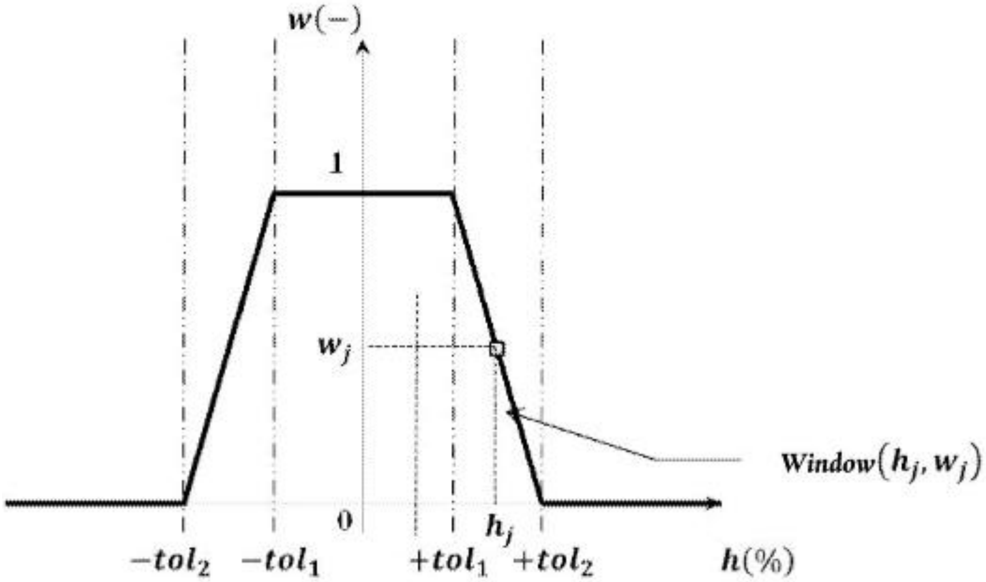


Figure 19 The weighing function of windows under the EMROAD tool. The range between $-tol_1$ and + tol_1 represent 25% deviation from the vehicle CO_2 characteristic curve (the area between green lines in figure 18. The range between $-tol_2$ and + tol_2 represent 50% deviation from the vehicle CO_2 characteristic curve (the area between the green and red lines in figure 18). Source: Appendix 5, paragraph 6.1 of the 1st RDE package.

10.2.2 *CLEAR*

CLEAR is a data evaluation tool developed by the Technical University of Graz (TUG). CLEAR normalizes results of different driving styles to ‘normal’ driving. In the first step the power demand during the RDE trip is, on a second by second basis, compared with the power demand as if the vehicle was driving a WLTP type-approval test:

$$P_{norm} = P_{WLTC}/P_{drive}$$

For every 3-second window of the RDE trip this P_{norm} is calculated and the emissions measured are weighted with the time share this power demand occurs in ‘normal’ driving, the ‘Power Frequency’.

In practice the CLEAR weighing method enhances emissions from moderate driving (P_{norm} in the range 0.1 to 1.0) and lowers results from very aggressive driving (P_{norm} above 1.5).

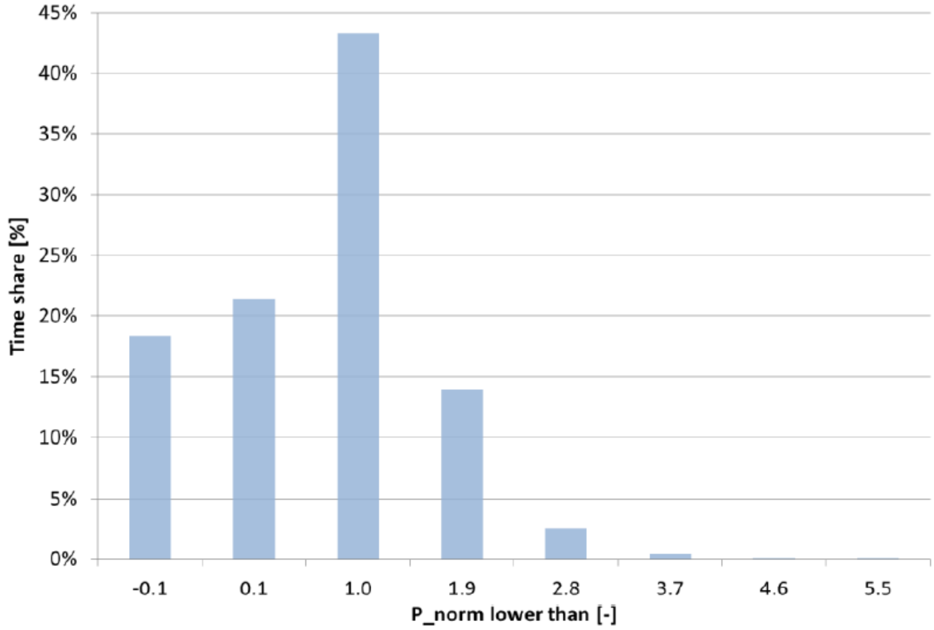


Figure 20 The ‘Power Frequency’ used in the CLEAR method derived from WLTC test data of 49 different cars. In the ‘Power Frequency’ the time share values of different P_{norm} bins are plotted.

