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fit for the future

Final report to T&E of Emissions Determination from RDE Regeneration Testing

Q019769; RD.19/063101.3; 20191122

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Contents

Introduction

- Discussions between T&E and Ricardo regarding DPF regeneration emissions testing on two Euro 6d-temp diesel vehicles commenced in April 2019.
- Vehicle procurement, post-delivery checks and instrumentation tasks were undertaken in early July 2019
- First testing activities commenced on the 25th July 2019 and completed on the 7th August 2019.
- Biweekly telecons were held to discuss progress
- The final report was submitted on 22 November 2019

Contents

Objectives

- T&E's stated Objectives in the RFQ were as follows:
  - The main objective of this testing program is to gain a better understanding of the magnitude of regulated and unregulated pollutants emitted during DPF regeneration and to assess how representative currently used Ki factors are compared to real world derived values
- Ricardo further interpreted the requirements as follows:
  - Ricardo to source two suitable vehicles as discussed with T&E (Nissan Qashqai and Opel Astra)
  - Ricardo to test these two vehicles on pump grade fuel over multiple on-dyno RDE cycles until one regeneration event is captured
  - Regulated and selected unregulated emissions to be recorded during all tests
  - Ricardo to analyse data, including emissions during regeneration, and prepare a test report detailing the findings of the project
- Modification of scope by T&E
  - The work was subsequently down-scoped slightly to limit investigations to the capture and recording of emissions from one active regeneration from each vehicle, along with associated non-regenerating cycles

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Project Elements#1

1. Test Vehicle → 2. Vehicle preparation → 3. Vehicle Instrumentation →

1. Test Vehicle

- Ricardo rented two Euro 6d-temp test vehicles from ProRent (Germany), having them shipped to the UK.
  - Opel Astra 1.6 D 81 kW / 110 hp - 6MT 2WD
  - Nissan Qashqai 1.5 dCi (115ps) - 6MT 2WD
- The vehicles were tested on the chassis dyno using road load data from the vehicles' respective certificates of conformity.

2. Vehicle preparation

- A safety check was performed on each vehicle to enable on-dyno testing
- OBD scans were undertaken on the vehicles and the absence of faults demonstrated
  - Available OBD channels were determined and those (available) relating to emissions control systems and engine operation identified and templates developed for their recording during testing

3. Vehicle Instrumentation

- The exhaust of each test vehicle was equipped with a surface thermocouple to aid detection of DPF regeneration events via the post-injection exotherm. No further instrumentation was required
- All tests were run with a laptop attached to the vehicles' CAN ports to record OBD data

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Project Elements#2

4. Fuel change to EN590 (UK grade)

- The vehicle was flushed and filled with UK pump-grade EN590 fuel from a dedicated batch
- An analysis of the fuel batch was performed and compliance with basic EN590 requirements confirmed

5. Prior on-road RDE drive

- An on-road RDE data set comprising speed, load & gradient from a D-Class vehicle was selected. These data were from a valid RDE (package #3) drive around one of the Ricardo routes (Eastbound route), equipped with a portable emissions measurement system (PEMS).

6. RDE transposition to the chassis dyno

- The relevant on-road RDE data (speed vs. time and gradient vs. time) were then transposed to a data file which was readable by the chassis dynamometer's drivers aid
- The resulting on-dyno RDE was driven on the chassis dyno and the speed and gradient profiles shown to match on-road RDE data
- The same RDE cycle was used for both test vehicles

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Project Elements#3

7. Vehicle preparation

- On 25th July the Qashqai was subjected to a WLTC preconditioning
- On 30th July the Astra was subjected to a WLTC preconditioning

8. Vehicle Testing

- Testing of on-dyno RDEs proceeded in pairs, with a cold start followed by a hot start, on the same day.
- Testing of the Qashqai commenced on 26th July with RDE pair#1, followed by RDE pair#2 on 29th July
- Testing of the Astra commenced on 31st July with RDE pair#1, followed by RDE pair#2 on 1st August

9. Extra tests

- Active DPF regenerations were observed on the first test of the first pair of on-dyno RDE tests on each vehicle
- Ricardo agreed with T&E to continue testing pairs of cold and hot RDE cycles on the Qashqai in order to determine the regeneration distance / periodicity
  - This additional testing completed with one additional pair on August 6th 2019
- Similar additional testing was then performed on the Opel Astra, completing with one additional pair on August 7th 2019

10. Reporting

- Coarse chemical analysis and evaluation of bagged dilute and certain continuous emissions were undertaken, and evaluated in the reporting phase
- Biweekly updates were provided to the project lead team
- The final report was issued on 22nd November 2019

Contents

Technical Approach – Sub-sections

- **Test vehicles**
- CoC data
- Fuel Analysis
- Lab-based instrumentation and on-vehicle equipment
- Drive cycle and testing
- Test Protocol and Sequence
- Test nomenclature

Opel Astra and tyres

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225/45 R17 (BRIDGESTONE)

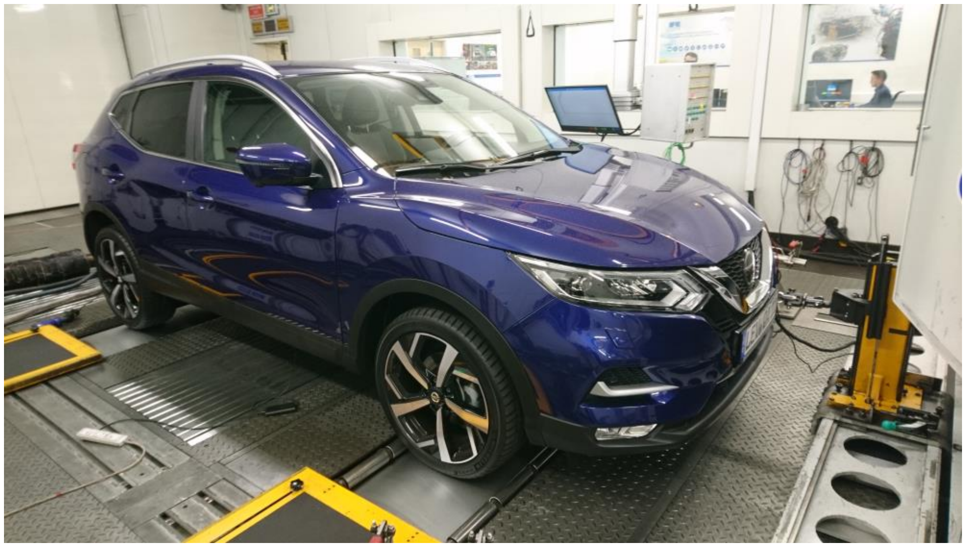
- Opel Astra 1.6 D 81 kW / 110 hp - 6MT 2WD
- 4 Cylinder
- Max Speed: 200 kph
- 81kW at 3500 rpm

- WLTC CO_2 (from CoC)

Benzin / Diesel WLTP-Werte	CO2-Emissionen [g/km]	Kraftstoffverbrauch [l/100km]
Niedrig	171	6.5
Mittel	130	5.0
Hoch	116	4.4
Höchstwert	135	5.1
Kombiniert	133	5.1

- NEDC CO_2 (from CoC)
  - Urban 148 g/km
  - Combined 118 g/km

Nissan Qashqai and tyres



- Nissan Qashqai 1.5 dCi (115ps) - 6MT 2WD
- 4 cylinder
- Max speed: 181 kph
- 85kW at 3750 rpm

225/45 ZR19 MICHELIN

- WLTC CO_2 (from CoC)

WLPT-Werte	CO₂-Emissionen	Kraftstoffverbrauch
Niedrig	158 g/km	6.1 l/100km
Mittel	138 g/km	5.2 l/100km
Hoch	126 g/km	4.8 l/100km
Höchstwert	158 g/km	6.0 l/100km
Kombiniert	144 g/km	5.5 l/100km

- NEDC CO_2 (from CoC)
  - Urban 122 g/km
  - Combined 110 g/km

Emissions Certification Data (Whole WLTC values)

	Cert. Limit [WLTP]	Astra	Qashqai
CO_2 [g/km]	[-]	133	144
CO [mg/km]	500	88.2	56.2
NOx [mg/km]	80	20.9	34.9
PM [mg/km]	4.5	0.24	0.683
PN [#/km]	$6x10^{11}$	5×10^9	12×10^9
HC + NOx [mg/km]	170	31.3	45.5

- Both vehicles were Euro 6d-temp classification [Euro 6 AG]

Final

Qashqai Certificate of Conformity

RICARDO

EG-ÜBEREINSTIMMUNGSBESCHEINIGUNG
für vollständige Fahrzeuge

Form ID: CM1D0NE 01-04 GER

Der Unterzeichner, James Moss, NISSAN Vice President bestätigt hiermit, dass das unten bezeichnete Fahrzeug:

0.1. Fabrikmarke (Firmenname des Herstellers) :NISSAN
0.2. Typ :J11
Variante :A
Version :A04
0.2.1. Handelsbezeichnung :NISSAN QASHQAI
0.4. Fahrzeugklasse :M1
0.5. Firmenname und Anschrift des Herstellers :Nissan International SA
Zone d'Activites La Piece 12
1180 Rolle
Switzerland
0.6. Anbringungsstelle und Anbringungsart der vorgeschriebenen Schilder :Aufkleber an der rechten B-Säule
Anbringungsstelle der Fahrzeug-Identifizierungsnummer :Rechts oben an der Spritzwand
0.9. Name und Anschrift des Bevollmächtigten des Herstellers :Nissan Technical Center Europe
Trading Division of NMUK(Ltd)
Cranfield Technology Park, Moulsoe Road
Cranfield, Bedfordshire, MK43 0DB, UK
0.10. Fahrzeug-Identifizierungsnummer :SJNFAAJ11U2408473

mit dem in der Genehmigung e11*2007/46*0963*18 erteilt am 05/07/2018 beschriebenen Typ in jeder Hinsicht übereinstimmt und zur fortwährenden Teilnahme am Straßenverkehr in Mitgliedstaaten mit Rechtsverkehr in denen metrische Einheiten für das Geschwindigkeitsmessgerät und metrische Einheiten für den Kilometerzähler (gegebenenfalls) verwendet werden, zugelassen werden kann.

Rolle, 18/09/2018

Vice President

Allgemeine Baumerkmale
1. Anzahl der Achsen : 2
und Räder : 4
3. Antriebsachsen (Zahl, Lage, Verbindung) : 1, vorn, Keine

Hauptabmessungen
4. Radstand : 2646 mm
4.1. Achsabstände 1-2: - mm
5. Länge : 4394 mm
6. Breite : 1806 mm
7. Höhe : 1590 mm

Massen
13. Masse im fahrbereiten Zustand : 1460 kg
13.2. Tatsächliche Masse des Fahrzeugs : 1497 kg
16. Technisch zulässige Höchstmassen:
16.1. Technisch zulässige Gesamtmasse in beladenem Zustand : 1955 kg
16.2. Technisch zulässige maximale Masse je Achse 1: 1040 kg 2: 995 kg 3: - kg
16.4. Technisch zulässige Gesamtmasse der Fahrzeugkombination : 3405 kg
18. Technisch zulässige maximale Anhängemasse bei Beförderung eines:
18.1. Deichselanhängers : - kg
18.3. Zentralachsanhängers : 1450 kg
18.4. ungebremsten Anhängers : 730 kg
19. Technisch zulässige Stützlast am Kupplungspunkt : 100 kg

Antriebsmaschine
20. Hersteller des Motors : RENAULT
21. Baumusterbezeichnung gemäß Kennzeichnung am Motor : K9K
22. Arbeitsweise : Selbstzündung, 4-Takt
23. Vollelektrisch : Nein
23.1. Art des [Elektro] Hybridfahrzeugs : -
24. Anzahl und Anordnung der Zylinder : 4, in Reihe
25. Hubraum : 1461 cm^3
26. Kraftstoff : Diesel
26.1. Fahrzeug mit Einstoffmotor : Einstoffbetrieb
26.2. Nur für Fahrzeuge mit Zweistoffmotor : -
27. Höchstleistung:
27.1. Höchste Nutzleistung (Verbrennungsmotor) : 85 kW bei 3750 min^{-1}
27.2. Größte Stundenleistung (Elektromotor) : - kW
27.3. Höchste Nutzleistung (Elektromotor) : - kW
27.4. Höchste 30-Minuten-Leistung (Elektromotor) : - kW

Höchstgeschwindigkeit
29. Höchstgeschwindigkeit : 181 km/h

Achsen und Radaufhängung
30. Spurweite 1: 1560 mm 2: 1560 mm 3: - mm
35. Reifen/Radkombination/Rollwiderstand 1: 215/65R16 86T-16x6.5J/B
2: 215/65R16 86T-16x6.5J/B

Bremsen
36. Anhänger-Bremsanschlüsse : mechanisch

Aufbau
38. Code des Aufbaus : AF Mehrzweckfahrzeug
40. Farbe des Fahrzeugs : Blau
41. Anzahl und Anordnung der Türen : 4, 2(vorn), 2(hinten)
42. Anzahl der Sitzplätze (einschließlich Fahrersitz) : 5
42.1. Sitz(e), der (die) nur zur Verwendung bei stehendem Fahrzeug bestimmt ist (sind) : -
42.3. Anzahl der für Rollstuhlfahrer zugänglichen Sitzplätze : -

Umweltverträglichkeit
46. Geräuschpegel

Standgeräusch	bei der Motordrehzahl	Fahrgeräusch
70 dB(A)	2813 min^{-1}	67.7 dB(A)

47. Abgasnorm : Euro 6AG
47.1. Parameter für die Emissionsprüfung
47.1.1. Prüfmasse : 1574.1 kg
47.1.2. Querschnittsfläche : - m^2
47.1.3. Fahrwiderstandskoeffizienten
47.1.3.0. f0 : 117.35 N
47.1.3.1. f1 : 0.7386 N/(km/h)
47.1.3.2. f2 : 0.03462 $N/(km/h)^2$

48. Abgasemissionen:
Nummer des Basisrechtsakts und des letzten gültigen Änderungsrechtsakts : 715/2007/EC*2017/1347/EC (AG)
1.1. Prüfverfahren: Typ I oder ESC

CO	HC	NO_x	HC+NO_x	Partikel	Rauchgastrübung (ELR)
- g/kWh	- g/kWh	- g/kWh	- g/kWh	- g/kWh	- m^{-1}

1.2. Prüfverfahren: Typ 1 (NEFZ Mittelwerte, WLTP Spitzenwerte)

CO	THC	NMHC	NO_x	THC+NO_x	NH_3	Partikelmasse	Partikelzahl
56.2 mg/km	12.05 mg/km	- mg/km	34.90 mg/km	45.5 mg/km	- ppm	0.683 mg/km	0.12E+11 #/km

EG-ÜBEREINSTIMMUNGSBESCHEINIGUNG
für vollständige Fahrzeuge

Seite 2

Form ID: CM1D0NE 01-04 GER

2.1. Prüfverfahren: ETC (falls zutreffend)

CO	NO_x	NMHC	THC	CH_4	Partikel
- g/kWh	- g/kWh	- g/kWh	- g/kWh	- g/kWh	- g/kWh

2.2. Prüfverfahren: WHTC (EURO VI)

CO	NO_x	NMHC	THC	CH_4	NH_3	Partikelmasse	Partikelzahl
- mg/kWh	- mg/kWh	- mg/kWh	- mg/kWh	- mg/kWh	- ppm	- mg/kWh	- #/kWh

48.1. Rauch korrigierter Wert des Absorptionskoeffizienten : 0.51 m^{-1}
48.2. Ggf. angegebene höchste RDE-Werte (falls zutreffend)

	NO_x	Partikel
Vollständige RDE-Fahrt	168 mg/km	9.00E+11 #/km
Innerstädtische RDE-Fahrt	168 mg/km	9.00E+11 #/km

49. CO_2-Emissionen/Kraftstoffverbrauch/Stromverbrauch:
1. Alle Antriebsarten außer reinen Elektrofahrzeugen (falls zutreffend)

NEFZ-Werte	CO_2-Emissionen	Kraftstoffverbrauch
Innerorts	122 g/km	4.6 l/100km
Außerorts	104 g/km	3.9 l/100km
Kombiniert	110 g/km	4.2 l/100km
Gewichtet, kombiniert	- g/km	- l/100km
Abweichungsfaktor	-	
Differenzierungsfaktor	d	

2. Reine Elektrofahrzeuge und extern aufladbare Hybridelektrofahrzeuge (falls zutreffend)

Stromverbrauch (gewichtet, kombiniert)	- Wh/km
Elektrische Reichweite	- km

3. Fahrzeug mit Ökoinnovation(en) ausgestattet : Nein
3.1. Allgemeiner Code der Ökoinnovation(en) : -
3.2. Gesamteinsparungen von CO_2-Emissionen durch die Ökoinnovation(en):
3.2.1. Einsparungen durch NEFZ : - g/km
3.2.2. Einsparungen durch WLPT : - g/km

4. Alle Antriebsarten außer reinen Elektrofahrzeugen, gemäß 2017/1151 (falls zutreffend)

WLPT-Werte	CO_2-Emissionen	Kraftstoffverbrauch
Niedrig	158 g/km	6.1 l/100km
Mittel	138 g/km	5.2 l/100km
Hoch	126 g/km	4.8 l/100km
Höchstwert	158 g/km	6.0 l/100km
Kombiniert	144 g/km	5.5 l/100km
Gewichtet, kombiniert	- g/km	- l/100km

5. Vollelektrische Fahrzeuge und extern aufladbare Hybrid-Elektro-Fahrzeuge, gemäß 2017/1151 (falls zutreffend)
5.1 Vollelektrische Fahrzeuge

Stromverbrauch	- Wh/km
Elektrische Reichweite	- km
Elektrische Reichweite innerorts	- km

5.2 Extern aufladbare Hybrid-Elektro-Fahrzeug

Stromverbrauch ($EC_{AC,gewichtet}$)	- Wh/km
Elektrische Reichweite (EAER)	- km
Elektrische Reichweite innerorts (EAER innerorts)	- km

Sonstiges
51. Bei Fahrzeugen mit besonderer Zweckbestimmung: Bezeichnung gemäß Anhang II, Abschnitt 5 : -
52. Anmerkungen:
35.(1) 215/60R17 86T-17x7J, 215/55R18 86T-18x7J
35.(1) 225/45R19 86T-19x7J
35.(2) 215/60R17 86T-17x7J, 215/55R18 86T-18x7J
35.(2) 225/45R19 86T-19x7J

Fahrzeug mit Kurzstreckenradargerät im Bereich 24GHz ausgerüstet : Nein

Astra Certificate of Conformity (#1)

RICARDO

Der Unterzeichner Holger Borger bestätigt hiermit, dass das Fahrzeug:

0.1. Fabrikmarke: **OPEL**

0.2. Typ: **B-K**

Variante: **CA062CB12**
Version: **BA1BALJUK15**

0.2.1. Handelsbezeichnung: **ASTRA**

0.4. Fahrzeugklasse: **M1**

0.5. Firmenname und Anschrift des Herstellers:
Opel Automobile GmbH
Bahnhofsplatz
65423 Rüsselsheim am Main
Deutschland

0.6. Anbringungsstelle und Anbringungsart der vorgeschriebenen Schilder:
an der linken B-Säule

Anbringungsstelle der Fahrzeug-Identifizierungsnummer:
im Fahrzeugboden vorn rechts

0.9. Name und Anschrift des Bevollmächtigten:
-

0.10. Fahrzeug-Identifizierungsnummer:
W0VBD6EFXKG323274

mit dem in der am **04.10.2018** erteilten Genehmigung **e4*2007/46*0996*15** beschriebenen Typ in jeder Hinsicht übereinstimmt und zur fortwährenden Teilnahme am Straßenverkehr in Mitgliedstaaten mit **Rechtsverkehr** in denen **metrische** Einheiten für das Geschwindigkeitsmessgerät verwendet werden, zugelassen werden kann.

Rüsselsheim — Ort
20.11.2018 — Datum

Borger — Unterschrift
Manager Vehicle Certification — Position

1. Anzahl der Achsen: **2**
und Räder: **4**

3. Antriebsachsen (Anzahl, Lage, gegenseitige Verbindung):
1; Achse 1

4. Radstand: **2662** mm

4.1. Achsabstände:
1 - 2: **2662** mm
2 - 3: - mm

5. Länge: **4370** mm

6. Breite: **1809** mm

7. Höhe: **1485** mm

13. Masse in fahrbereitem Zustand: **1364** kg

13.2 Tatsächliche Masse des Fahrzeugs: **1408** kg

16. Technisch zulässige Höchstmassen:
16.1. Technisch zulässige Gesamtmasse in beladenem Zustand: **1890** kg

16.2. Technisch zulässige maximale Masse je Achse:
1: **970** kg
2: **930** kg
3: - kg

16.4. Technisch zulässige Gesamtmasse der Fahrzeugkombination: **3290** kg

18. Technisch zulässige maximale Anhängemasse bei Beförderung eines
18.1. Deichselanhängers: - kg
18.3. Zentralachsanhängers: **1400** kg
18.4. ungebremsten Anhängers: **660** kg

19. Technisch zulässige Stützlast am Kupplungspunkt: **60** kg

20. Hersteller der Antriebsmaschine:
Opel

21. Baumusterbezeichnung gemäß Kennzeichnung am Motor:
LVL

22. Arbeitsverfahren:
Selbstzündung / 4-Takt

23. Reiner Elektroantrieb: **nein**
23.1. Hybrid-(Elektro-)Fahrzeug: **nein**

24. Anzahl und Anordnung der Zylinder: **4 ; in Reihe**

25. Hubraum: **1598** cm^3

26. Kraftstoff:
Diesel
26.1. **Einstoff**
26.2. (Nur Zweistoffmotoren) Typ: -

27. Höchstleistung
27.1. Höchste Nennleistung: **81,00** kW bei: **3500** min^{-1} (Verbrennungsmotor)
27.2. Höchste Stundenleistung: - kW (Elektromotor)
27.3. Höchste Nennleistung: - kW (Elektromotor)
27.4. Höchste 30-Minuten-Leistung: - kW (Elektromotor)

29. Höchstgeschwindigkeit: **200** km/h

30. Spurweite:
1: **1548** mm
2: **1565** mm
3: - mm

35. Reifen/Radkombination:
Rollwiderstand: **C1 B**
1: **225/45 R17 91V 7.5Jx17 ET44**
2: **225/45 R17 91V 7.5Jx17 ET44**
3: - -

36. Anhänger-Bremsanschlüsse:
-

38. Code des Aufbaus:
AB Schräghecklimousine

40. Farbe des Fahrzeugs:
grau

41. Anzahl und Anordnung der Türen:
5 ; 2 links, 2 rechts, 1 hinten

42. Anzahl der Sitzplätze (einschließlich Fahrersitz):
5

42.1. Sitz(e), der (die) nur zur Verwendung bei stehendem Fahrzeug bestimmt ist (sind):
-

42.3. Anzahl der für Rollstuhlfahrer zugänglichen Sitzplätze:
-

46. Geräuschpegel:
Standgeräusch: **73.00** dB(A)
bei der Drehzahl: **2625** min^{-1}
Fahrgeräusch: **66.00** dB(A)

47. Abgasnorm: **Euro 6 AG**

47.1 Parameter für die Emissionsprüfung
47.1.1 Prüfmasse: **1490** kg
47.1.2 Querschnittsfläche **0.685** m^2

47.1.3 Fahrwiderstandskoeffizienten
47.1.3.0. f0: **80.9** N
47.1.3.1. f1: **1.134** N/(km/h)
47.1.3.2. f2: **0.02895** $N/(km/h)^2$

48. Abgasverhalten: **715/2007*2017/1347AG**

1.2. Prüfverfahren: Typ 1 (NEFZ Mittelwerte, WLTP Spitzenwerte) [mg/km] oder WHSC (EURO VI) [mg/kWh]

	Benzin / Diesel	Gas	Andere (siehe 26.)	
CO	88,1	-	-	mg/km
THC	-	-	-	mg/km
NMHC	-	-	-	mg/km
NOx	20,9	-	-	mg/km
THC+NOx	31.3	-	-	mg/km
NH3	-	-	-	ppm
Partikelmasse	0,24	-	-	mg/km
Partikelzahl	0,05	-	-	10^{11}/km

2.2. Prüfverfahren: WHTC (EURO VI)

	Benzin / Diesel	Gas	Andere (siehe 26.)	
CO	-	-	-	mg/kWh
NOx	-	-	-	mg/kWh
NMHC	-	-	-	mg/kWh
THC	-	-	-	mg/kWh
CH4	-	-	-	mg/kWh
NH3	-	-	-	ppm
Partikelmasse	-	-	-	mg/kWh
Partikelzahl	-	-	-	10^{11}/kWh

48.1.