10.2.3 *Impact of EMROAD and CLEAR on RDE results*

Currently RDE testing at TNO is to replicate average behaviour which is expected on the Dutch roads within the boundaries of RDE. These RDE tests do currently not seek out the boundaries in driving behaviour or vehicle use. It is therefore not expected the evaluation tools show a large systematic effect, towards a different average than the measurement results. The evaluation tools are meant to compensate to correct for nonstandard use. In most cases the evaluations tools change the result less than 20% either upward or downward. Both tools are intended to achieve a similar effect, but in many cases there is no correlation to the corrections, or normalizations, EMROAD and CLEAR perform on the same RDE dataset.

10.2.4 *Strengths and weaknesses of EMROAD and CLEAR*

In most cases the corrections by CLEAR and EMROAD are within a bandwidth of ±20%; substantial corrections given the fact that the RDE trips driven are ‘normal’ driving (all or most windows in between the green lines of figure 18). There are worrisome corrections to the data by the EMROAD tool, where up to 60% reduction occurs in the urban test, and 40% reduction in the total trip result. It is unclear why EMROAD gives much lower numbers for the comparison with the emission limit than the measurement results. For the urban test, the long windows with limited urban contributions is partly to blame for this effect. The effects of EMROAD and CLEAR on the data are often unexpected. In many cases, it is hard to reconstruct the precise cause of the differences between the measurement data and the emissions after normalization.

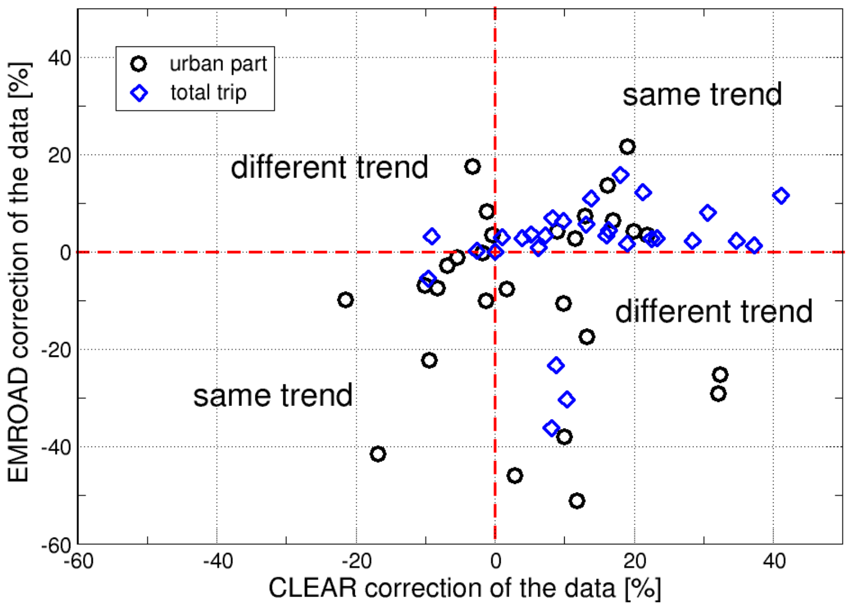


Figure 21. The impact of the evaluation tools. The measurements, raw data, are compared with the calculated emissions after applying EMROAD and CLEAR. EMROAD and CLEAR do often not follow the same trend in the normalization of the result, certainly not for the urban part. This together with the reduction of 60% on the urban test and 40% on the total trip of the measured average on RDE tests in EMROAD do raise concerns on the purpose of the tools. The tests performed are considered not extreme in any manner. Source: TNO 2016 R11177 “NO_x emissions of fifteen Euro 6 diesel cars: Results of the Dutch road vehicle emission testing program 2016”, Heijne et.al.

In previous investigations, in 2015, the CLEAR method seemed to reduce the NO_x emissions of vehicles from the measured results. These analyses were done with the previous version of CLEAR on the first Euro-6 vehicles. Current analyses concern the mainstream Euro-6 vehicle models. The fact that the correction is now more often upward than downward with CLEAR, can be related to the change in RDE trip, the small sample of vehicles, the different vehicle segments or technologies, and the new version of the evaluation tool. In itself, the tools make it almost impossible to investigate the interplay of these effects. The spread of 20% seems to be the natural variation caused be the evaluation tools.