Rauch	0.5	m^{-1}

48.2 Angegebene höchste RDE-Werte

	NOx [mg/km]	Partikelzahl [10^{11}/km]
Vollständige RDE-Fahrt	168	6
Innerstädtische RDE-Fahrt	168	6

49. CO2-Emissionen/Kraftstoffverbrauch/Stromverbrauch:
1. Alle Antriebsarten außer reinen Elektrofahrzeugen

Benzin / Diesel NEFZ-Werte	CO2-Emissionen [g/km]	Kraftstoffverbrauch [l/100km]
Innerorts	148	5,6
Außerorts	101	3,8
Kombiniert	118	4,5
Gewichtet, kombiniert	-	-

Gas NEFZ-Werte	CO2-Emissionen [g/km]	Kraftstoffverbrauch [l/100km]	Kraftstoffverbrauch [m^3/100km]
Innerorts	-	-	-
Außerorts	-	-	-
Kombiniert	-	-	-

Abweichungsfaktor	-	-0,1 %
Differenzierungsfaktor	-	0

Astra Certificate of Conformity (#2)

Andere (siehe 26.) NEFZ-Werte	CO2-Emissionen [g/km]	Kraftstoffverbrauch [l/100km]	Kraftstoffverbrauch [m³/100km]
Innerorts	-	-	-
Außerorts	-	-	-
Kombiniert	-	-	-
Abweichungsfaktor	-	-	-
Differenzierungsfaktor	-	-	-

2. Reine Elektrofahrzeuge und extern aufladbare Hybridelektrofahrzeuge

Stromverbrauch (gewichtet, kombiniert):	-	Wh/km
Elektrische Reichweite:	-	km

3. Fahrzeug mit Ökoinnovation(en) ausgestattet: **nein**
3.1. Allgemeiner Code der Ökoinnovation(en): -
3.2. Gesamteinsparung von CO2-Emissionen durch Öko-Innovation(en):
3.2.1. Einsparungen durch NEFZ

Benzin / Diesel	-	g/km
Gas	-	g/km
Andere (siehe 26.)	-	g/km

3.2.2. Einsparungen durch WLTP

Benzin / Diesel	-	g/km
Gas	-	g/km
Andere (siehe 26.)	-	g/km

4. Alle Antriebsarten außer reinen Elektrofahrzeugen, gemäß Verordnung (EU) 2017/1151

Benzin / Diesel WLTP-Werte	CO2-Emissionen [g/km]	Kraftstoffverbrauch [l/100km]
Niedrig	**171**	**6.5**
Mittel	**130**	**5.0**
Hoch	**116**	**4.4**
Höchstwert	**135**	**5.1**
Kombiniert	**133**	**5.1**
Gewichtet, kombiniert	-	-

Gas WLTP-Werte	CO2-Emissionen [g/km]	Kraftstoffverbrauch [l/100km]	Kraftstoffverbrauch [m³/100km]
Niedrig	-	-	-
Mittel	-	-	-
Hoch	-	-	-
Höchstwert	-	-	-
Kombiniert	-	-	-
Gewichtet, kombiniert	-	-	-

Andere (siehe 26.) WLTP-Werte	CO2-Emissionen [g/km]	Kraftstoffverbrauch [l/100km]	Kraftstoffverbrauch [m³/100km]
Niedrig	-	-	-
Mittel	-	-	-
Hoch	-	-	-
Höchstwert	-	-	-
Kombiniert	-	-	-
Gewichtet, kombiniert	-	-	-

5. Vollelektrische Fahrzeuge und extern aufladbare Hybrid-Elektro-Fahrzeuge, gemäß Verordnung (EU) 2017/1151
5.1 Vollelektrische Fahrzeuge

Stromverbrauch	-	Wh/km
Elektrische Reichweite	-	km
Elektrische Reichweite innerorts	-	km

5.2 Extern aufladbare Hybrid-Elektro-Fahrzeuge

Stromverbrauch (ECAC, weighted)	-	Wh/km
Elektrische Reichweite (EAER)	-	km
Elektrische Reichweite innerorts (EAER city)	-	km

51. Bei Fahrzeugen mit besonderer Zweckbestimmung: Bezeichnung gemäß Anhang II Nummer 5:
-

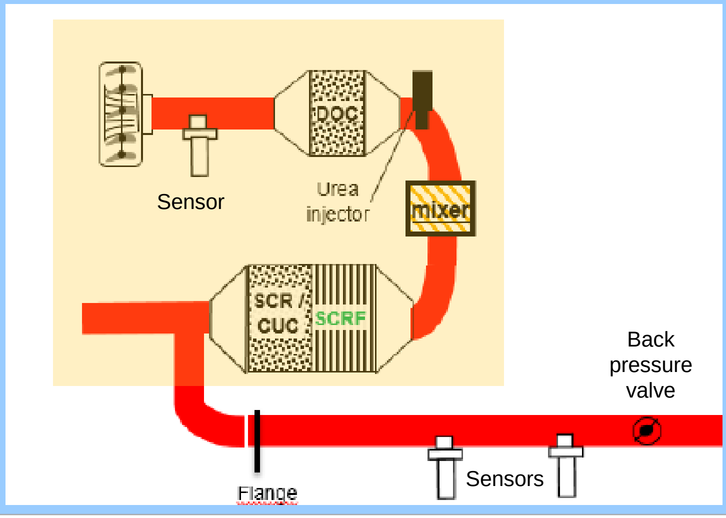
52. Zusätzliche Reifen-Felgenkombinationen: technische Parameter (keine Bezugnahme auf RR)
zu Nr. 5: ww. 4386;
zu Nr. 7: ww. 1437 - 1531;
zu Nr. 16.2: Achse 2 +40 bei Anh.betr.;
zu Nr. 35:
195/65 R15 91V auf 6.0JX15 ET37;
205/55 R16 91V auf 6.5JX16 ET41;
205/55 R16 91V auf 7.0JX16 ET41;
225/45 R17 91V auf 7.5JX17 ET44;
205/55 R16 94V XL auf 6.5JX16 ET41;
205/55 R16 94V XL auf 7.0JX16 ET41;
225/40 R18 92W XL auf 7.5JX18 ET44;
Die Verwendung der optionalen Reifen kann zu Abweichungen von den offiziellen Werten für Kraftstoffverbrauch und CO2-Ausstoß führen
zu Nr. 48: Fzg. mit Partikelfilter ausgerüstet;
Vermerke des Herstellers:
weitere Angaben siehe Bedienungsanleitung
Job- PA-Nummer 0026VXRF
Haendler Code DE0367
B/E
Motorkennzeichnung A3183099
Motorseriennummer JSXX0161
KFZ-Brief wurde erstellt

Emissions Control Systems on Euro 6 Diesel Vehicles

Emissions Control System	Detail
DOC	Diesel Oxidation Catalyst: oxidizes CO and HC to CO_2 and water, and NO to NO_2
DPF	Diesel Particulate Filter: wall-flow substrate that captures soot. Requires regeneration using oxygen at high temperatures. Passive partial regeneration, with NO_2 as oxidant, occurs at lower temperatures
Long route (low pressure) EGR	Cool exhaust gases returned to the intake air from downstream of the DPF
Short route (high pressure) EGR	Exhaust gases returned to the intake air from upstream of any aftertreatment
Ammonia SCR	Uses ammonia (usually from thermal decomposition of aqueous urea) to reduce NOx to nitrogen over a special catalyst
SCRF	As SCR, but the SCR catalyst is coated on to a DPF substrate
ASC (or clean-up catalyst)	Ammonia Slip Catalyst: used to eliminate unreacted ammonia that escapes SCR reactions
PNA	Passive NOx adsorber: stores NO at low temperatures and releases it at higher temperatures when downstream NOx aftertreatment is active

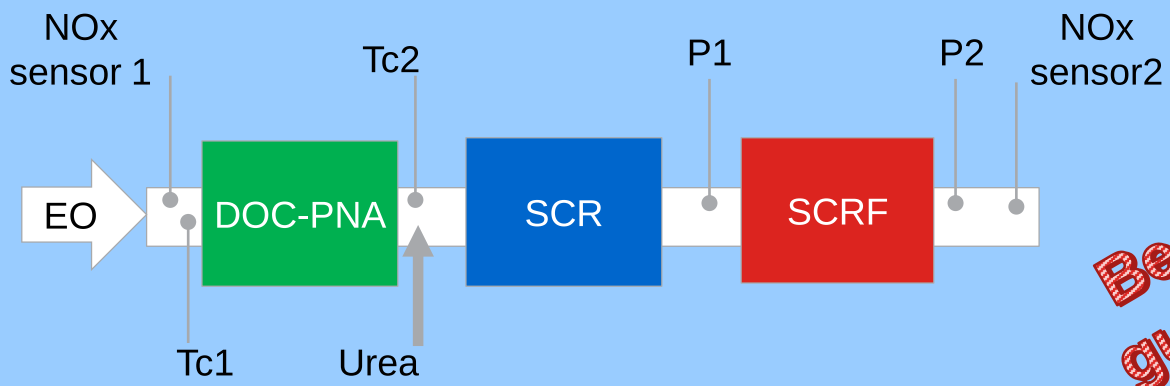
Test Vehicles’ Aftertreatment Systems

- **Qashqai**
  - **C class**
  - **NOx control via dual (high pressure and low pressure) EGR, urea SCRF-SCR and ASC**



Reference: The New Renault 200HP 2.0 litre Diesel; C. Bergeris; SIA Powertrain Rouen, May 16th 2018

- **Astra**
  - **C class**
  - **NOx control via HP-EGR, PNA, urea SCR-SCRF**
  - **Likely absence of ASC**



Best guess

Technical Approach – Sub-sections

- Test vehicle
- **Road-load data**
- Fuel Analysis
- Lab-based instrumentation and on-vehicle equipment
- Drive cycle and testing
- Test nomenclature

Road-load data and test mass

- Vehicle test masses and road-load data were derived from the certificates of conformity

	Qashqai	Astra
Test mass (kg)	1574.1	1490
F0 (N)	117.35	80.9
F1 (N/(km/h)	0.7386	1.134
F2 $(N/(km/h)^2$	0.03482	0.02895

Highway terms essentially reproduce the road loads that would have been derived from track-based coast-downs, while dyno terms drawn from the CoCs are the values input to the dynamometer to replicate those highway terms

ASTRA

Coastdown Terms	Inertia (kg)	A (N)	B (N/(km/h))	C (N/(km/h)2)
Dyno	1490	0.76	0.3629	0.03032
Highway	1490	80.90	1.1340	0.02895

Qashqai

Coastdown Terms	Inertia (kg)	A (N)	B (N/(km/h))	C (N/(km/h)2)
Dyno	1574	1.30	0.0780	0.03652
Highway	1574	117.35	0.7386	0.03482

Technical Approach – Sub-sections

- Test vehicle
- Road-load data
- **Fuel Analysis**
- Lab-based instrumentation and on-vehicle equipment
- Drive cycle and testing
- Test Protocol and Sequence
- Test nomenclature

Fuel Analysis – Physical Properties, EN590

- A batch of 200 litres of fuel was set aside for T&E testing, this was drawn from the latest bulk delivery of EN590 diesel regularly brought to STC
  - These deliveries are warranted to be EN590 compliant, but since tankers deliver from different batches and these may become blended, an precise analysis of fuel properties is not available from the supplier
  - A sample of the fuel was sent to Haltermann-Carless for analysis. With the results presented on the right
  - C, H, O mass fractions, density and nett calorific value are used in emissions and fuel consumption calculations
- Fuel was barrelled, sealed and stored in the fuel farm on-site at Ricardo STC

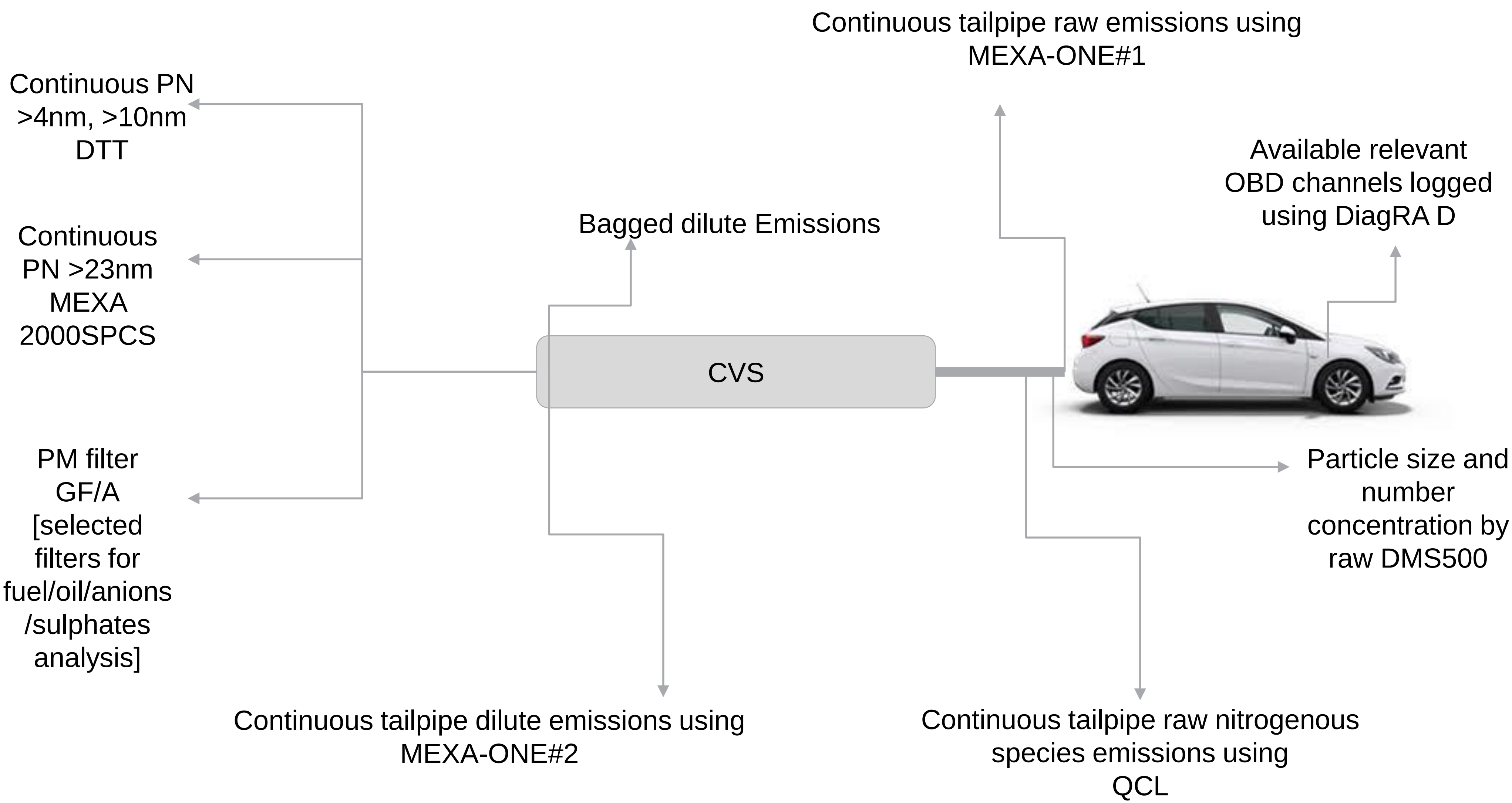
Analysis of EN590 batch used for the test programme

Test		Method	001-00
Cetane Number		EN ISO 5165	54.9
Density at 15 oC	kg/m3	EN ISO 12185	830.0
Sulphur Content	mg/kg	EN ISO 20846	10.0
F.A.M.E.	% (v/v)	BS EN 14078	4.4
Range		BS EN 14078	B
Total Carbon	% (m/m)	ASTM D5291	85.66
Total Hydrogen	% (m/m)	ASTM D5291	13.07
Gross Calorific Value	MJ/kg	IP 12	45.58
Nett Calorific Value	MJ/kg	Calculated from IP 12	42.82
I.B.P	°C	ISO 3405	165.8
5% v rec. at	°C	ISO 3405	185.6
10% v rec. at	°C	ISO 3405	194.5
20% v rec. at	°C	ISO 3405	214.6
30% v rec. at	°C	ISO 3405	234.7
40% v rec. at	°C	ISO 3405	253.6
50% v rec. at	°C	ISO 3405	270.8
60% v rec. at	°C	ISO 3405	285.8
70% v rec. at	°C	ISO 3405	299.9
80% v rec. at	°C	ISO 3405	315.8
90% v rec. at	°C	ISO 3405	334.8
95% v rec. at	°C	ISO 3405	349.1
F.B.P	°C	ISO 3405	358.9
% v rec. at 180 oC	% (v/v)	ISO 3405	2.6
% v rec. at 250 oC	% (v/v)	ISO 3405	37.9
% v rec. at 350 oC	% (v/v)	ISO 3405	95.2
Recovery	% (v/v)	ISO 3405	98.3
Residue	% (v/v)	ISO 3405	1.2
Loss	% (v/v)	ISO 3405	0.5
Oxygen	% (wt/wt)	MT/ELE/21	0.42

Technical Approach – Sub-sections

- Test vehicle
- Road-load data
- Fuel Analysis
- **Lab-based instrumentation and on-vehicle equipment**
- Drive cycle and testing
- Test nomenclature

Measurement instrumentation: sampling schematic



Details of measurement equipment employed can be found in Appendix 1

DiagRA D Logged Channels Nissan Qashqai

	Property	Unit
PID 0C E8	Engine RPM	1/min
PID 0C EE	Engine RPM	1/min
PID 0D E8	Vehicle speed sensor	km/h
PID 0D EE	Vehicle speed sensor	km/h
PID 10 E8	Air flow rate from mass air flow sensor	g/s
PID 11 E8	Absolute throttle position	%
PID 3C E8	Catalyst temperature Bank 1 Sensor 1	°C
PID 43 E8	Absolute load value	%
PID 49 E8	Accelerator pedal position D	%
PID 4A E8	Accelerator pedal position E	%
PID 67 E8	Engine Coolant Temperature 1	°C
PID 67 E8	Engine Coolant Temperature 2	°C
PID 69 E8	Commanded EGR A Duty Cycle/Position	%
PID 69 E8	Actual EGR A Duty Cycle/Position	%
PID 69 E8	EGR A Error	%
PID 69 E8	Commanded EGR B Duty Cycle/Position	%
PID 69 E8	Actual EGR B Duty Cycle/Position	%
PID 69 E8	EGR B Error	%
PID 78 E8	Exhaust Gas Temperature Bank 1 Sensor 1	°C
PID 78 E8	Exhaust Gas Temperature Bank 1 Sensor 2	°C

	Property	Unit
PID 78 E8	Exhaust Gas Temperature Bank 1 Sensor 3	°C
PID 78 E8	Exhaust Gas Temperature Bank 1 Sensor 4	°C
PID 7A E8	Particulate Filter Bank 1 Delta Pressure	kPa
PID 85 E8	Average Reagent Consumption	L/h
PID 85 E8	Average Demanded Reagent Consumption	L/h
PID 85 E8	Reagent Tank Level	%
PID 88 E8	SCR inducement system actual state	Bit
PID 88 E8	SCR inducement system state 10K/20K history	Bit
PID 88 E8	SCR inducement system state 30K/40K history	Bit
PID 88 E8	Distance travelled while inducement system active in current 10K block	km
PID 88 E8	Distance travelled in current 10K block	km
PID 88 E8	Distance travelled while inducement system active in 20K block	km
PID 88 E8	Distance travelled while inducement system active in 30K block	km
PID 88 E8	Distance travelled while inducement system active in 40K block	km
PID 8B E8	Aftertreatment Status	Bit
PID 8C E8	O2 Sensor Concentration Bank 1 Sensor 1	%
PID 8C E8	O2 Sensor Lambda Bank 1 Sensor 1	
PID 9D E8	Engine fuel rate	g/s
PID 9D E8	Vehicle fuel rate	g/s
PID 9E E8	Engine Exhaust Flow Rate	kg/h