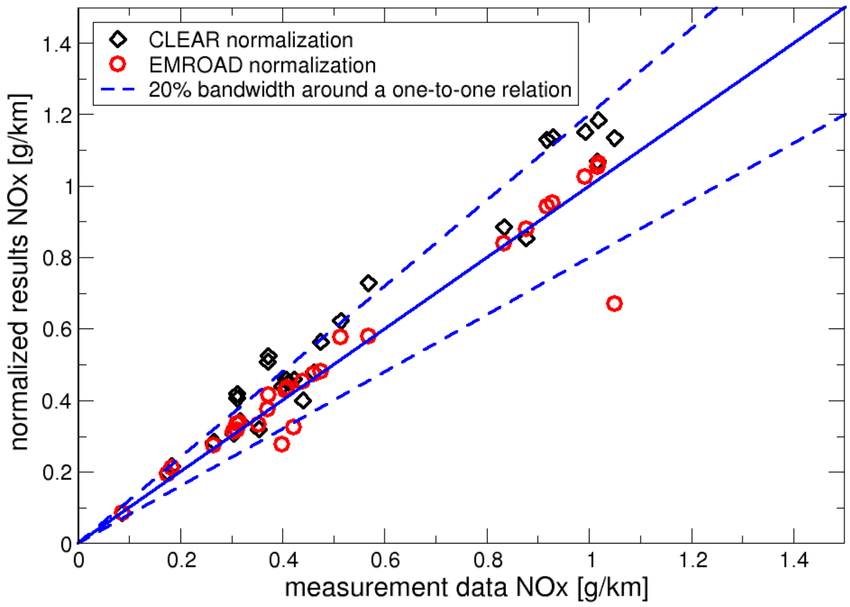


Figure 22 The full RDE test of recent EURO-6 vehicles comparing the measurement results on the x-axis and the evaluation results of CLEAR and EMROAD on the y-axis. A random scatter up and down of the evaluation tools up to 20% is normally observed. In some cases EMROAD does reduce the results more than that. Source: TNO 2016 R11177 "NO_x emissions of fifteen Euro 6 diesel cars: Results of the Dutch road vehicle emission testing program 2016", Heijne et.al.

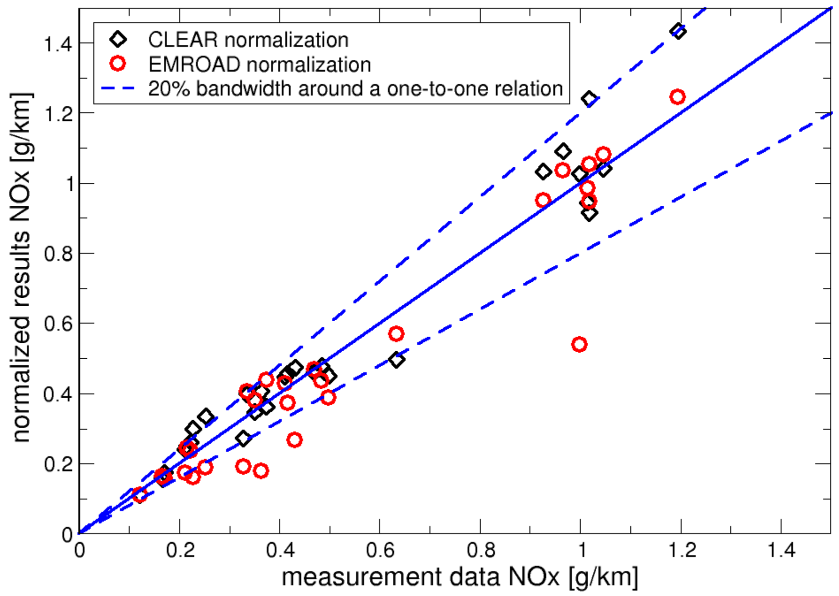


Figure 23 The evaluation of the urban part of the RDE test show the same variation. Also here, EMROAD has occasionally a much lower value than the NO_x measured emission of the Euro-6 vehicles. Source: TNO 2016 R11177 "NO_x emissions of fifteen Euro 6 diesel cars: Results of the Dutch road vehicle emission testing program 2016", Heijne et.al.

It should be noted that the emissions of most of the tested vehicles are high, often very high, compared to even the conformity factor 2.1 of phase 1 of RDE. The results might be different if the evaluation tools were applied to data sets of low emitting cars.

At the moment it is not possible to do an evaluation of the tools in all its details. This requires WLTP tests. The CO_2 WLTP test results of current Euro-6 vehicles are not widely available. Therefore, in some cases the results of a similar vehicle are used as input to the evaluation. This kind of hindrances will stand in the way of independent testing for years to come.

The lack of transparency of what's happening inside the evaluation tools EMROAD and CLEAR complicates the assessment of the tools and the assessment of what the corrections would be for future RDE compliant vehicle. Test results from the RDE monitoring phase, that started from 20 April 2016, have not been made available so far. Only if the test results become available to parties involved in the RDE-LDV expert group a proper assessment of the evaluation tools can be conducted.

10.3 Conformity factors

The Conformity Factors cannot be seen independently of the evaluation method.

RDE testing was meant to be unbounded, i.e., covering all normal conditions of use, only restricted by traffic regulations, such as speed limits, and the vehicle capabilities. The explicit choice to design the emission criterion as a Not To Exceed (NTE) limit supports this interpretation. In principle NTE means that the vehicle's emissions are below a certain level at all points in time of normal operation.

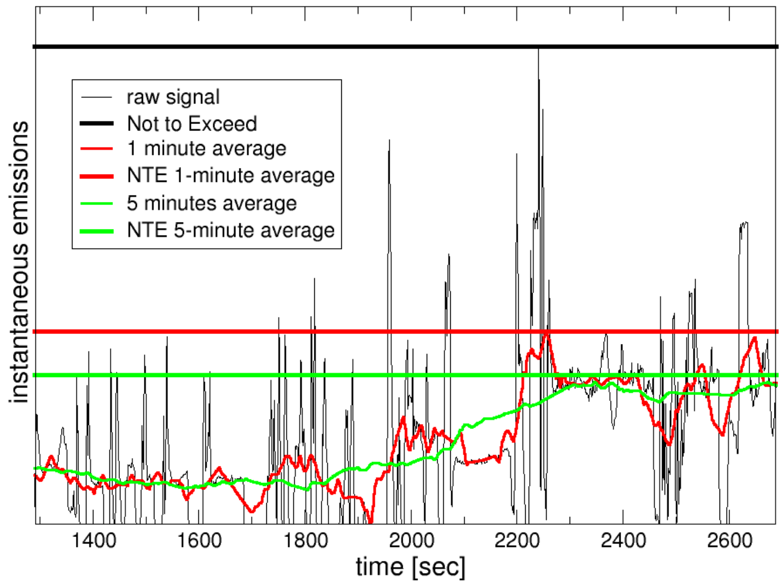


Figure 24 The maximum of the raw signal is typically much higher than the signal which is smoothed, in this example it is smoothed over time. The maxima of smoothed signals are typically at about a third of the real maximum. A limit associated with a particular maximum therefore depends on the evaluation method. Results to be published.

Such a NTE limit would certainly require a conformity factor given the variations in emissions normally observed. A proper NTE limit would lead to much lower average emissions, as to ensure low emissions in all circumstances. If the peaks in the emissions are below a limit, the average is normally at about a third of that value.

In the course of RDE development the evaluation methods were introduced that imply a shift from a proper NTE (all normal conditions of use) to an average number for average use. The evaluation tools EMROAD and CLEAR 'normalize' the RDE-trips to standard NEDC severity and reduce the reduce the impact of emission events that deviate from the average situation. As a result the RDE legislation now compares only the average and normalized emission of the urban part and the total RDE trip with the emission limit.

On top of the evaluation methods, the ambient and driving boundaries described in the Chapters 5 to 7 included, prevent for extreme test conditions and as such further limit the variation in emissions.

Given this pile of 'normalizations', 'averages' and 'boundaries' any argument to apply a conformity factor higher than 1.0, with only an additional margin for state of the art accuracy of PEMS equipment, in the final phase of RDE legislation has expired.