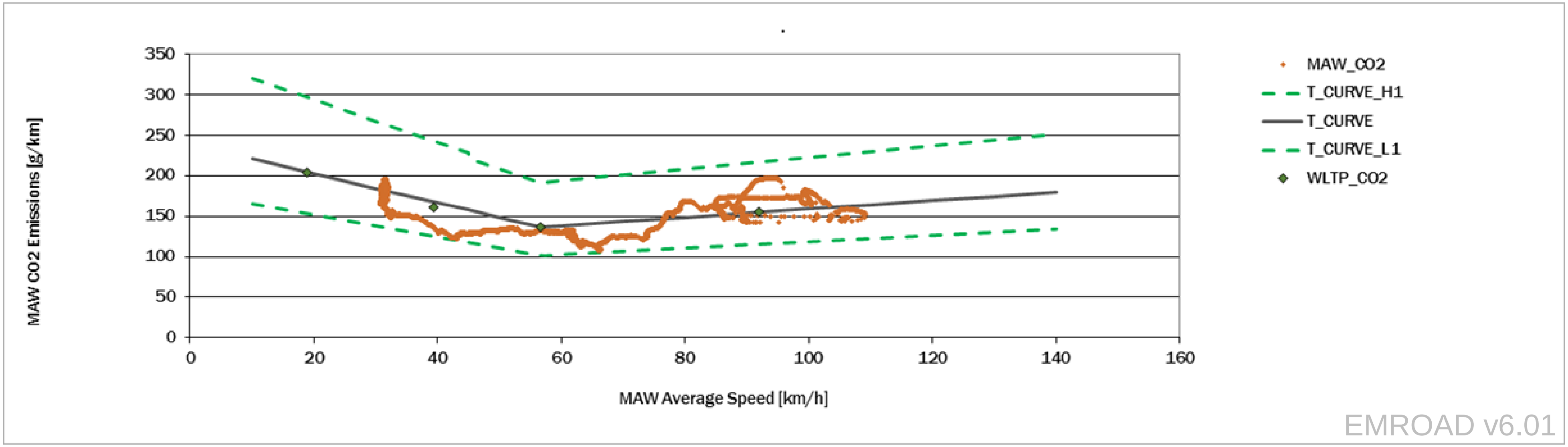
DiagRA D Logged Channels Opel Astra

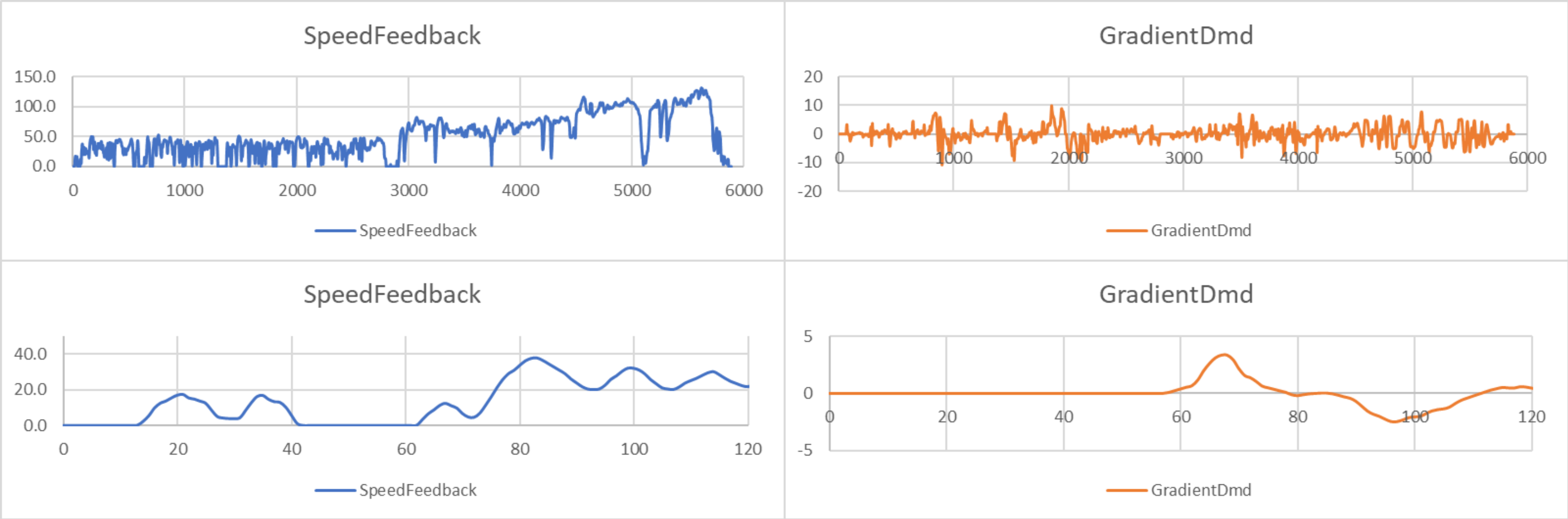
	Property	Unit
PID 04 E8	Calculated load value	%
PID 05 E8	Engine coolant temperature	°C
PID 0C E8	Engine RPM	1/min
PID 0D E8	Vehicle speed sensor	km/h
PID 10 E8	Air flow rate from mass air flow sensor	g/s
PID 49 E8	Accelerator pedal position D	%
PID 62 E8	Actual engine - percent torque	%
PID 6A E8	Commanded Intake Air Flow A Control	%
PID 6A E8	Relative Intake Air Flow A Position	%
PID 88 E8	SCR inducement system actual state	Bit
PID 88 E8	SCR inducement system state 10K/20K history	Bit
PID 88 E8	SCR inducement system state 30K/40K history	Bit
PID 88 E8	Distance travelled while inducement system active in current 10K block	km
PID 88 E8	Distance travelled in current 10K block	km
PID 88 E8	Distance travelled while inducement system active in 20K block	km
PID 88 E8	Distance travelled while inducement system active in 30K block	km
PID 88 E8	Distance travelled while inducement system active in 40K block	km
PID 8B E8	Aftertreatment Status	Bit
PID 8B E8	Normalized Trigger for DPF Regen	%
PID 8B E8	Average Time Between DPF Regens	min
PID 8B E8	Average Distance Between DPF Regens	km
PID 9D E8	Engine fuel rate	g/s
PID 9D E8	Vehicle fuel rate	g/s

Technical Approach – Sub-sections

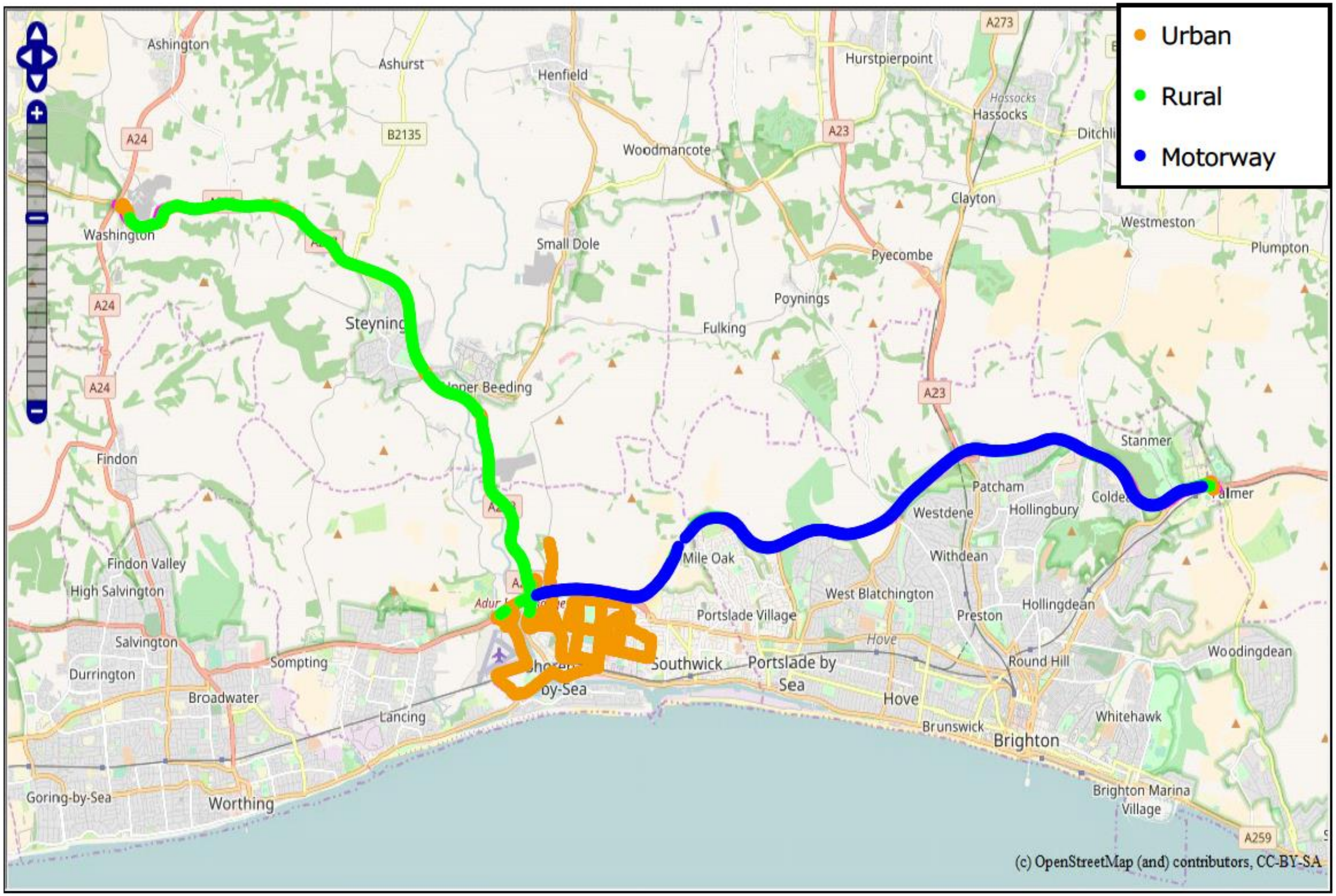
- Test vehicle
- Road-load data
- Fuel Analysis
- Lab-based instrumentation and on-vehicle equipment
- **Drive cycle and testing**
- Test nomenclature

An on-dyno RDE cycle, from a valid drive on a D-Class diesel, was employed for all tests on both vehicles

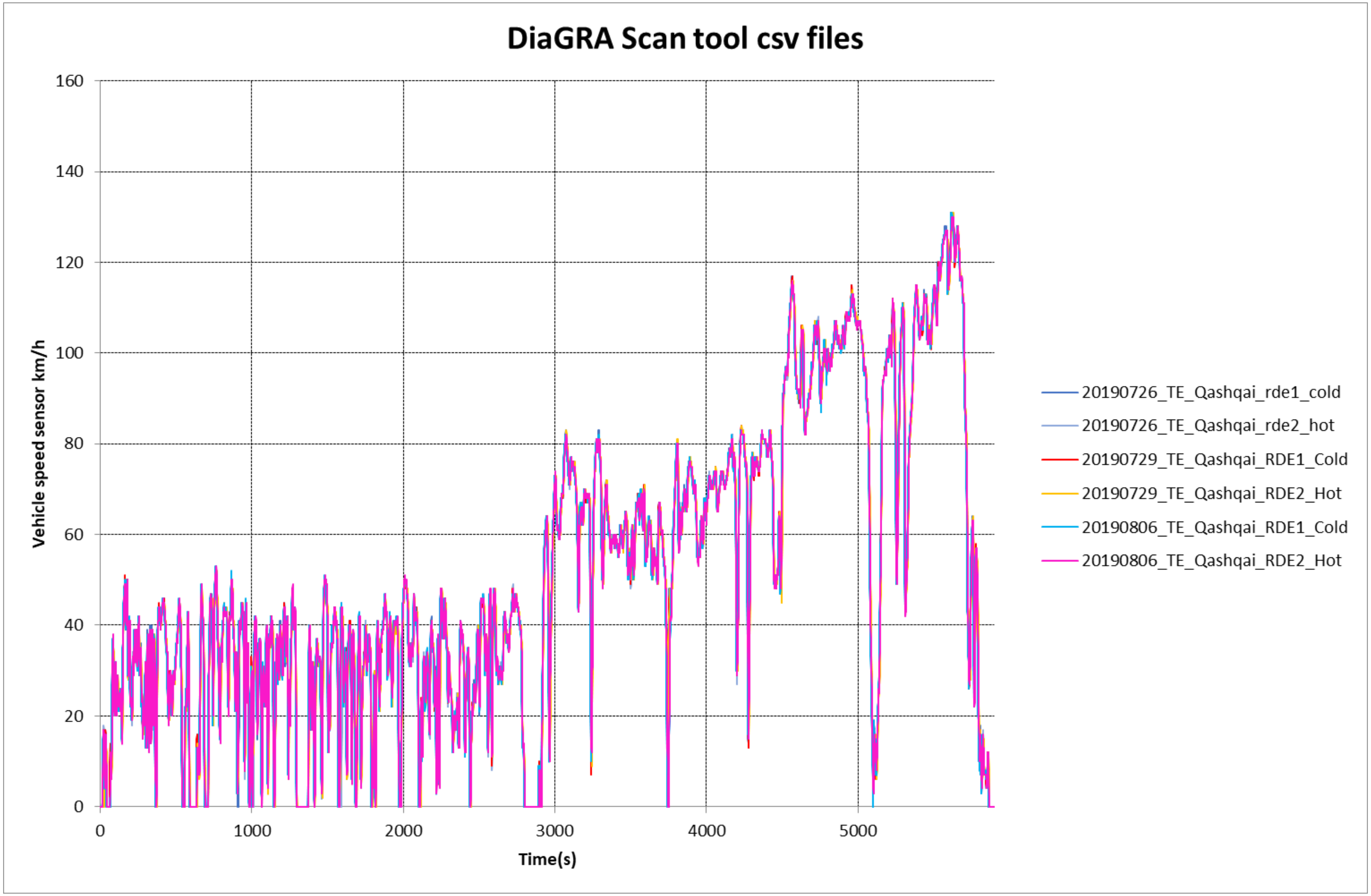




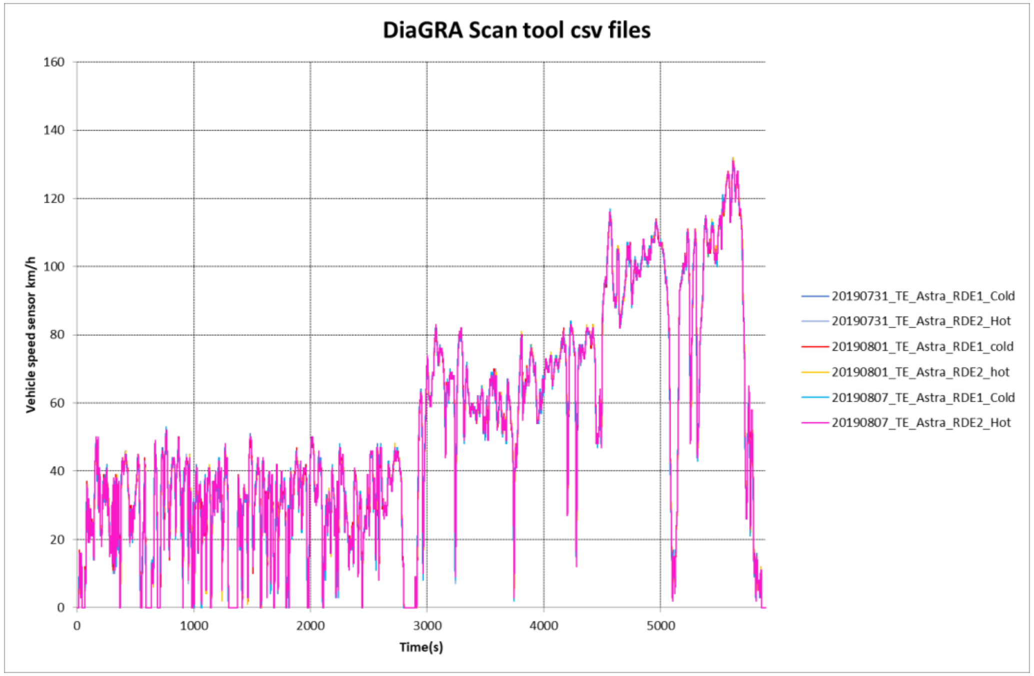
RDE Cycle was driven on the roads and hills around Shoreham-by-Sea, UK



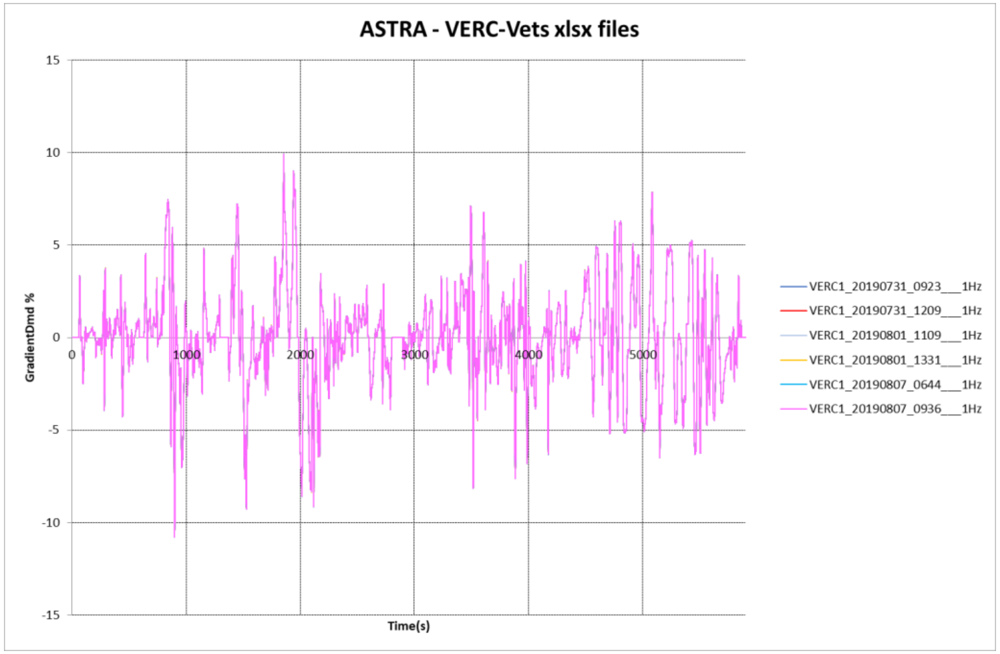
Repeatability of Road Speed (Qashqai), from OBD



Repeatability of Road Speed (Astra), from OBD, and facility gradient

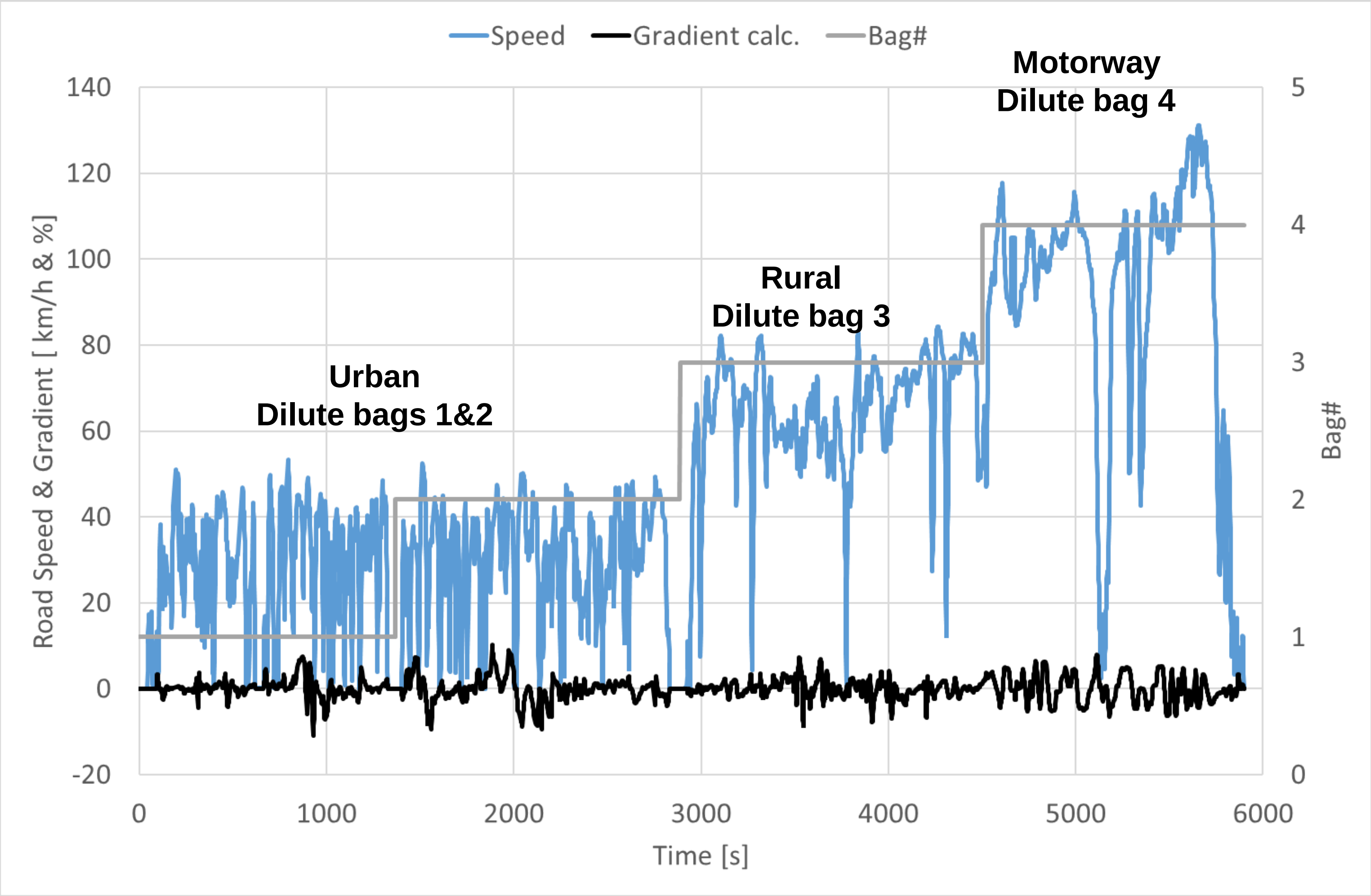


Highly repeatable road speed and gradient data ensures comparability between tests



Final

Compliant RDE on-dyno with gradient



- For regulated gaseous emissions, the on-dyno RDE was split into 4 dilute bags
  - Two urban bags, one rural bag and one dilute bag

Tests completed

- Six on-dyno RDE tests were completed on each vehicle. These were tested in pairs, with the first test a 23°C “cold start” and the second a hot start later the same day.
- Test dates and times are summarised below:

Qashqai	Date	Time (SoT)
Cold#1	20190726	08:39
Hot#1	20190726	11:12
Cold#2	20190729	11:49
Hot#2	20190729	14:36
Cold#3	20190806	08:55
Hot#3	20190806	11:59

Astra	Date	Time (SoT)
Cold#1	20190731	09:23
Hot#1	20190731	12:09
Cold#2	20190801	11:09
Hot#2	20190801	13:31
Cold#3	20190807	06:44
Hot#3	20190807	09:36

Regenerations observed

- A regeneration was observed in the first cold-start RDE test conducted on each vehicle
- On the Nissan Qashqai the regeneration completed, but on the Opel Astra, the regeneration was incomplete at end of the test
- Emissions of the first hot start RDE on the Astra were impacted by the incomplete regeneration – some further regeneration activity was observed at the start of the cycle. This was not the case with the Qashqai
- Further tests were run on the two vehicles and in the sixth RDE (hot start), on each vehicle, another regeneration was observed. In both cases these ran to completion before the RDE ended

Technical Approach – Sub-sections

- Test vehicle
- Road-load data
- Fuel Analysis
- Lab-based instrumentation and on-vehicle equipment
- Drive cycle and testing
- **Test nomenclature**

Nomenclature

- Test data from the facility can be traced to the specific test by date and time (for example, test facility data including continuous emissions, road speed etc at 10Hz from the first Astra test is found in this file: "***VERC1 20190731 0923 - 10Hz.xlsx***"
- For graphical emissions comparisons, a simpler format has been adopted:
  - ***Astra/Qashqai tests are prefixed with A or Q***
  - ***then numbered sequentially 1-6***
  - ***(each numerical test is also allocated a colour, vehicle independent)***
  - ***then indicated as cold "c" or hot "h"***
  - ***a regeneration appends R, continuation of regeneration as "R"***
- So, the whole sequence of Astra tests becomes
  - **A1cR, A2h"R", A3c, A4h, A5c, A6hR**
- and the Qashqai sequence is
  - **Q1cR, Q2h, Q3c, Q4h, Q5c, Q6hR**

Contents

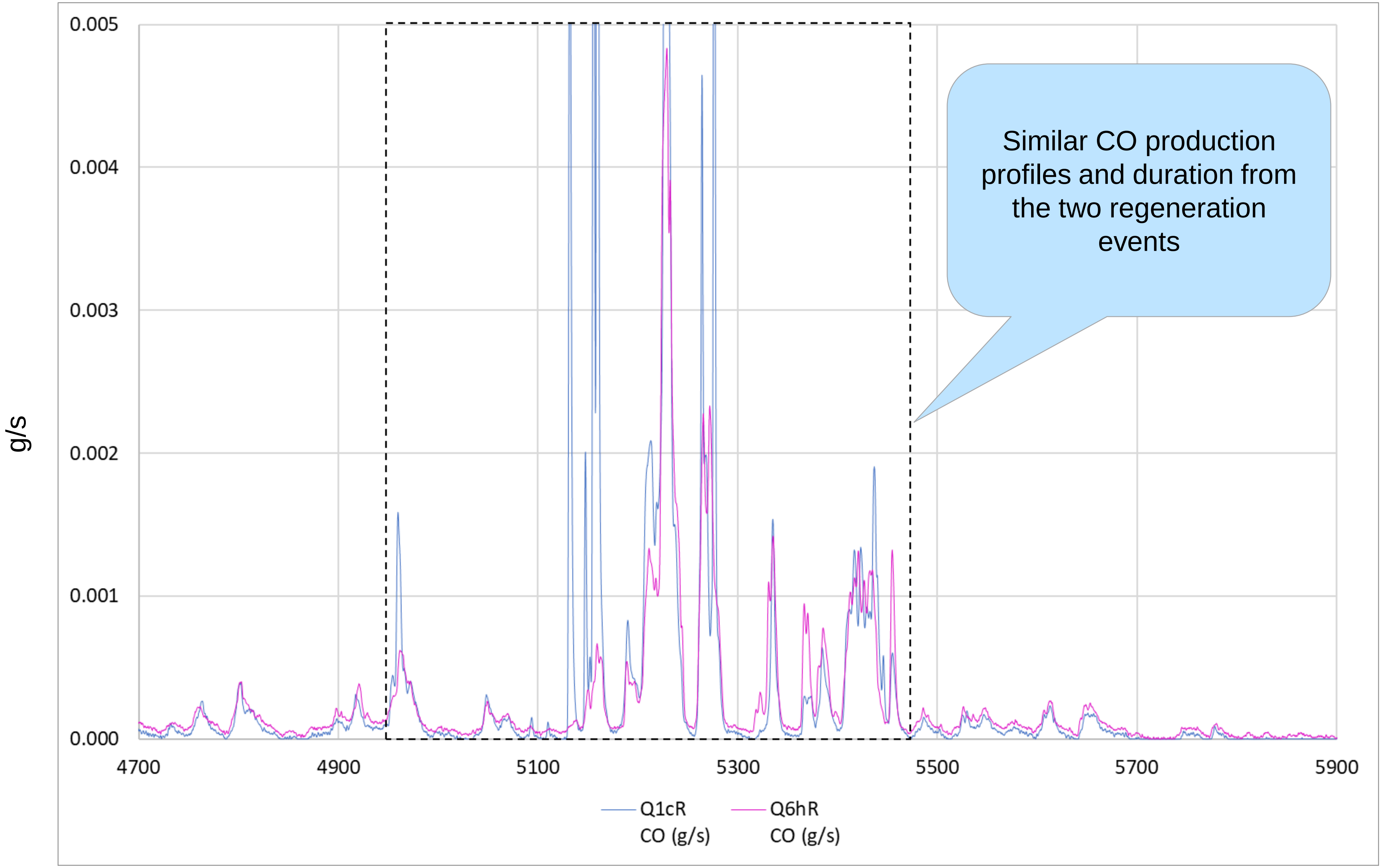
Emissions Results Sub-sections

- Regeneration occurrences and identification
- Regeneration duration, regeneration periodicity/cycle
- Bagged Emissions Results
- Additional gaseous and particle emissions
- Quantifying regeneration impact

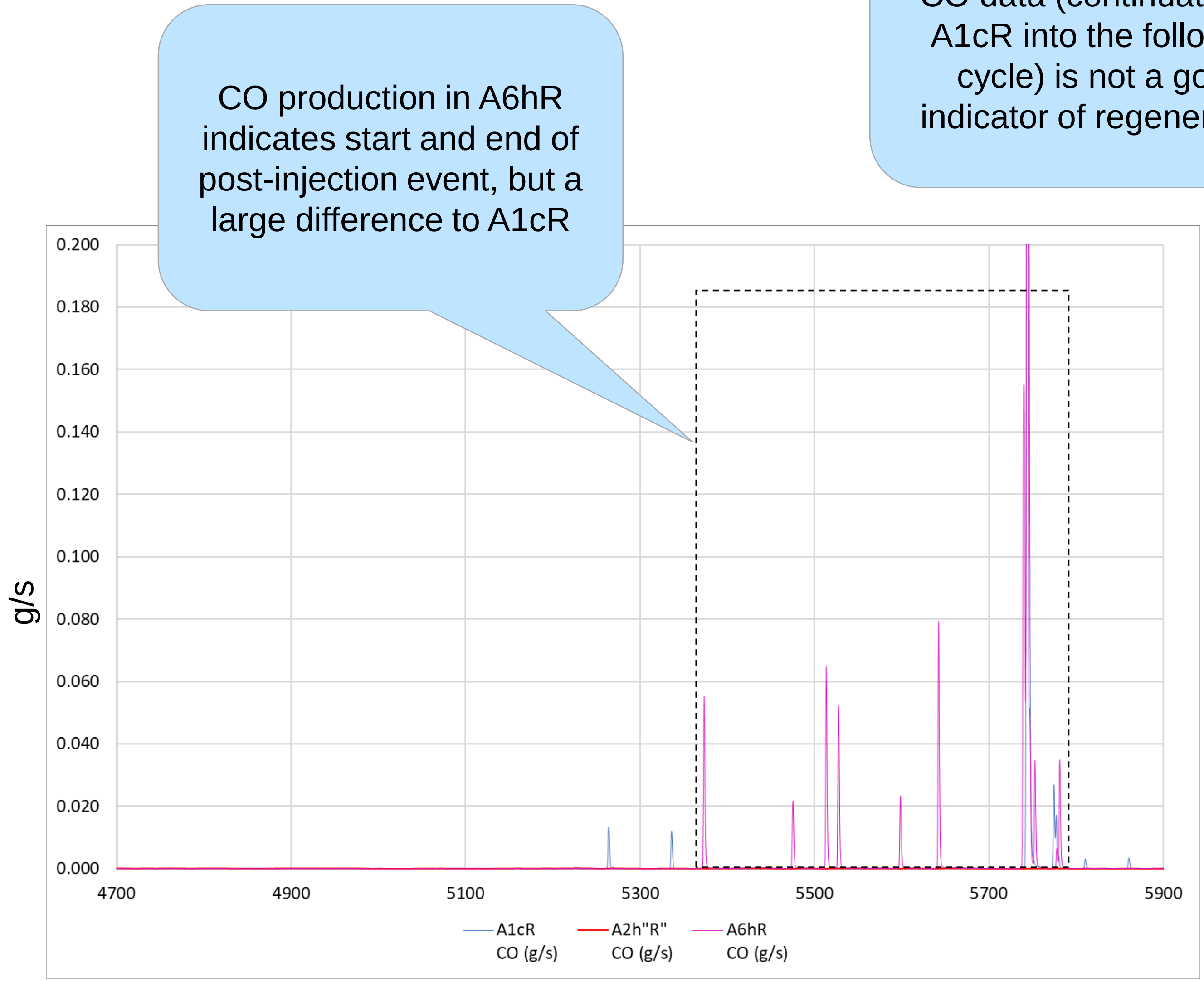
DPF regeneration detection

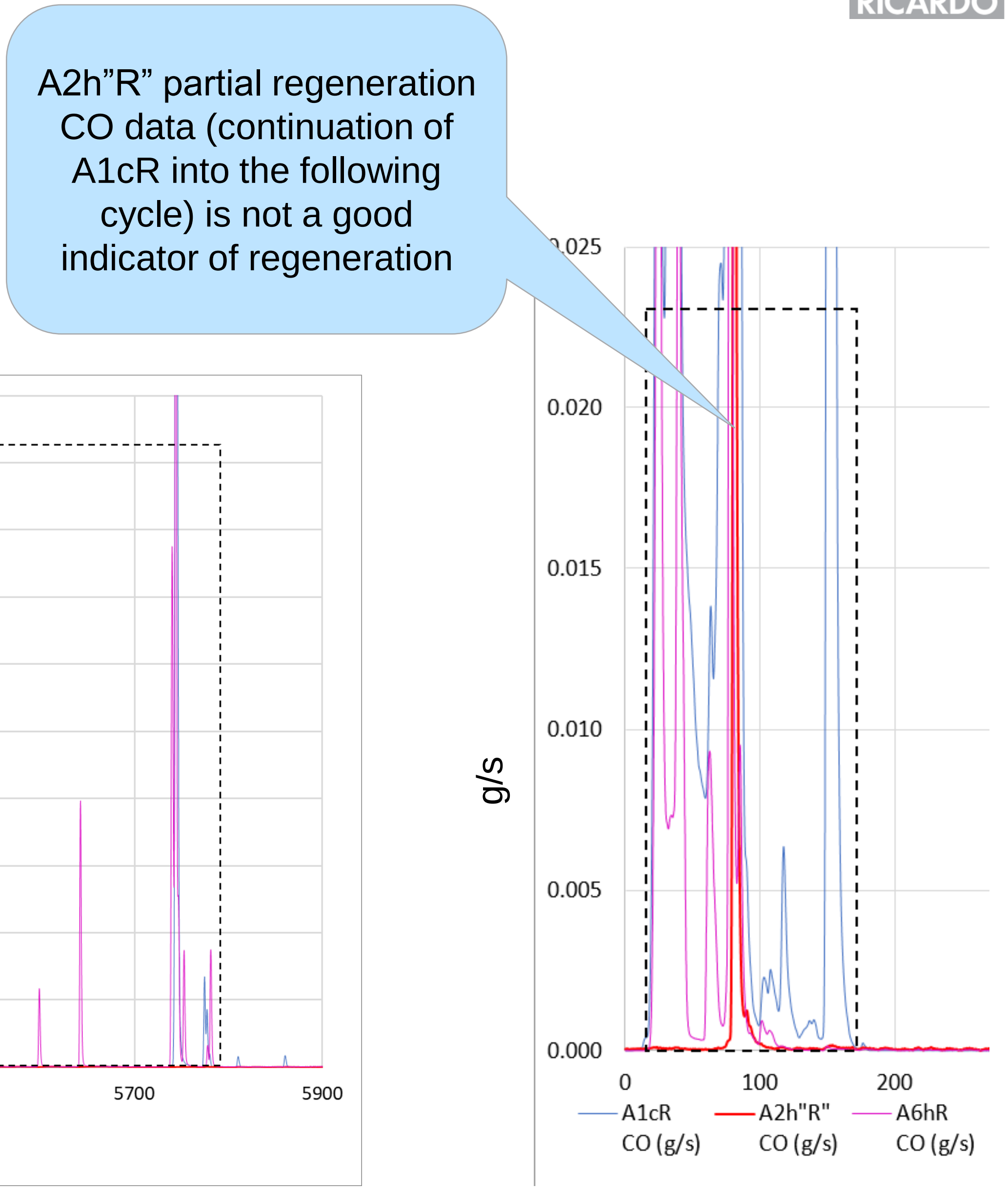
- All DPF regenerations commenced in the **motorway** section of the RDE
- DPF regenerations proved best observable in the following ways:
  - Through emissions events, using CO, HC and PN
    - [Astra and Qashqai]
  - Through thermal profiles, using OBD channels
    - [Qashqai]
  - Through thermal profiles, using a surface thermocouple
    - [Astra]
  - Through a binary regeneration indicator in the OBD data
    - [Qashqai]
- Examples of these are shown in the following slides

Regeneration Event Indicated by CO, Qashqai

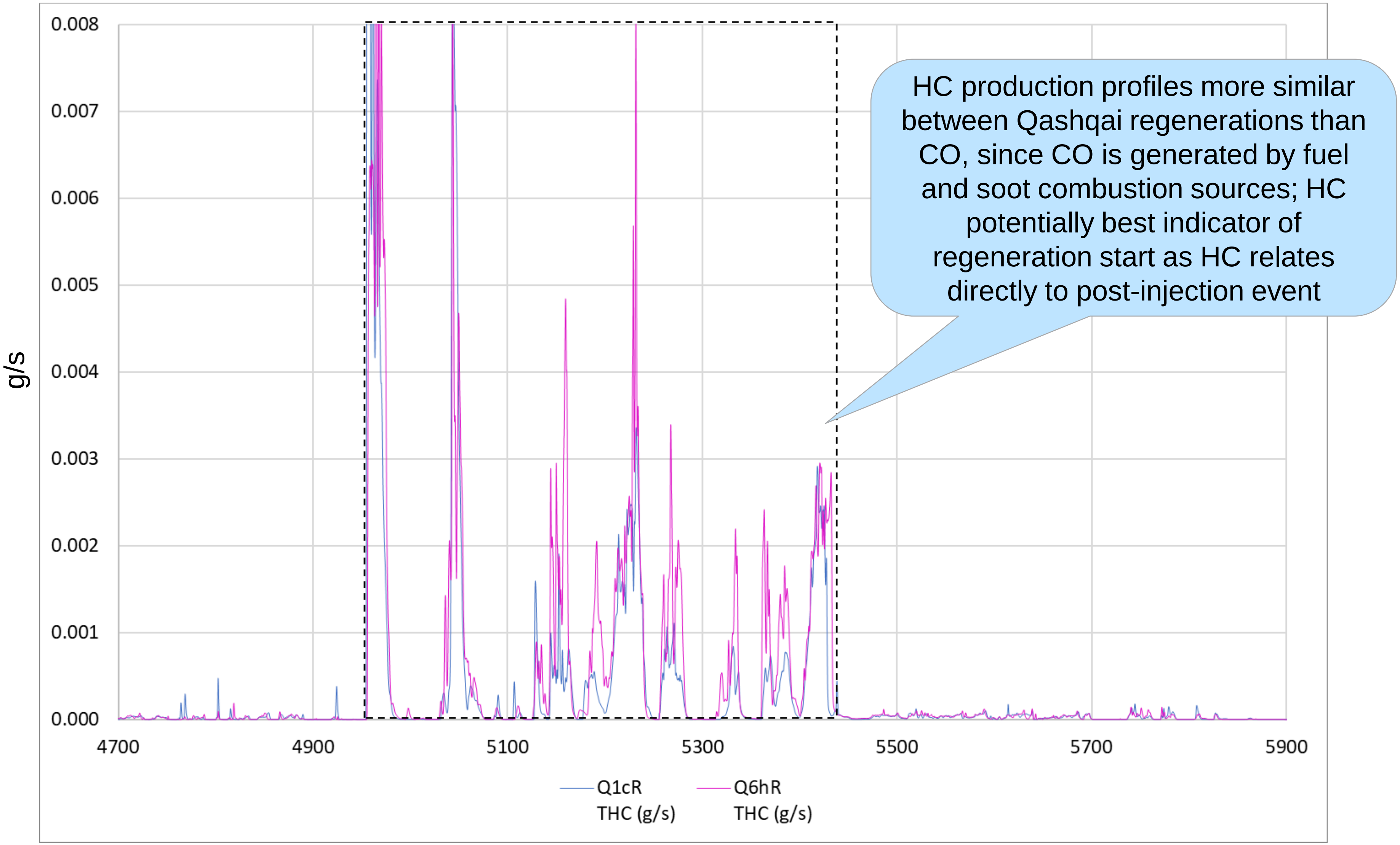


Regeneration Events Indicated by CO, Astra





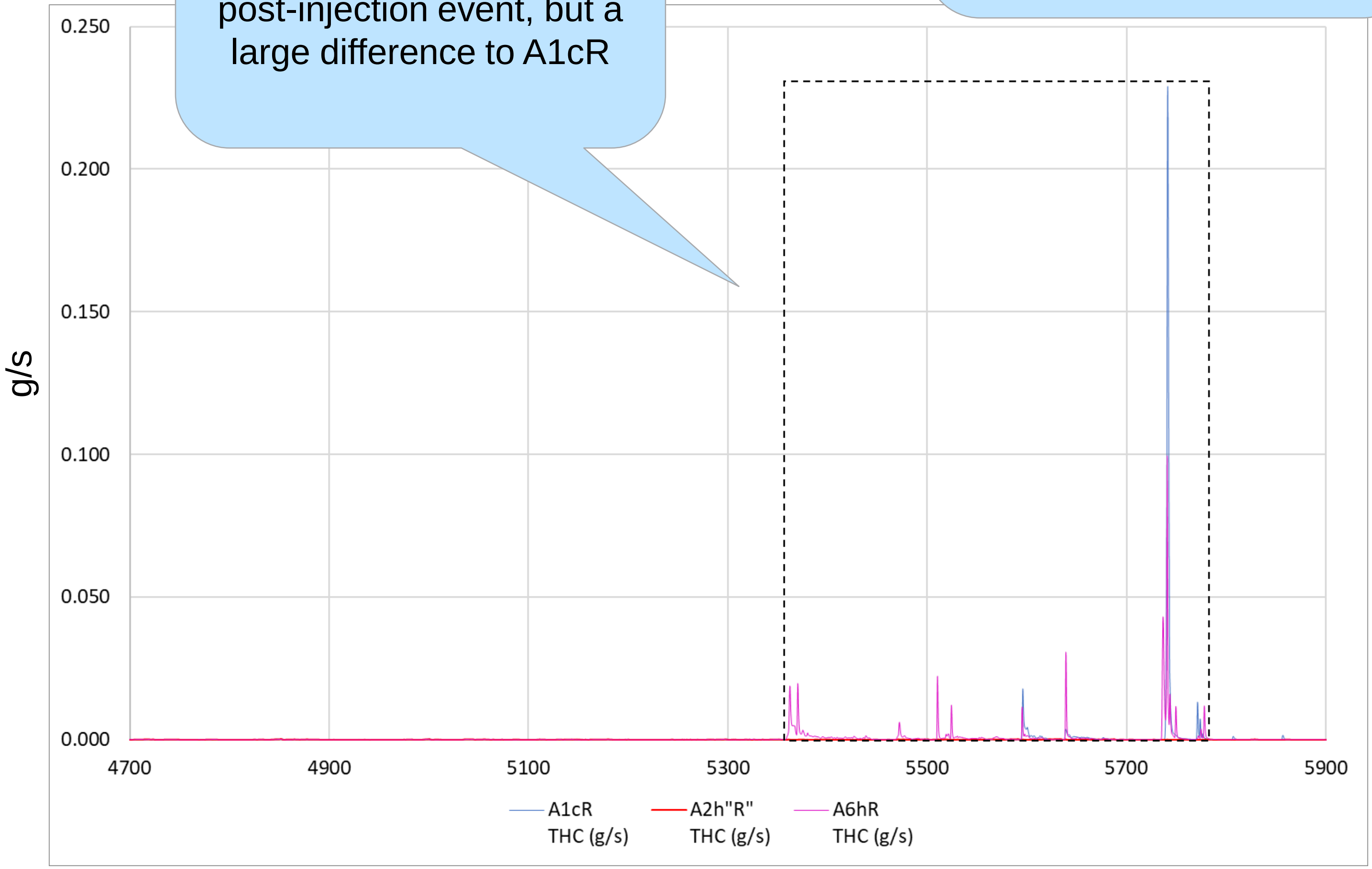
Regeneration Events Indicated by HC, Qashqai