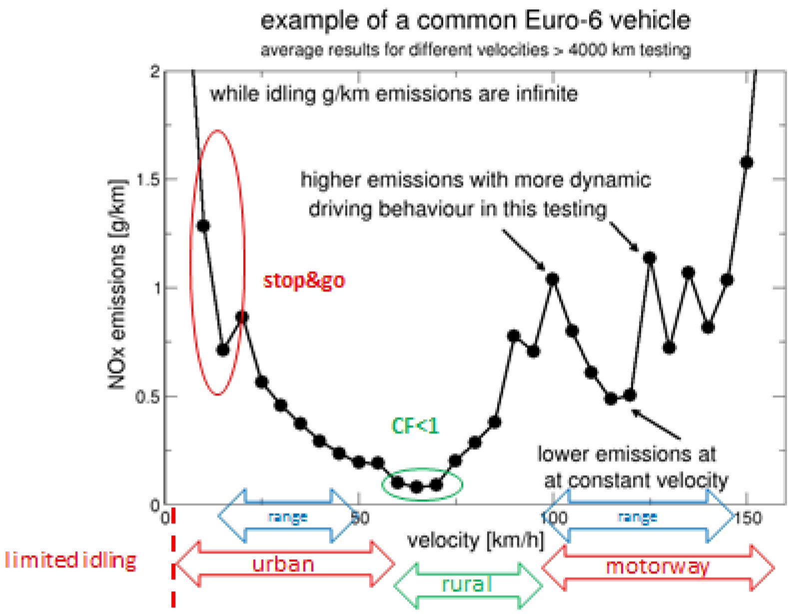


Figure 25 Restrictions in the average velocities are a smaller range than the full range of urban, rural, and motorway driving. This will restrict the time of driving at both high and low velocities in which the emissions can be substantially higher, as in this example of a diesel Euro-6 vehicle. Source: translation of information delivered to the Dutch parliament (https://www.tweedekamer.nl/kamerstukken/detail?id=2016D15169&did=2016D15169)

A positive development in the course of time is the introduction in the 2nd package of a separate evaluation of urban driving. An evaluation of only the total RDE trip would have enabled compensation of high urban emissions by low rural emissions; very undesirable from a perspective of air quality and human health. The separate urban evaluation ensures proper real-world emission in urban areas. However, there is a requirement on the average urban velocity, which restrict the amount of stop-and-go driving in the test.

10.4 Transfer functions

The option to introduce a differentiated Transfer function is still left open. A placeholder is present in current legislation, as part of the 2nd package. This differentiation is meant to take account of the severity of emission control due to variations in RDE trips. An introduction should be justified by objective scientific reasons.

As highlighted in the previous paragraph, by the introduction of boundaries and evaluation tools, the RDE legislation gives some margin against contingencies to the car manufacturers.

The evaluation methods EMROAD and CLEAR, in their current form, do not fully reduce the risk for the manufacturers of certain specific high emission events affecting the final result. In principle a robust emission control optimization is still needed with RDE to cover all possible RDE trips. This is for air-quality a desirable situation. But it means that in some RDE tests the emissions will be higher than in other tests. The critical RDE tests are essential to ensure robust emission control also for these conditions of vehicle use. This is a fundamental principle of RDE testing, but contains a risk for manufacturers. Normalizing the emission results in RDE in such a manner that the results are always comparable with the RDE test carried out in the type-approval phase goes against the principle that RDE should test the robustness of emission control. If introduced, the Transfer functions are aimed to reduce risk on the basis that there is a physical reason why emissions are higher in certain situation, not covered by the current evaluation tools. Ambient temperatures and road slopes are part of normal conditions encountered while using a vehicle. These are mentioned as options to include into the Transfer function. Consequently, it would mean that people living in colder climates or mountainous areas have to accept higher emission levels than the average European. This cannot be the interpretation of the regulation and it takes RDE another step away from the original Not-To-Exceed limit.

Introduction of a differentiated Transfer function is superfluous. Even though it is stated in the 2nd RDE package that “if the transfer function is amended, this shall be done in a manner which is not detrimental to the environmental impact and the effectiveness of the RDE test procedures”, any amendment on top of all the RDE boundary conditions and evaluation tools already applied in the RDE legislation can only be considered as an attempt to weaken the effectiveness of RDE.

The Transfer functions strikes at the heart of RDE legislation in threefold.

- It is input from the industry to increase the overall complexity of RDE legislation and obfuscates the possibilities to optimize emission control towards legislation rather than develop robust emission control towards real-world conditions.
- Second, it extends the current status quo where high NO_x emissions of diesel vehicles are seen as the natural consequences of vehicle usage and they cannot be avoided by improved engineering design.
- Third, it suggests there is a natural average vehicle operation towards which all other vehicle usages should be compared. Instead, RDE legislation should ensure robustness of emission control technology, extending the conditions in which the emission control technology functions properly to most conditions observed on European roads.

11 RDE 3rd package

The European Commission is currently preparing the 3rd RDE package and announced this package will comprise:

- Particle number (PN) PEMS testing
- Coverage of the vehicle cold start – already discussed in paragraph 1 of Chapter 10.
- Hybrid vehicles testing
- Improvements in the methodology to handle emissions during regeneration of particulate filters.

Additional requests of the car industry for special provisions have been discussed in the RDE-LDV expert group, but it's unclear if the Commission will include them in the 3rd or 4th package proposal.

11.1 Particle number

With the adoption of the 2nd RDE package the conformity factor for NO_x emissions has been established. The announced conformity factor for PN (particle number) is expected to be included in the 3rd package.