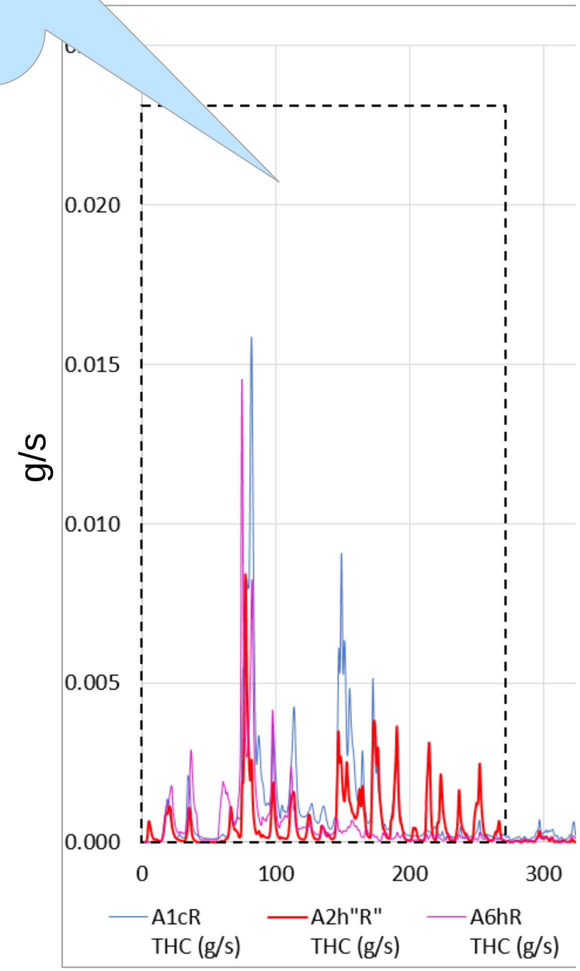


Regeneration Event Indicated by HC, Astra

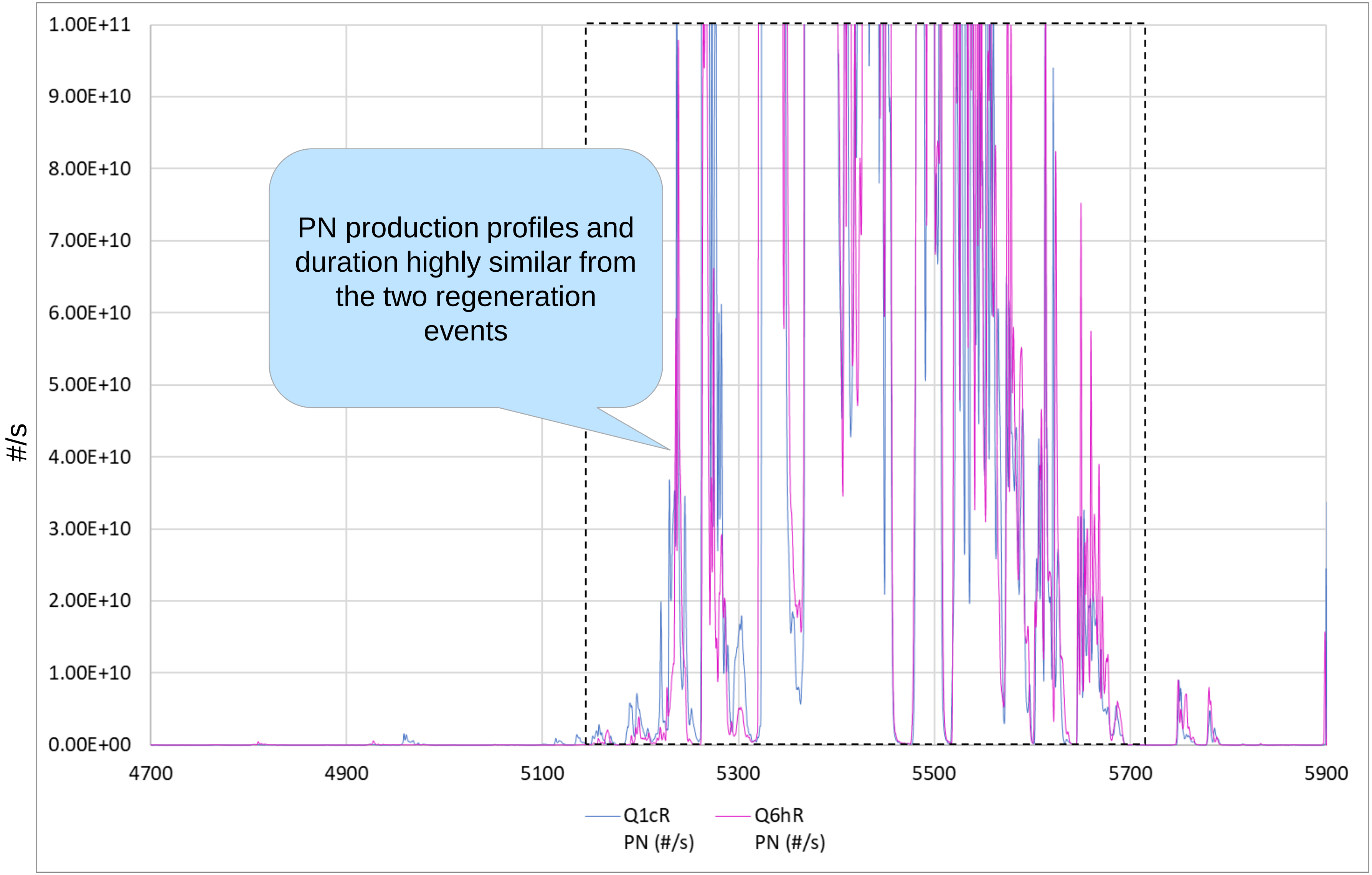
HC production in A6hR indicates start and end of post-injection event, but a large difference to A1cR

A2h"R" partial regeneration HC data (continuation of A1cR into the following cycle) appears to be a much better indicator of regeneration than CO





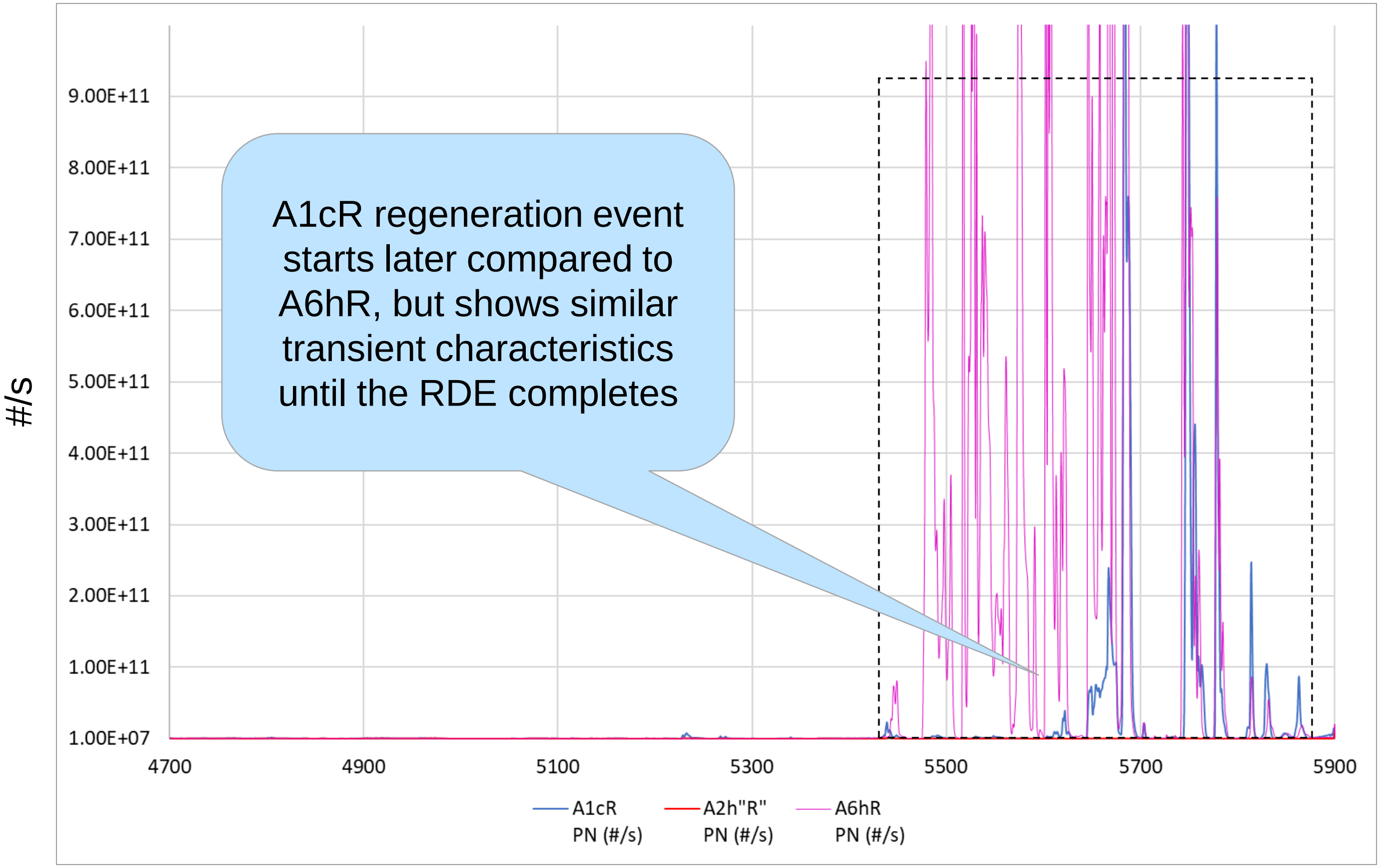
Regeneration Events Indicated by PN, Qashqai

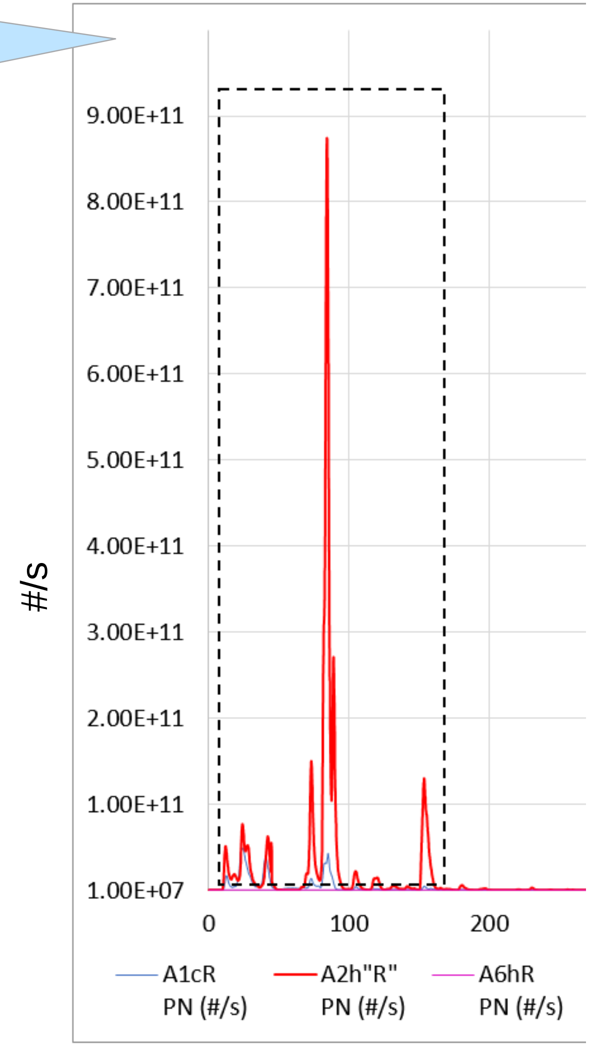


Regeneration Events Indicated by PN, Astra

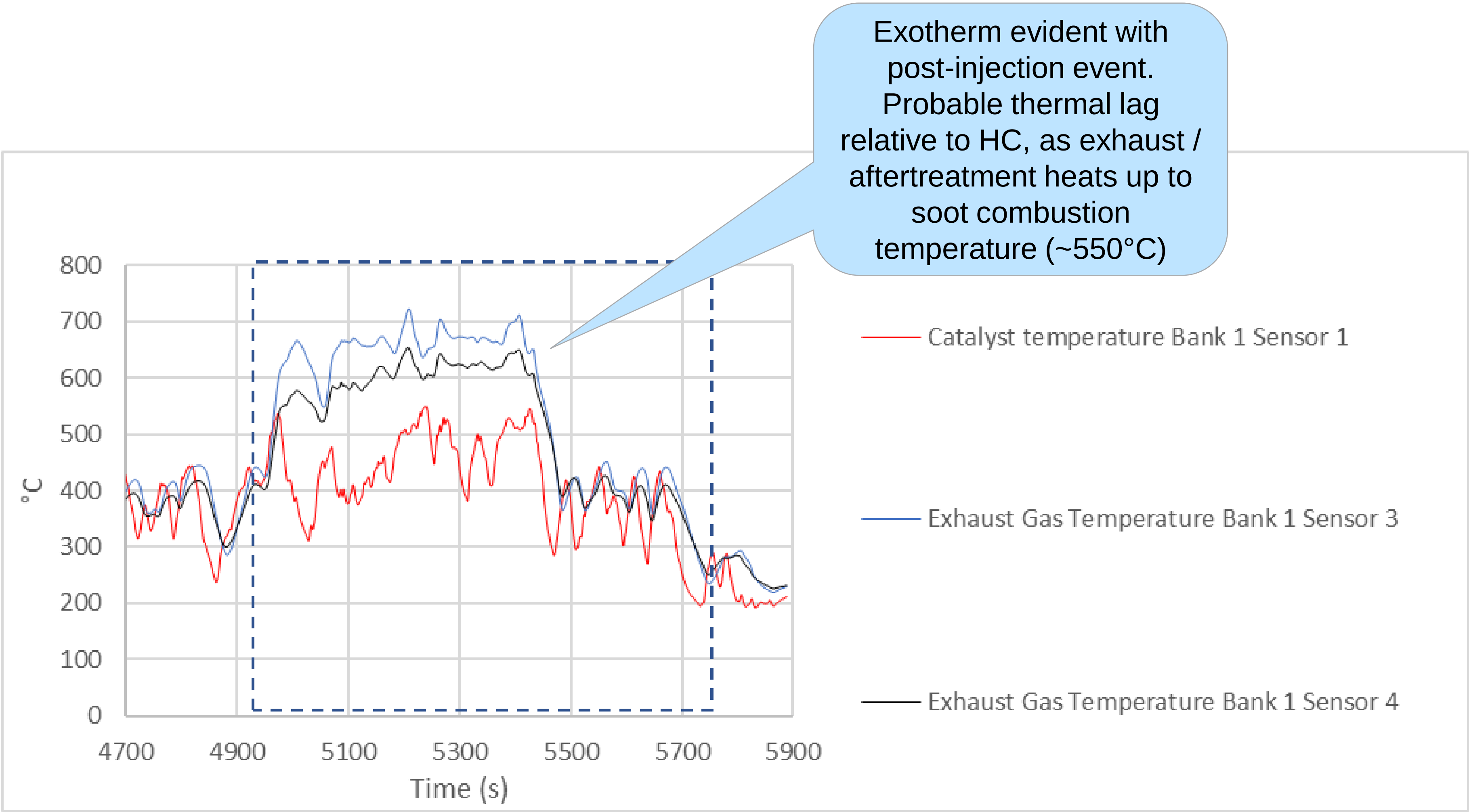
A2h"R" partial regeneration PN data indicates high PN for duration of regeneration event at the start of the test, with emissions levels higher than cold start

A1cR regeneration event starts later compared to A6hR, but shows similar transient characteristics until the RDE completes

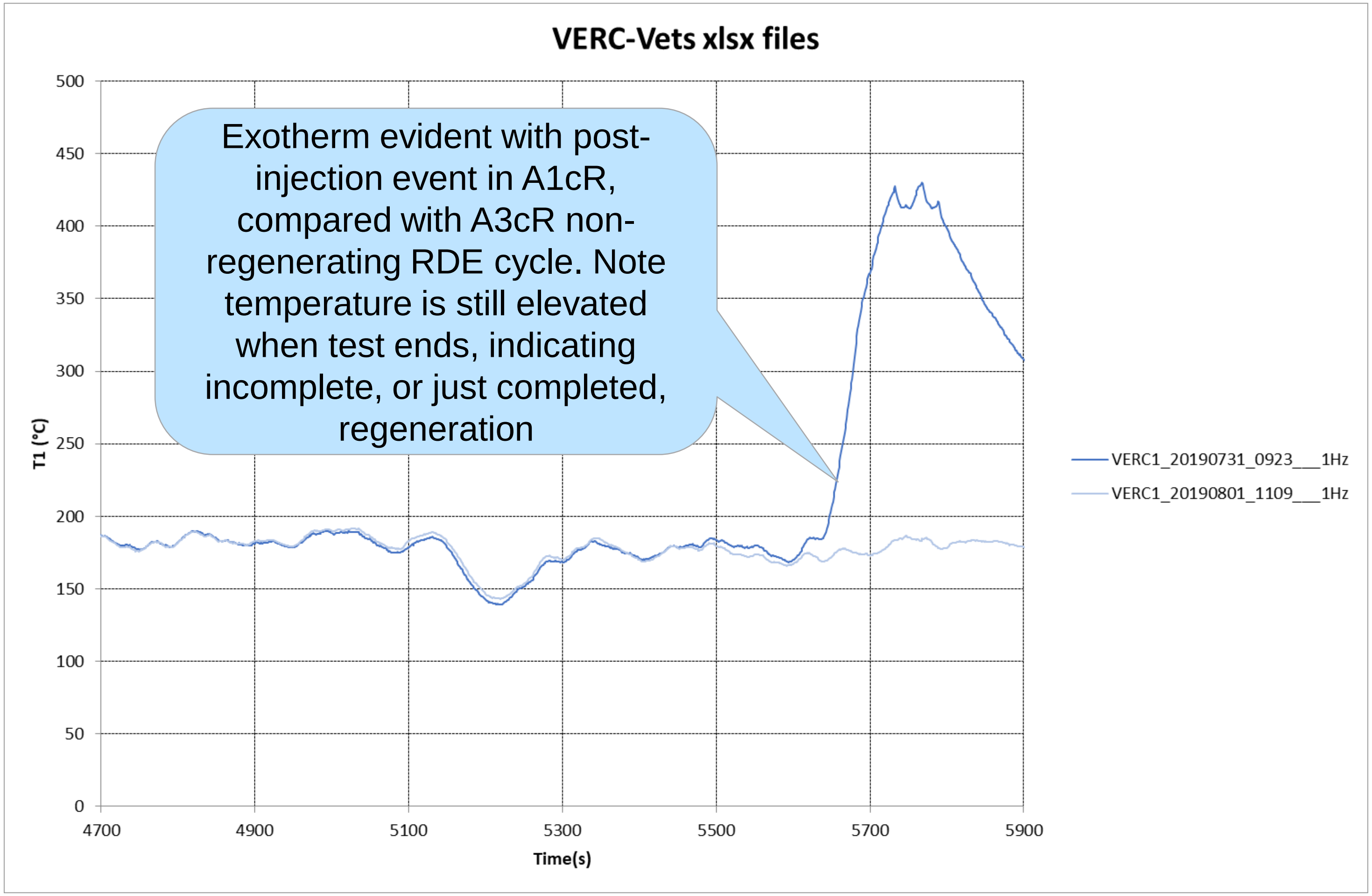




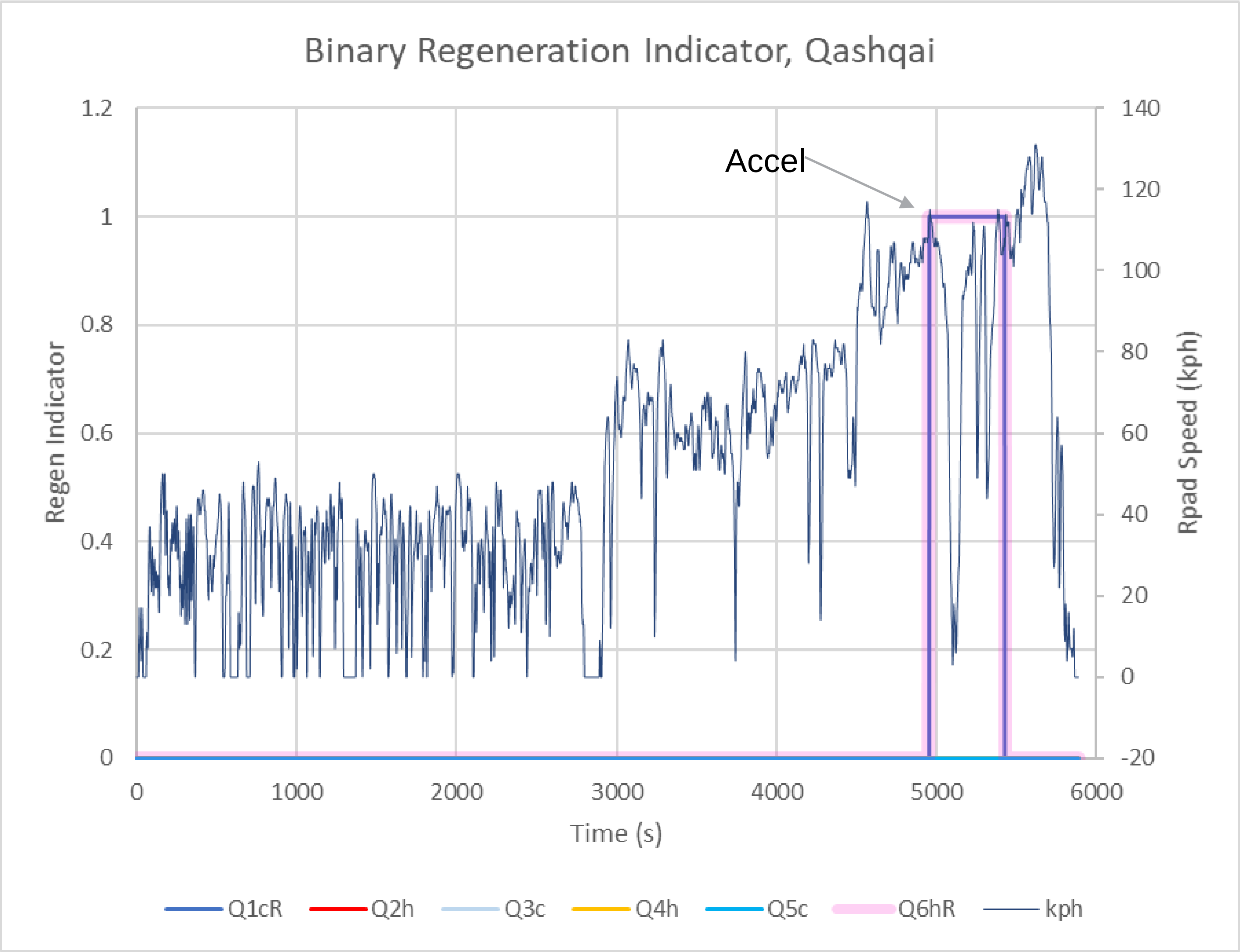
Regeneration event indicated by OBD thermal profiles, Qashqai



Surface thermocouple data, Astra



Binary regeneration indicator - Qashqai

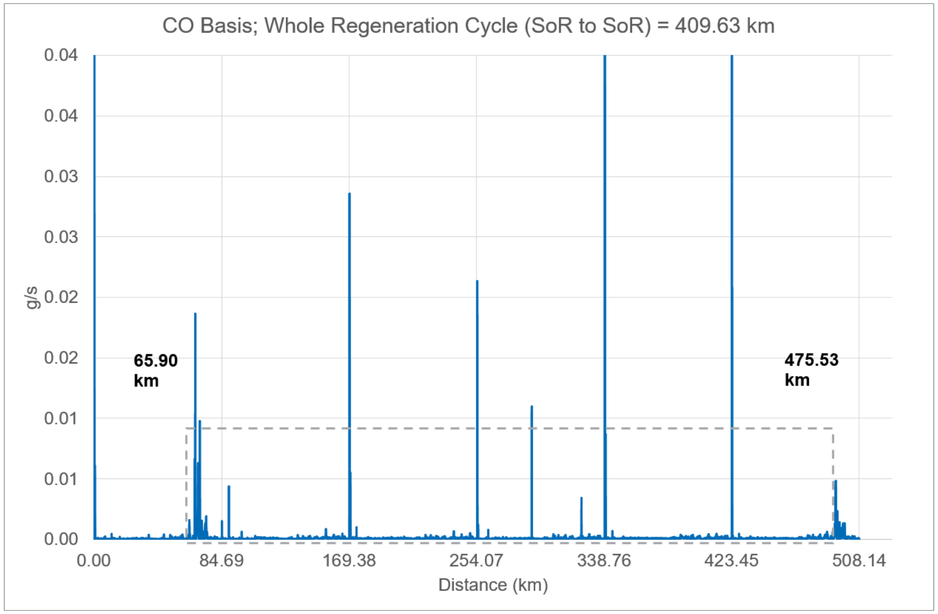


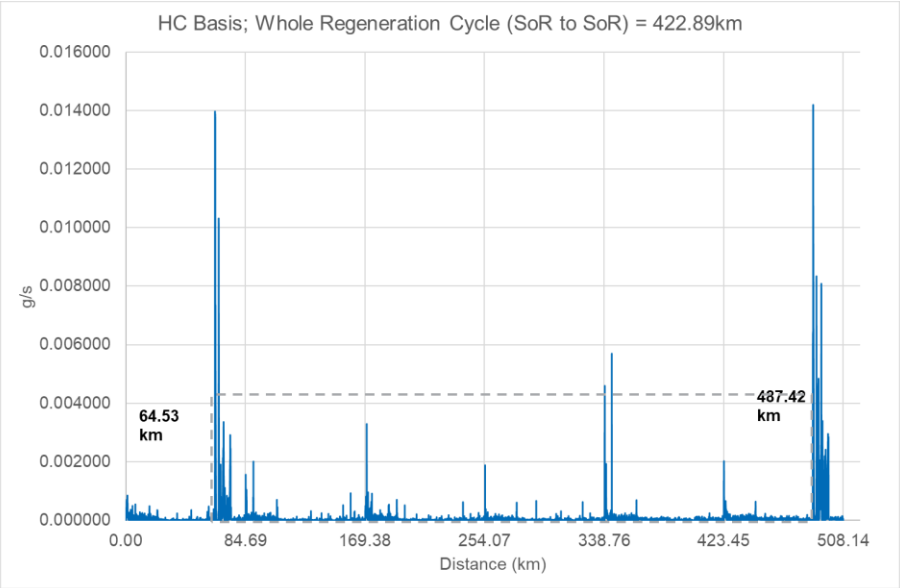
- Both regenerations (Q1cR & Q6hR) on the Qashqai trigger at exactly the same moment in the motorway section of the on-dyno RDE
  - during an accel from an existing high speed point
  - and last for the same length of time

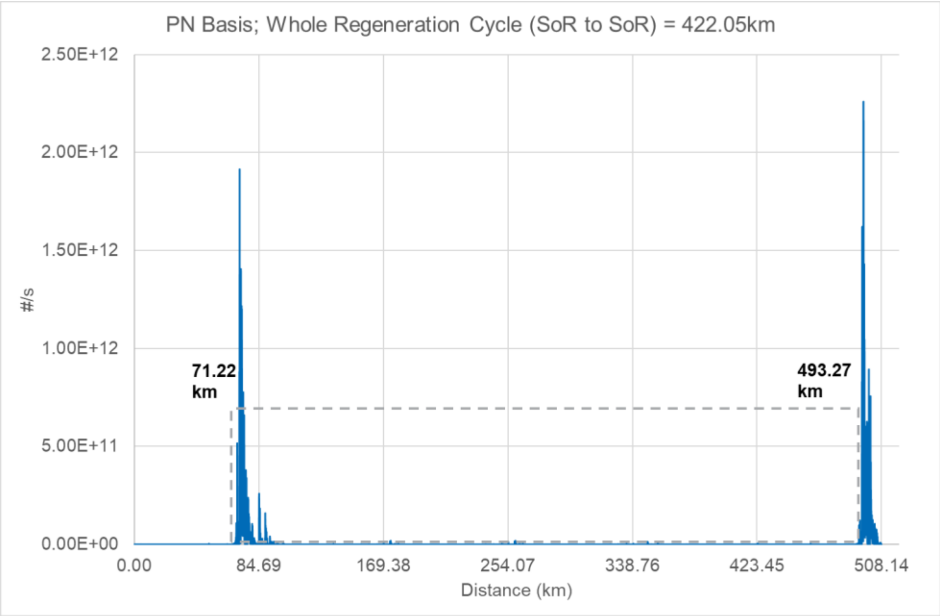
Emissions Results Sub-sections

- Regeneration occurrences and identification
- Regeneration duration, regeneration periodicity/cycle
- Bagged Emissions Results
- Additional gaseous and particle emissions
- Quantifying regeneration impact

Qashqai regeneration cycle intervals from CO, HC & PN (~423 km)

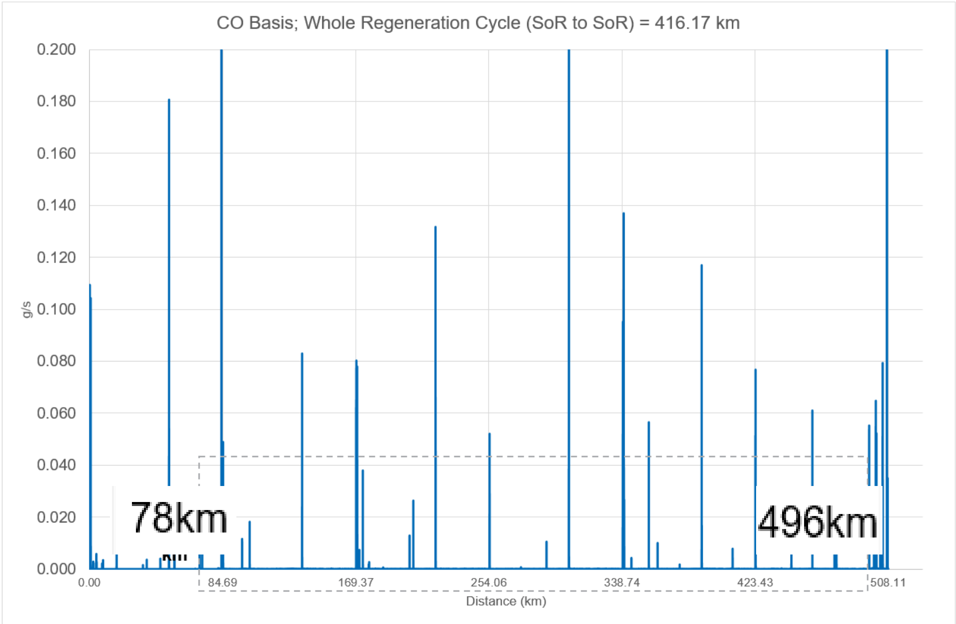


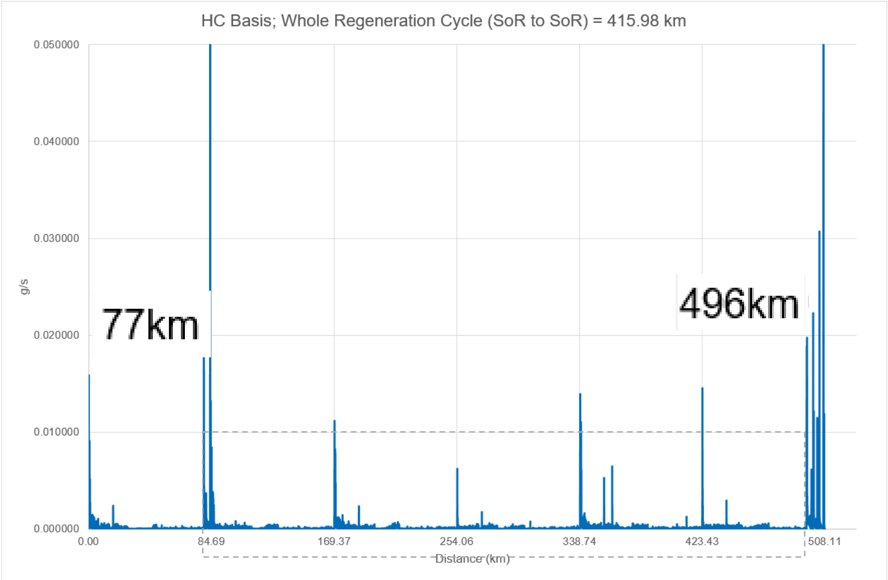


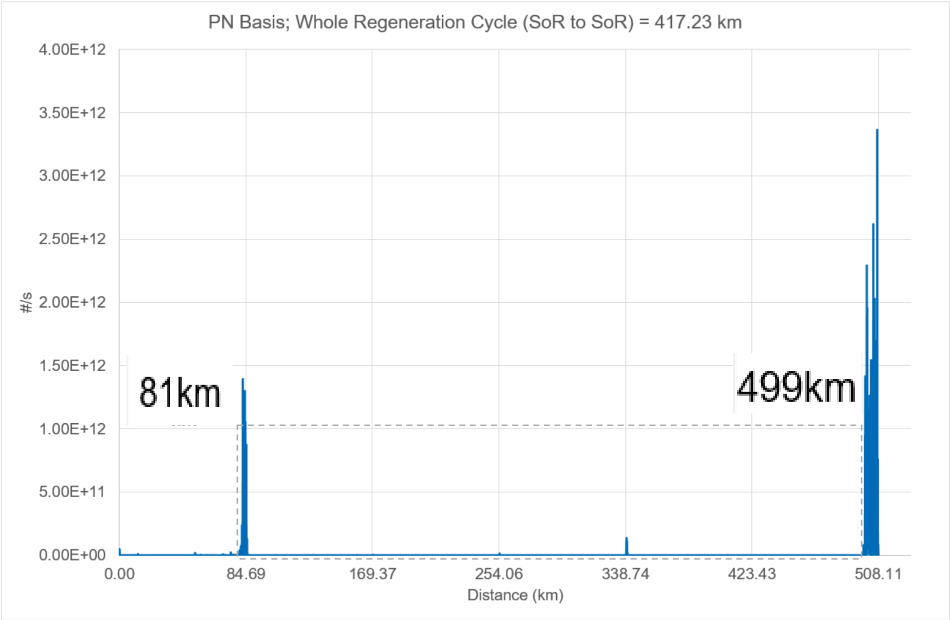


- Regeneration cycle intervals, start of regeneration (SoR) to start of regeneration, are broadly similar when determined from CO, HC and PN
  – CO = 409.63km (5048-34103s; 29055s)
  – HC = 422.89km (5000-34527s; 29527s)
  – PN = 422.05km (5274-34800s; 29526s)
- CO and PN are temporally shifted to later start times relative to HC
  – HC indicates regeneration cause, CO and PN are regeneration effects

Astra regeneration cycle intervals from CO, HC & PN (~419km)

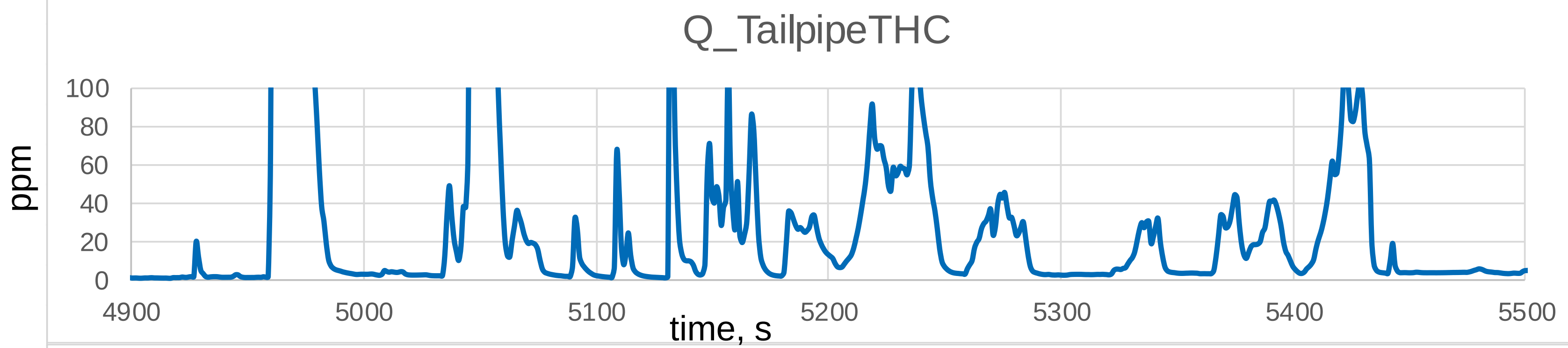


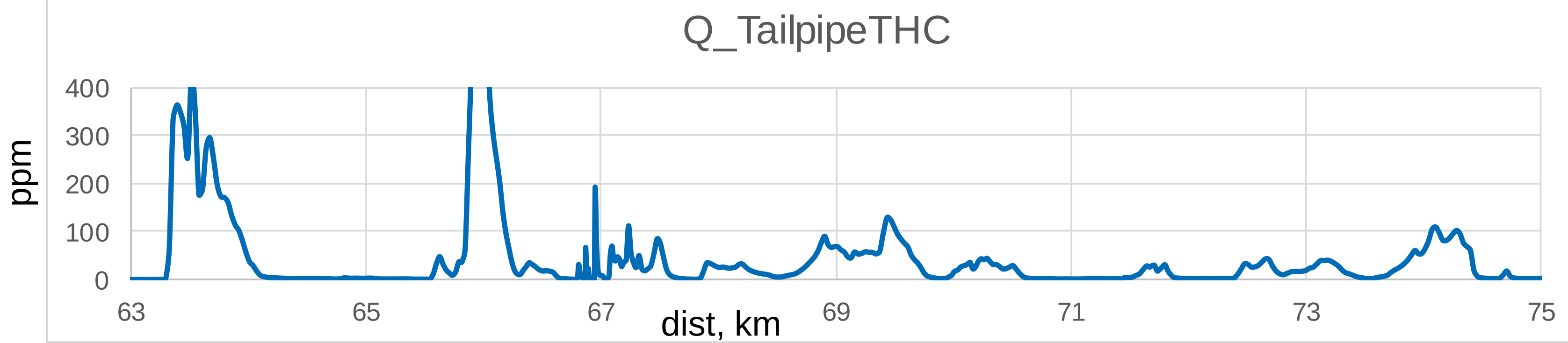




- Regeneration cycle intervals (SoR to SoR), determined visually from the real-time emissions data to within a few km accuracy, are broadly similar when determined from CO, HC and PN, and are
  - CO = 418 km
  - HC = 419 km
  - PN = 418 km
  - CO and especially PN are temporally shifted to later starts relative to HC. HC indicates regeneration cause, and so is used to determine regeneration interval in this work, while CO and PN are regeneration effects
- From the HC data, a 419km regeneration interval has been employed for calculation of Ki factors

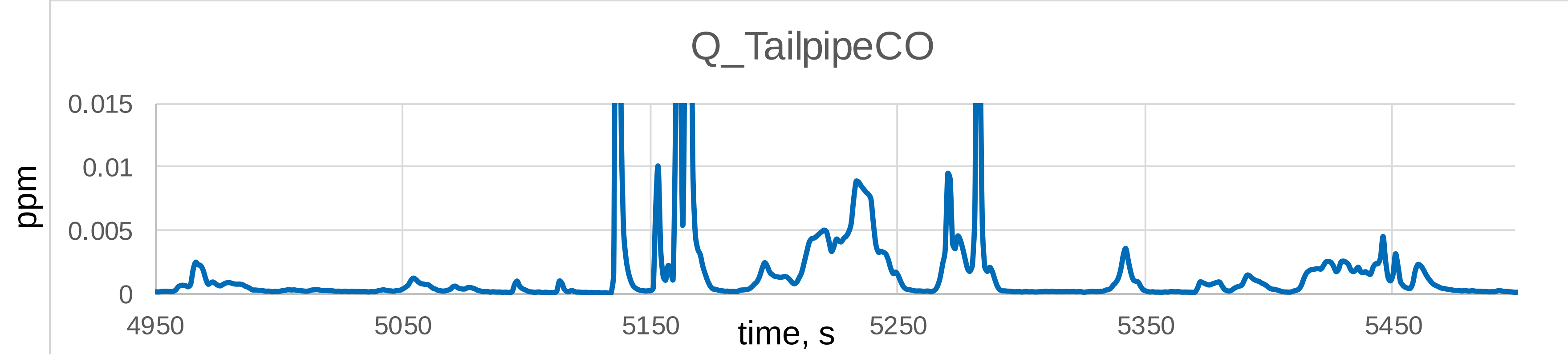
Qashqai Q1cR: Single regen time & distance (based upon THC ppm)

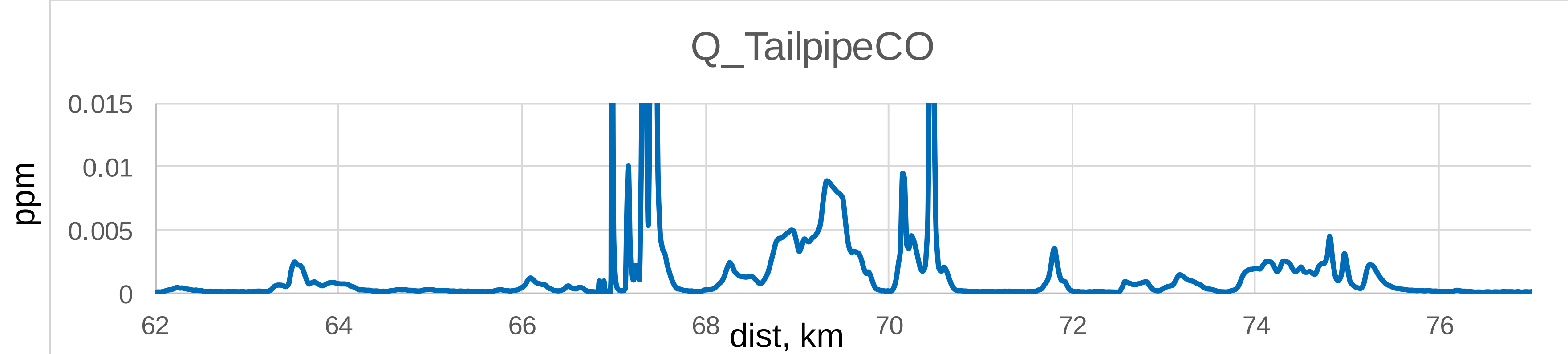




	Start	End	
THC (time)	4959	5445	486
THC (dist)	63.286	74.772	11.486

Qashqai Q1cR: Single regen time & distance (based upon CO ppm)