JRC has demonstrated the feasibility of PN PEMS testing at an acceptable level of measurement uncertainty[17]. Recent validation tests show PN PEMS equipment is robust under all normal driving conditions[18] at inaccuracy levels similar to NO_x PEMS equipment and is readily available. Vehicle technology required to meet future RDE PN criteria is also readily available.

If for PN the same approach were to be followed as for NO_x, a reasonable 3rd package proposal would consist of a PN Conformity factor of 1.0 + *margin* for both the 1st and 2nd step, with an initial value of 0.5 for the *margin* given similar inaccuracy levels for NO_x and PN PEMS equipment.

The introduction of a PN conformity factor is particularly important for GDI's, petrol vehicles with direct fuel injection. Under Euro-6 standards a temporary PN limit of $6x10^{12}$ was added to give GDI's additional lead time to meet the intended PN limit value of $6x10^{11}$, equal to the PN limit for diesel vehicles. It was expected that the application of a particulate filter (GPF) is required to meet the final limit. The application of GPF's has been announced by several manufacturers. Other manufacturer, however, seem to rely on engine optimization. As is the case for NO_x emissions of current diesel cars, engine optimization is not expected to be a robust solution that delivers low on-road emissions under real driving conditions.

Measurements on a modern GDI[19] show that manufacturers are close to meeting the final PN limit under type-approval conditions with engine optimization only. Even meeting RDE requirements might be feasible if the PN conformity factor is too

[17] JRC has delivered its information to the RDE-LDV expert group.
[18] Information exchanged in the RDE-LDV expert group
[19] Based on information of AECC, the Association of Emissions Control by Catalyst, on its PN test programme delivered to the RDE-LDV expert group.

lenient. The application of a GPF will secure low PN emissions under all conditions. If introduced on a large scale GPF costs are well below €50 per vehicle. No CO_2 penalty or increase of fuel consumption is observed for GDI equipped with a GPF[20].

The current PN test procedure has a cut-off size of 23 nm, leaving 20-50% of the (ultra-fine) particles undetected. A GPF will also strongly reduce the emission of these ultra-fine particles under 23 nm.

PN emission levels of GPF-equipped cars are far below the limit values, implicating that setting a PN conformity factor is less sensitive for measurement uncertainties. PEMS equipment capable of measuring down to 10 nm is ready for market introduction.

If the aim is to secure low PN emissions under real driving conditions, the application of a GPF is required. Application of a GPF will only be secured if the conformity factor for PN in the 3rd package is set at 1.0 without an additional margin and the measurement cut-off size is reduced to 10 nm on grounds of technical progress, without an increase of the Euro-6 PN limit values. However, this might be considered being a strengthening of the emission values and as such outside the mandate given by the Euro5/6 legislation.

11.2 RDE testing conditions for hybrid vehicles

Hybrids and plug-in hybrids will be a wide spread technology in the near future. Assessment of (plug-in) hybrids emissions requires modifications of the current RDE evaluation methods. All stakeholders support the inclusion of hybrids in the RDE legislation.

Car manufacturers have proposed strategies which require more detailed information of the vehicle, either from the WLTP test or from the engine control unit, or require the test to be performed under a specific protocol. This is considered undesirable, as it limits the freedom to test the vehicle independently under RDE without interference from the vehicle manufacturer.

JRC proposed a methodology based on testing a vehicle with a low battery charge, such that the vehicle will use the combustion engine as the main source of propulsion energy. This proposal will only work if EMROAD is applied as evaluation tool and only under a limit number of charging strategies. The method will fail if a vehicle charges its battery at one velocity range to drive electric at another velocity range. The method also fails if CLEAR is applied.

The Netherlands has proposed a practically applicable RDE test protocol without limitations for the manner in which the hybrids are tested. The method is based on the TNO RDE evaluation method of comparing the NO_x emissions with the CO_2 emissions. CO_2 emissions are directly related to the fuel consumption and the engine operation. More energy demand, such as from up-hill driving, battery charging, air-conditioning usage, etc. leads to a higher fuel consumption. It could be

[20] Information delivered by a test programme of AECC and confirmed by tests conducted by Ford. One might expect a fuel penalty of an additional filter being added to the exhaust of a petrol vehicle, but the GPF allows for improved turbo charging and engine mapping. As a result no significant, measurable, impact on fuel consumption is found.

considered acceptable that the pollutant emissions increase at the same rate. This makes different tests in which the fuel consumption can vary greatly comparable, as is the case for hybrids. The pollutant emissions of modern vehicles increase generally more rapidly than the CO_2 emissions. This is one of the undesirable situations which should be controlled. Translating the fixed ratio of NO_x/CO_2 to the legislative unit [g/km] requires a conversion factor, for which the CO2 emission in [g/km] on the WLTP test can serve.