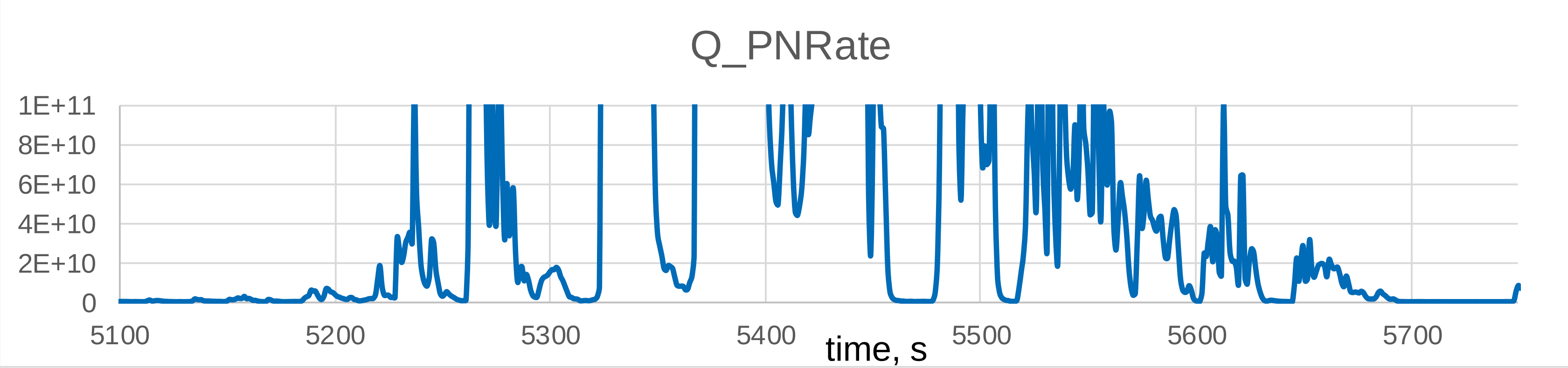


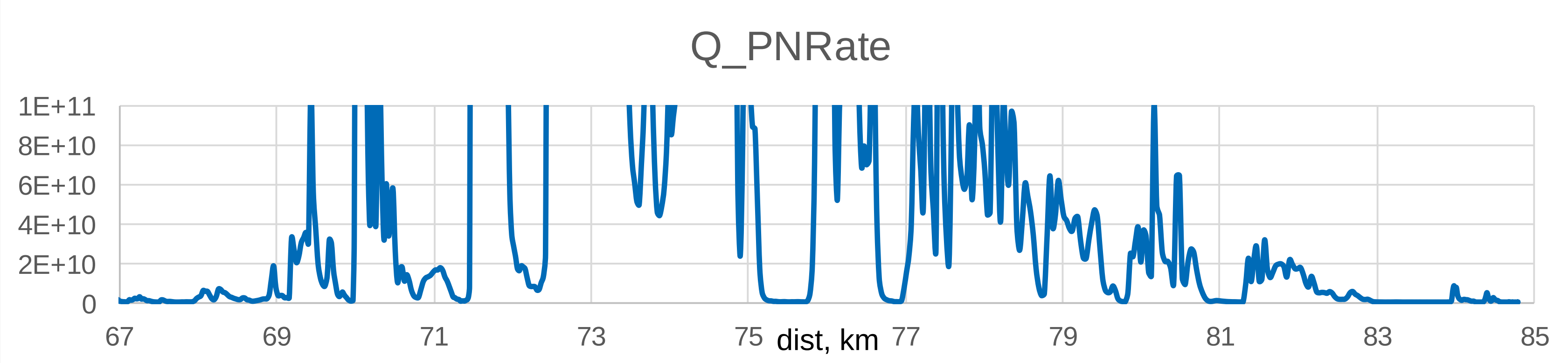


	Start	End	
CO (time)	4957	5478	521
CO (dist)	63.318	75.757	12.439

Final

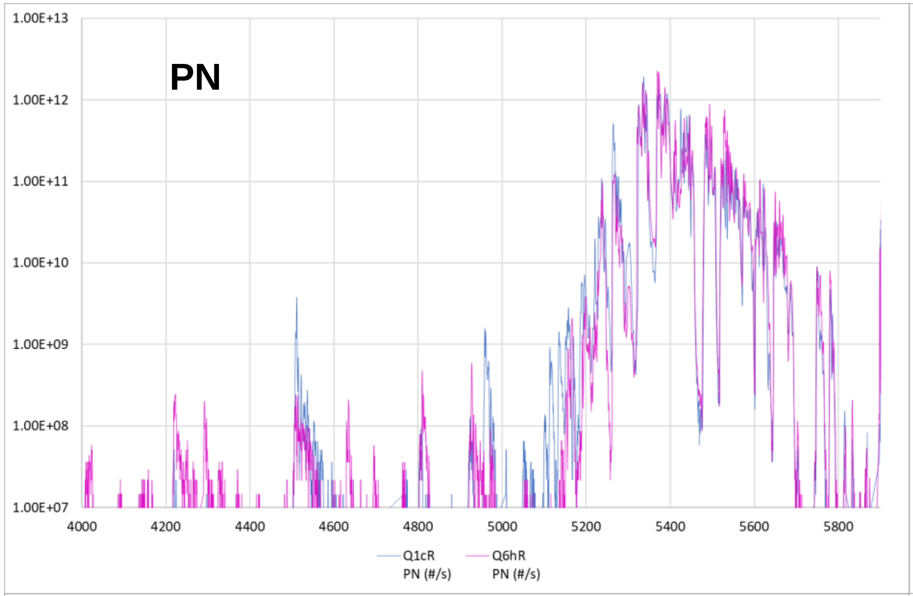
Qashqai Q1cR: Single regen time & distance (based upon PN #/s)

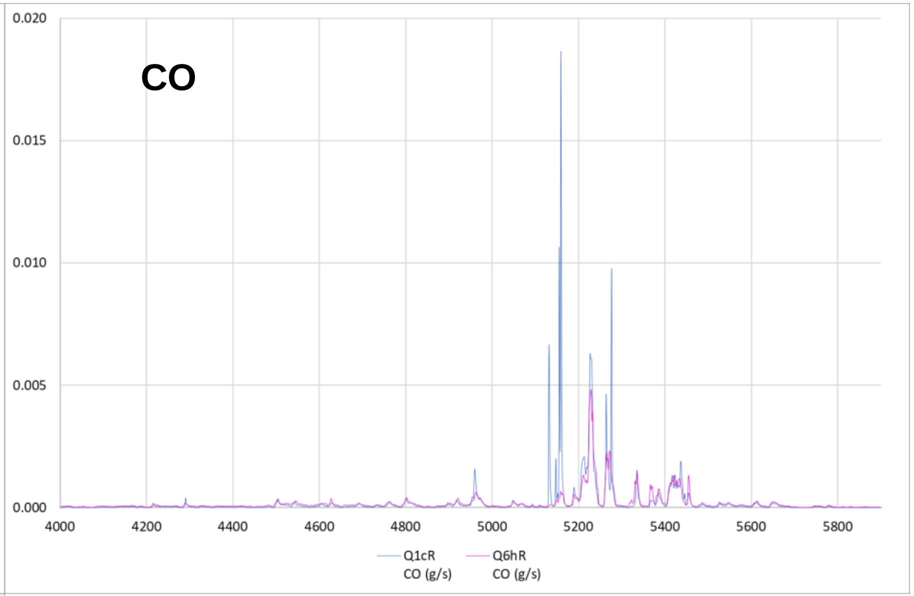


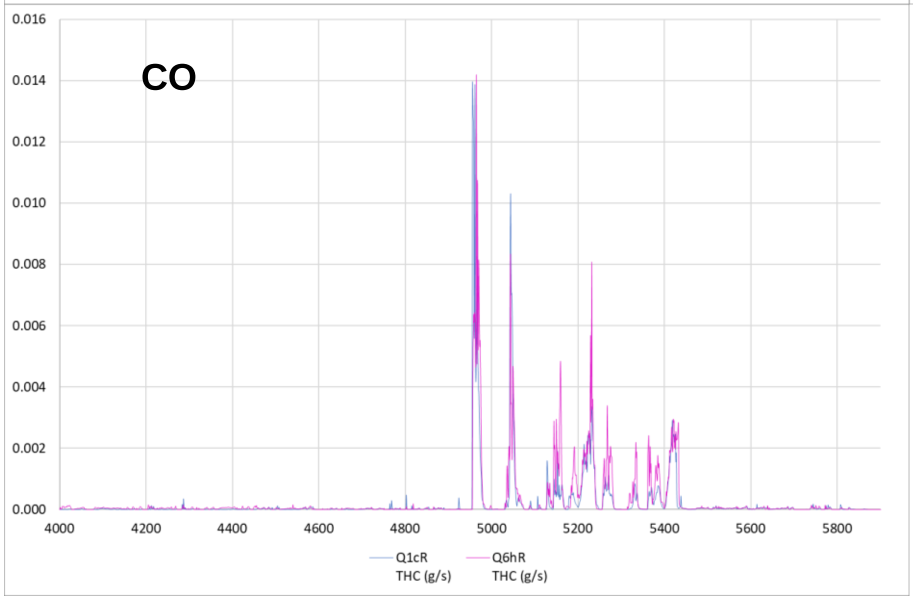


	Start	End	
PN (time)	5185	5698	513
PN (dist)	67.95	83.075	15.125

Qashqai regenerations Q1cR & Q6hR compared (10Hz data)

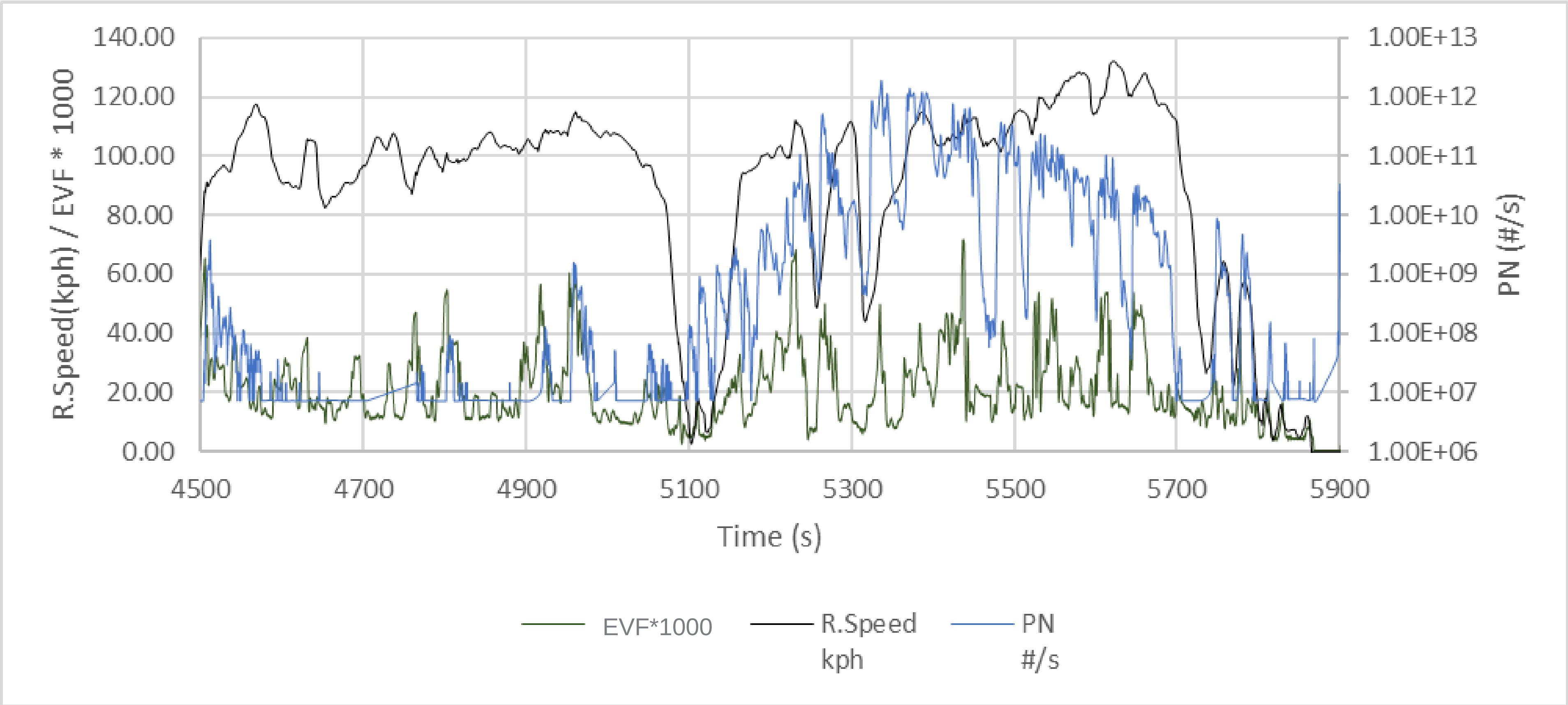






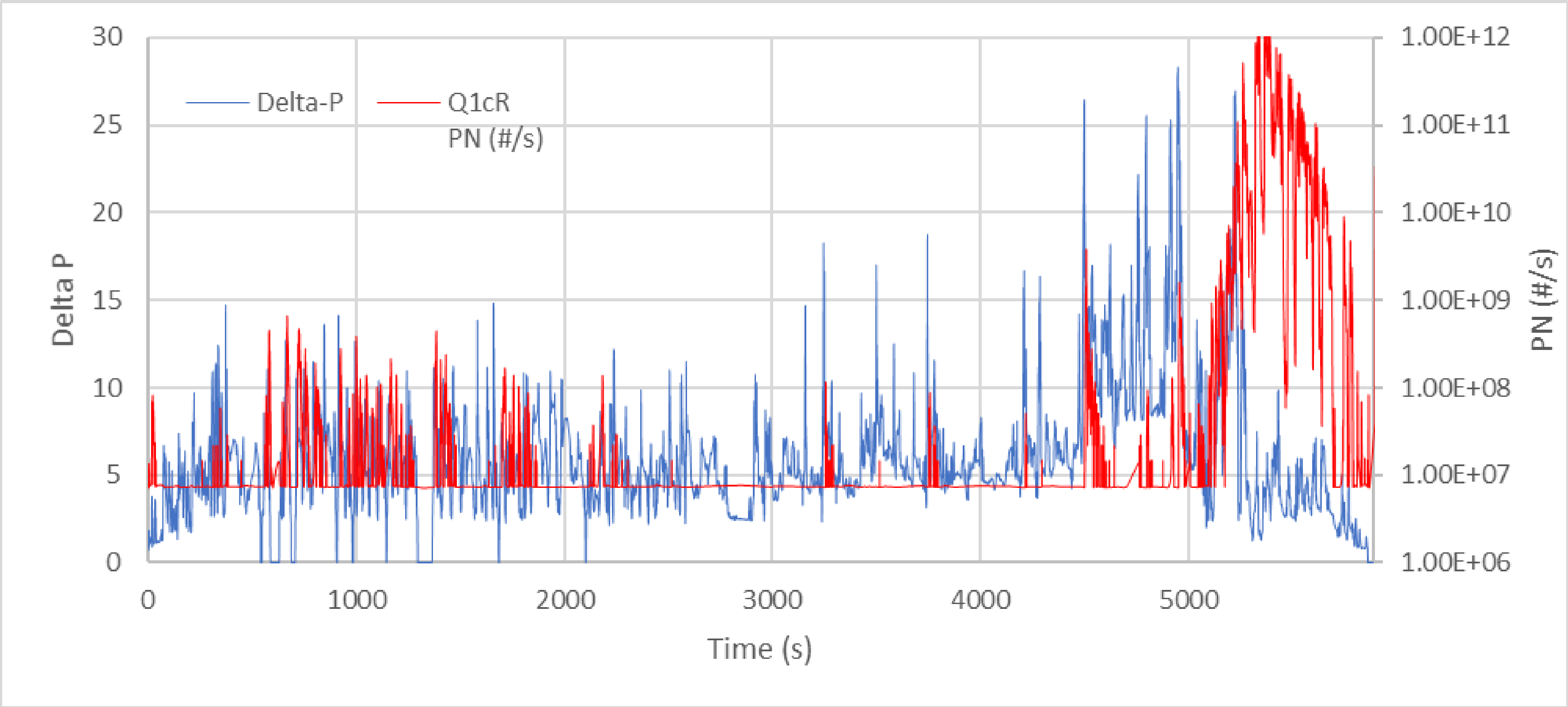
- Qashqai
  - Regeneration durations virtually identical
  - PN and THC emissions also almost identical, CO less so
  - CO will be derived from a combination of both fuel HC burning (expected to be repeatable) and soot combusting (which may be less repeatable)

Regulatory PN23 emissions, Road Speed and Exhaust Volume Flow (Q1cR)



- There is no obvious correlation of regen PN emissions with high exhaust flow, indicating that PN emissions are derived from combustion events and not “blow-off” from the DPF, as observed in the past with partial/open DPFs

Q1cR – clear reduction in OBD delta-P during regeneration



- In the period of highest PN emissions (>5000s) during the active regeneration, the DPF ΔP can be clearly seen to substantially reduce in response to soot removal
- This follows the period of highest cycle ΔP (4500 – 5000s)

Temporal regeneration offsets

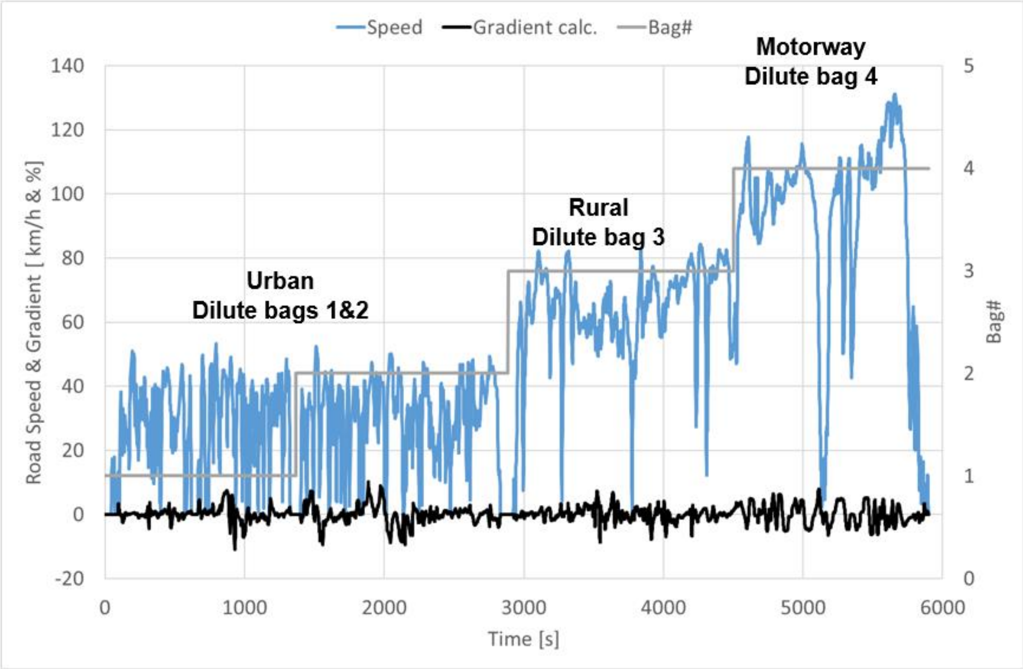
- Regenerations are observed first in HC, since these reflect the additional emissions arising from the late post-injection of fuel that drives the exotherm for soot combustion
- CO follows soon after, primarily as a product of the incomplete combustion of the extra fuel injected
- PN arises later, as the exhaust temperature must rise to ~550°C for soot burning to be substantial. PN emissions remain elevated after fuel and soot combustion has completed until the DPF restores the soot cake and filtration efficiency climbs
- Regeneration periods for THC, CO and PN are relatively similar but, as shown for the Qashqai, the start of the PN 'window' is delayed
  - 486s (THC), 521s (CO), 513s (PN)
- Different distances apply to the regeneration periods, both because the durations differ and because the vehicle speeds during the different time periods vary
  - 11.486km (THC), 12.439km (CO), 15.125km (PN)
- Data are available for analysis where the regeneration impact on all emissions exists within a single on-dyno RDE test, so the easiest way to consider regeneration impacts and Ki factor calculation, is to consider whole regenerating and non-regenerating RDE cycles and determine the regeneration influence by difference
- The regeneration distance determined for THC appears to be similar to PN and longer than CO, and since HC is the driver for regeneration, this distance is considered most appropriate for Ki and related calculations

Emissions Results Sub-sections

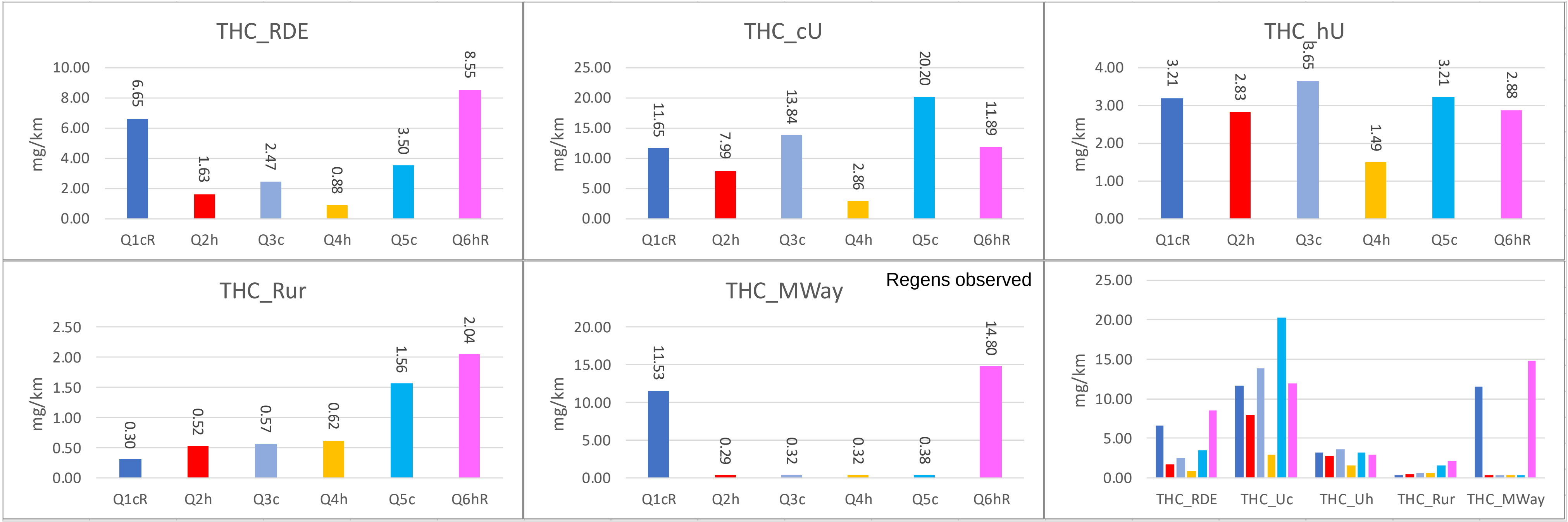
- Regeneration occurrences and identification
- Regeneration duration, regeneration periodicity/cycle
- Bagged Emissions Results
- Additional gaseous and particle emissions
- Quantifying regeneration impact

Bagged Emissions Results

- The following section presents drive cycle emissions results from selected species measured dilute (from the CVS)
- Results are shown for the Qashqai and Astra and include dilute emissions from 4 bags:
  - The whole RDE cycle result (RDE)
  - The first bag / initial part of urban (cU)
  - The second bag / final part of urban (hU)
  - The third bag / rural (Rur)
  - The fourth bag / Motorway (MWay)
- Emissions species shown are: THC, CO, NOx, PM, PN, NO_2, HC + NOx, CO_2