The EMROAD and CLEAR method both serve the same purpose to compensate for the variation of vehicle use, typically expressed in velocity and acceleration. However, they do so in a manner unsuited for hybrid vehicles. Both methods however, use also the CO_2 as a means to arrive at a robust evaluation.

Testing one diesel plug-in hybrid, with a substantial battery capacity, showed that the variation in the results was halved by the NO_x/CO_2 evaluation method. Moreover, the parts of the trips with substantial electric driving fall in the same band as the trips on the combustion engine. Likewise, the charging of the battery does not lead to excessive results.

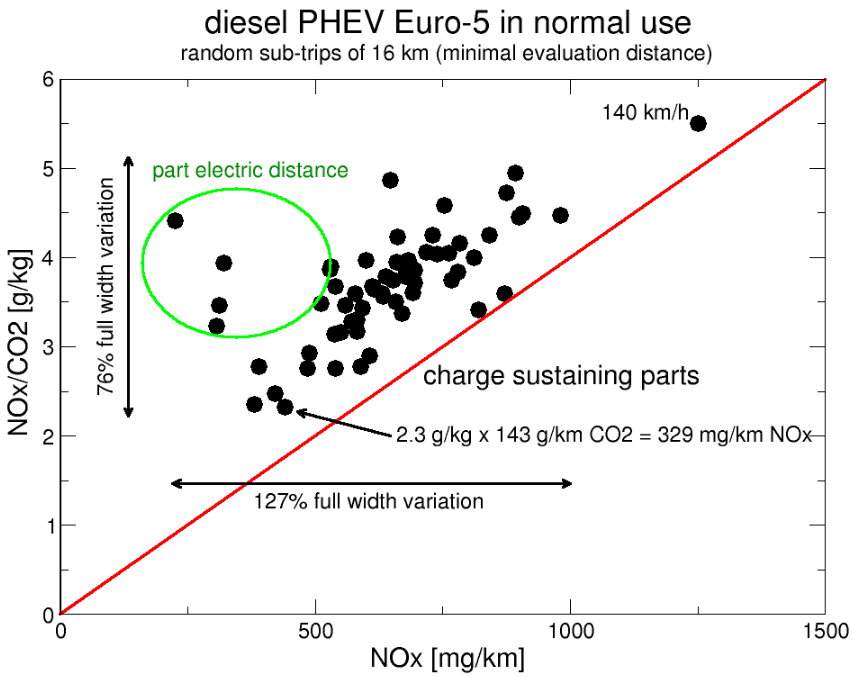


Figure 26 The variation in the emission results of plug-in hybrids expressed as NO_x/CO_2 is about half the variation in terms of NO_x/km. The trips are segmented into 16 km parts, which is the shortest evaluation distance, related to the urban part. Source: information delivered by the Dutch delegation to the RDE-LDV expert group.

The advantages of the Dutch proposal are manifold. First of all, the RDE testing is unrestricted and it does not require additional information or signals. Moreover, since the engine does not need to start at the beginning of the trip, the cold start evaluation can be included. Depending on the choices made for the cold start inclusion this will add no or only limited complexity to any hybrid test.

The Dutch proposal received support of most parties involved in RDE development and is expected to be included in the 3rd package proposal of the Commission.

11.3 Regeneration of DPF during RDE test

The RDE legislation, up to the 2nd package included, prescribes that a new RDE test is required if regeneration of a filter occurs during the RDE test. The car manufacturers requested not to be obliged to perform a second test, if the emissions of the first test remain below the RDE NTE limit. The manufacturers also request to clarify that the Ki factor, that is applicable in the first test if no regeneration occurs, shall also be applied if no regeneration occurs in the second test. Under the condition that the provision will be drafted in such a wat that no signals of the vehicle are required, the Dutch expressed support for these proposals as they simplify and clarify the RDE provisions and procedures.

11.4 Additional issues

In the course of the preparation of the 3rd RDE package numerous proposals to modify the RDE legislation have been discussed in the RDE-LDV expert group. Two requests have received sympathy from the Commission and might make it to the 3rd or 4th package.

11.4.1 Fuel quality

Even though European petrol quality is regulated by the Fuel Quality Directive (FQD)[21], substantial differences in petrol composition are reported across the EU. Heavier petrol fractions are known to increase particle number (PN) emissions, but the impact varies with different vehicle technologies. On a limited scale supply of very heavy petrol has been reported, particularly in Eastern-Europe. The car industry requested to exclude heavy petrol from RDE testing. The provision proposed is to check petrol quality if a vehicle fails to meet the RDE criterion and to perform a retest if the petrol contains a high percentage of heavy fractions.

In general RDE testing should cover as much as possible conditions that can be encountered across the EU. In this respect a provision to limit the window of allowed petrol quality should be as restraint as possible. If only the 10% heaviest petrol is excluded from RDE testing, the environmental impact for The Netherlands will be negligible.

Preferably, the impact of petrol quality on PN emissions should be taken into consideration in future FQD evaluations.

11.4.2 Small volume manufacturers

The association of small volume car manufacturers requested an exemption being included in the RDE legislation similar to the one in the European CO_2 standards. The exemption concerns some additional lead time for the small volume manufacturers to comply with the RDE legislation. The exemption will cover only a very limited volume - approximately 12000 vehicles annually - and the environmental impact is negligible. There seems to be no reason to object the exemption.

[21] Directive 98/70/EC

12 Independent testing (4th package)

RDE legislation is a paradigm shift in light-duty vehicle testing, necessary since the single type-approval laboratory test did not deliver low real-world emissions. No longer a strict protocol for comparable emission results, but a variety in testing to cover the normal conditions of use. The manufacturer may test the vehicle at 25 °C ambient temperature in the type-approval procedure, but the vehicle should satisfy a test at 5 °C as well. There are many more variations in the RDE test, apart from ambient temperature, such as payload and auxiliary use. This variety requires independent testing to test the robustness of the emission control technology. This kind of paradigm shift requires many more tests, also seeking out the possible weak spots in emission control for particular, yet common, vehicle use.

The possibility of such independent surveillance testing is particularly important, if not decisive, for the effectiveness of the RDE test procedures, since the latter contain random elements and are based on the legal requirement that NTE emission limits are not exceeded for a wide variety of different PEMS trips.

Moreover, these independent tests, market surveillance, must have a proper status in the type-approval procedure. The same understanding across Europe on RDE testing must exist, and the failure to meet RDE limits in a correctly executed RDE tests must have consequences for the type-approval of that vehicle model family. The type-approval authorities and their oversight in Europe is to be adapted to make enforcement of emission legislation possible.

The market surveillance to ensure RDE compliant vehicles will only function if a number of conditions are met:

- A sufficient number of independent parties will test vehicles across Europe to ensure the robustness of emission control technologies in a variety of conditions.
- The results of these tests are recognized as input for the type-approval process and review for vehicles already accepted on the European roads.
- The escalation and sanctioning of both the manufacturer and the type-approval authority for insufficient actions on a non-compliant vehicle are foreseen.

Third party testing is currently very limited: only a few member states besides the Netherlands sponsor independent testing of vehicles for their real-world performance. With the scandal around diesel vehicles from September 2015, a number of commercial parties have executed a variety of emission testing. Currently, such tests have limited stature, as they are not part of the type-approval protocol. However, in the future it should be possible to act upon indications that certain vehicles are not RDE compliant. From the first indications, a path should be set out to arrive at a decision whether the type-approval is issued unjustly, which can also clear a manufacturer of any wrongdoings. This is not a simple task, especially if it is carried out in the public domain in which certain third parties are likely to operate. It may be more fruitful to set up independent RDE testing across Europe by the member states which cover all vehicles and all RDE-compliant conditions. Independent verification of emission performances of vehicles will settle more quickly claims of non-compliance from other parties, because results can be compared.

From a certain moment onwards an official protocol must be set out to investigate the claims of non-compliance. This protocol cannot be too restrictive in accepting claims to be investigated and it must pre-empt somewhat the media tumult that can be generated without substantiating evidence. This requires an open process of following up concerns and openness on the method of investigation and its findings. The current media attention for diesel vehicle emissions was mainly the result of the limited enforcement of emission standards despite the mounting evidence such enforcement was warranted. This situation should be remedied. A comprehensive testing scheme for RDE compliance is needed. Moreover, such as scheme should establish the RDE boundaries in practice, as it is a new playing field for all parties. There will be claims of non-compliance which eventually fail to materialize. In this case the fault with the initial findings must be found, to remove lingering doubts. This may be more difficult than determining non-compliance.

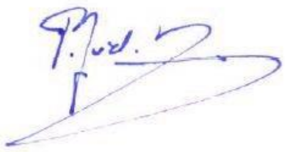
The 4th RDE package should adequately secure that independent on-road RDE testing can be performed by independent parties.

Only by independent RDE testing information required to review the (in)accuracy margin of PEMS (see Chapter 9) can be delivered.

13 Signature

Delft, 27 September 2016

TNO



P. van der Mark
Project leader

R.F.A. Cuelenaere
Author