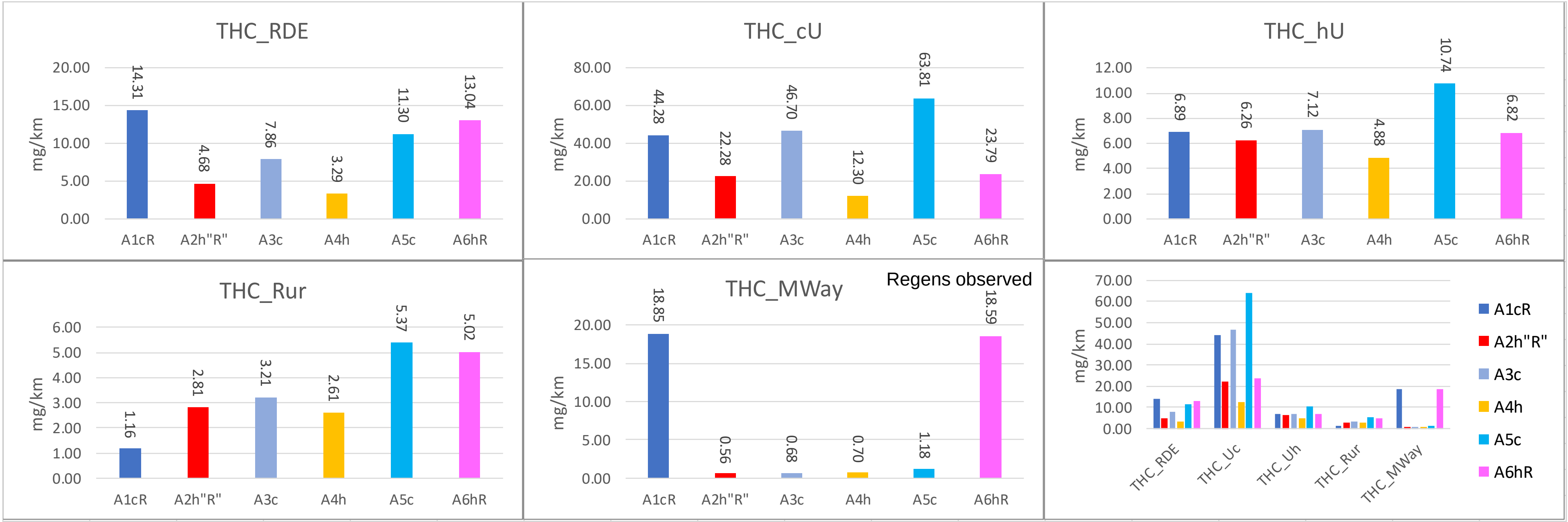


Qashqai THC



- No HC limit for diesel vehicles, but HC+NOx and NOx limits of 170mg and 80mg respectively, suggest 90mg/km as a benchmark for comparisons
- RDE THC is always <10% of the 90mg/km benchmark
- There is an obvious hot v cold start effect with THC in THC_cU (as expected), this disappears in later phases
- An increase in THC is observed during regenerations (within the motorway phase) from <0.5mg/km to >10mg/km

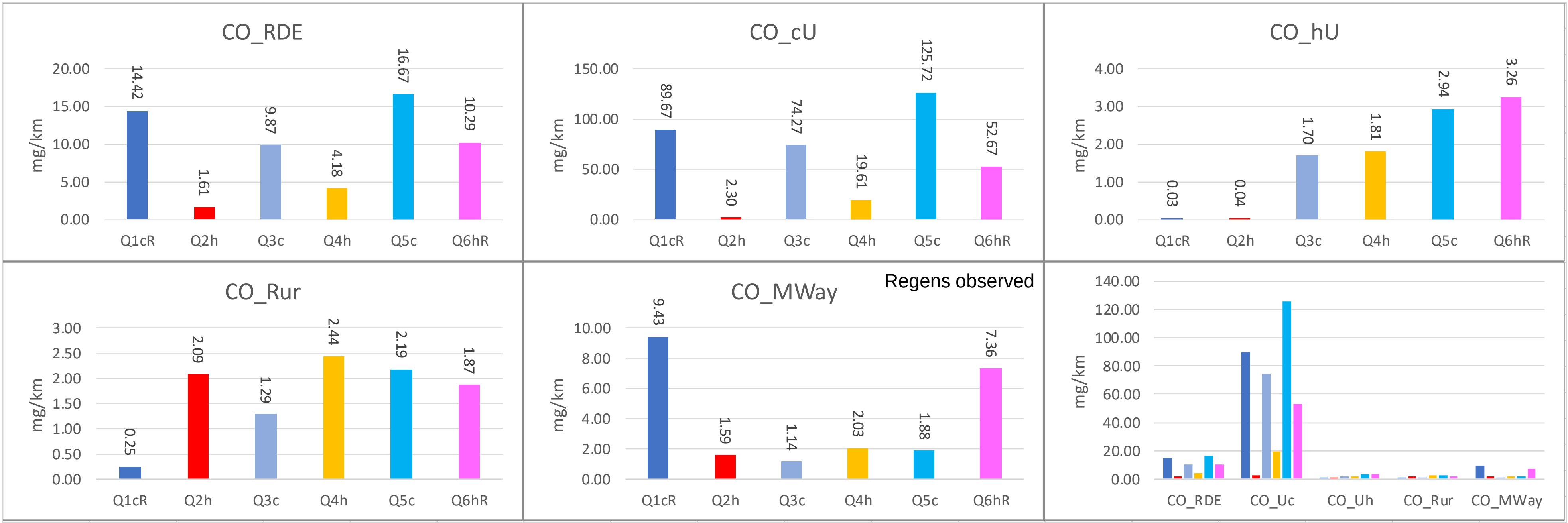
Astra THC



- RDE THC is always <17% of the Euro 6d 90 mg/km THC benchmark (but slightly higher than the Qashqai)
- There is an obvious hot v cold start effect with THC in THC_cU, with cold start emissions 20-40mg/km higher than hot start
- An increase in THC is observed during regenerations (within the motorway phase) from ≤0.7mg/km to >18mg/km

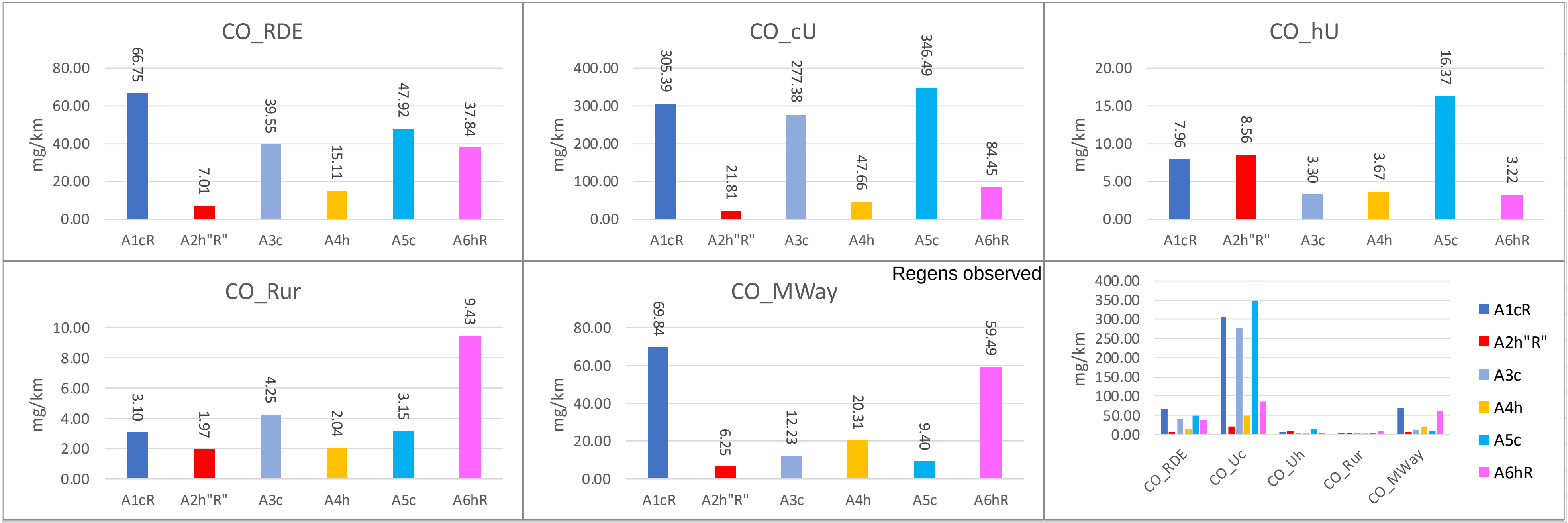
Final

Qashqai CO



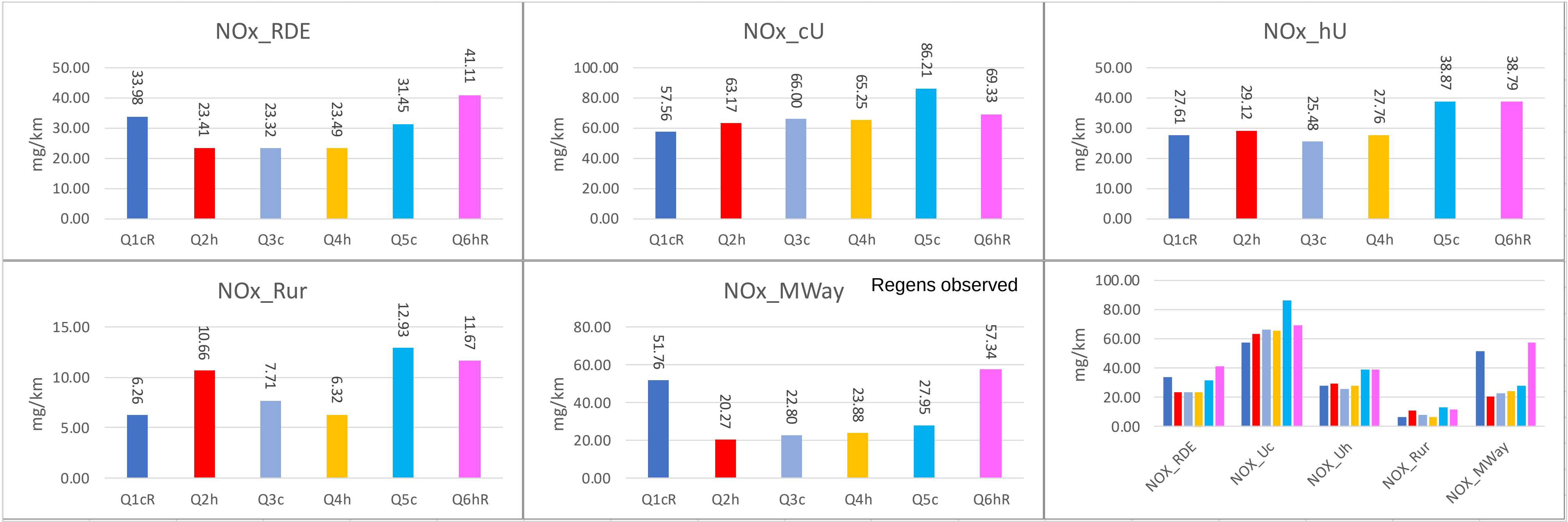
- RDE CO emissions are < 20mg/km compared with a 500mg/km Euro 6d limit
- As with THC there is a marked cold v hot start effect on CO emissions, particularly in CO_cU which dominates overall CO emissions
- An increase in CO emissions can be seen during regenerations
  - from ≤ 2mg/km to 7-10mg/km

Astra CO



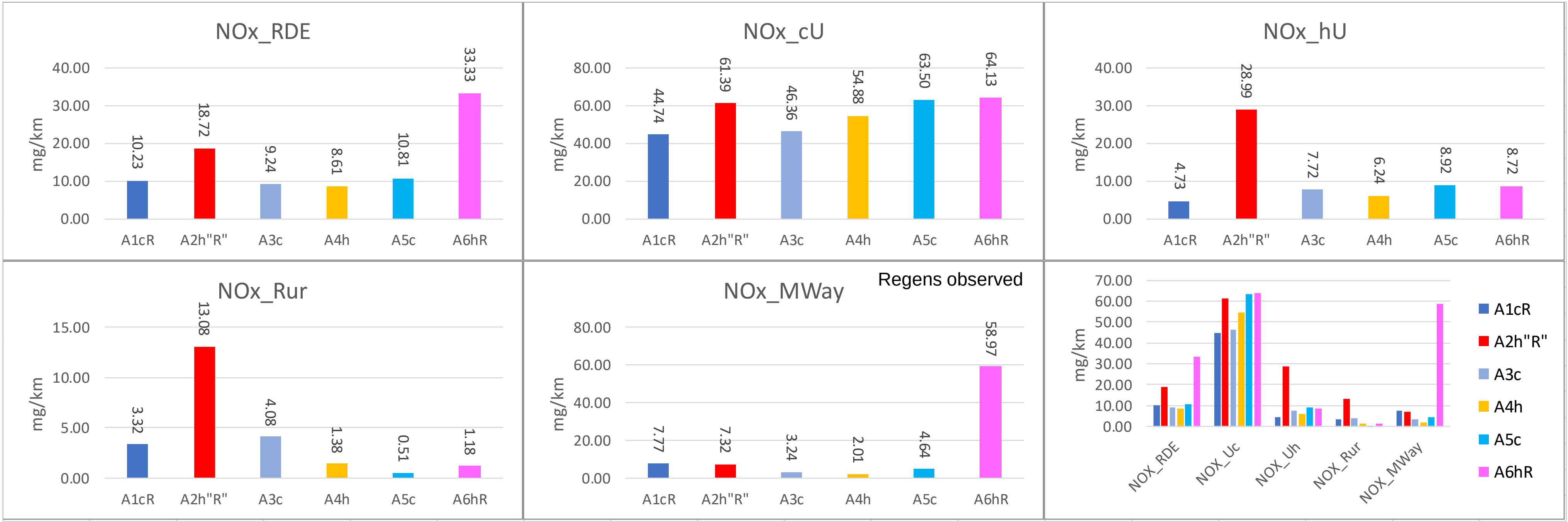
- RDE CO emissions are < 70mg/km compared with a 500mg/km Euro 6d limit, significantly higher than the Qashqai (which was < 20mg/km), this may indicate a lower PGM loading on the catalyst and/or reduced warm-up strategy to conserve fuel
- As with THC there is a marked cold v hot start effect on CO emissions, particularly in CO_cU which dominates overall CO emissions. In this phase Astra CO emissions are at least double those of the Qashqai
- An increase in CO emissions can be seen during regenerations
  - from ≤ 20mg/km to 60-70 mg/km

Qashqai NOx



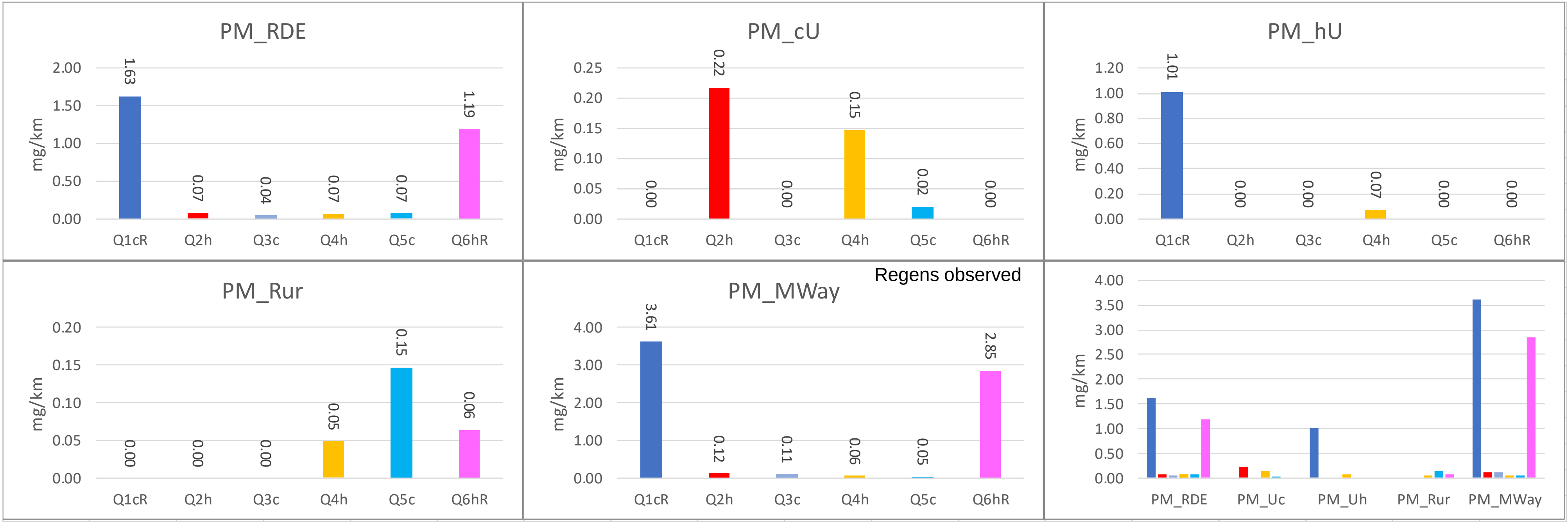
- RDE NOx is < 60mg/km even during the motorway phase when regenerations were observed (Euro 6d limit value is 80mg/km)
- Comparing Q3c with Q4h shows minimal cold start v hot start effect visible for NOx over both the whole RDE and the first bag, indicating good NOx control in urban as well as during regeneration. One test (Q5c) showed NOx marginally above the 80mg/km limit from the first urban bag (~10km length) indicating that shorter urban RDE cycles will present a greater challenge to meeting NOx limits
- Clear impact of regenerations in motorway phase (+~30mg/km), when comparing Q1cR and Q6hR with the other tests

Astra NOx



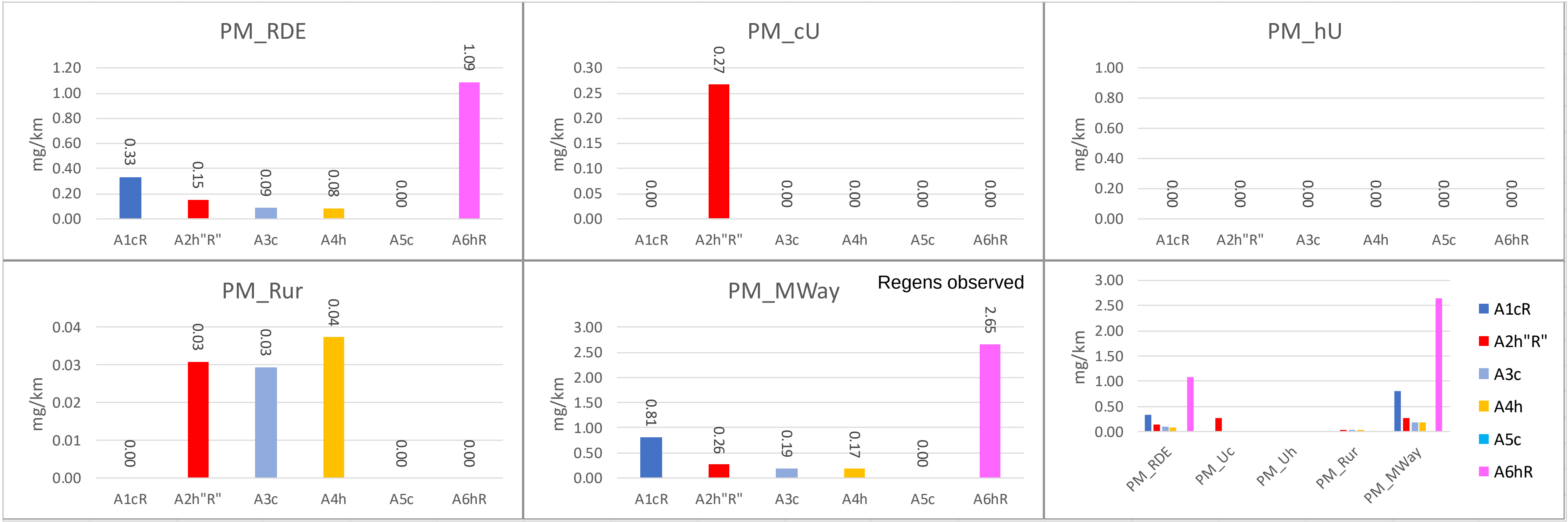
- RDE NOx is <65 mg/km even during the motorway phase when a regeneration was observed
- Comparing A3c with A4h indicates no cold start v hot start effect visible for NOx over both the whole RDE and the first bag, indicating good NOx control in urban as well as during regeneration
- There is a clear impact of the regeneration in the motorway phase of A6hR (+~50mg/km), when comparing this with the other tests. There was minimal impact of the partial regeneration in A1cR on NOx, although the subsequent test A2h shows increased NOx emissions in both urban and rural phases relative to the other non-regenerating hot-start test (A4h)

Qashqai PM Emissions



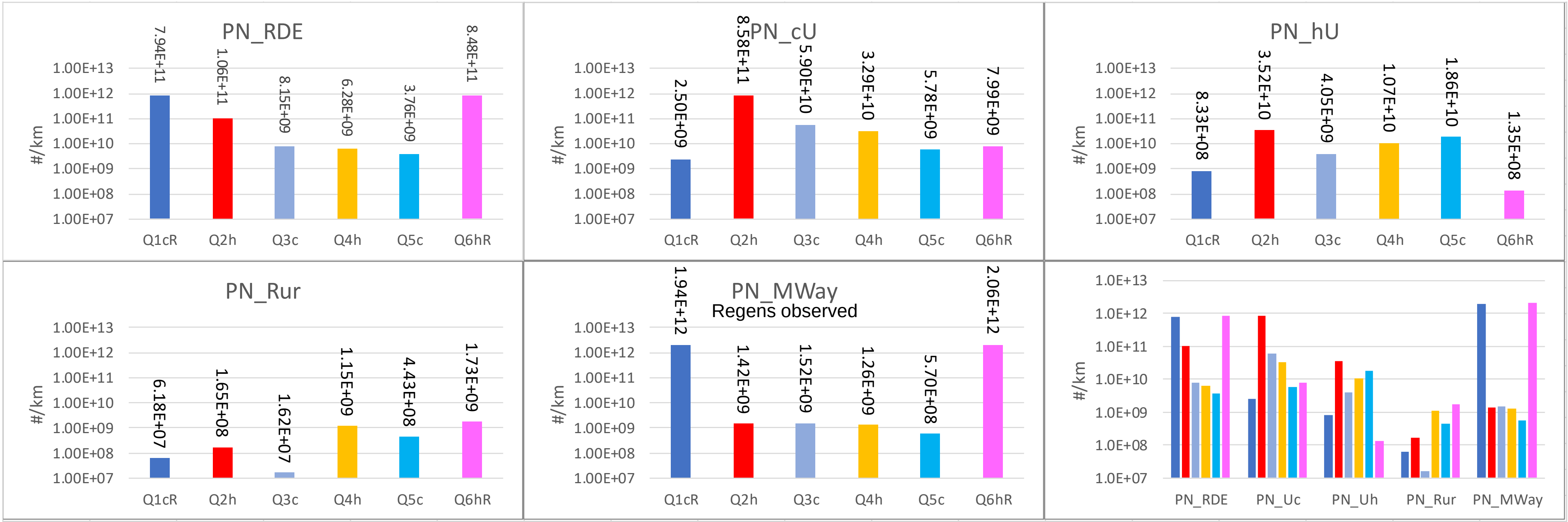
- PM emissions from the whole RDE, including cycles containing regenerations are <2mg/km (Euro 6d limit value is 4.5mg/km)
- From the two regenerations in the MWay section, PM emissions were at ~2.8mg/km (Q6hR) and ~3.6 mg/km (Q1cR)
- The impact of the regeneration in reducing filtration efficiency appears evident in elevated PM in Q2h

Astra PM Emissions



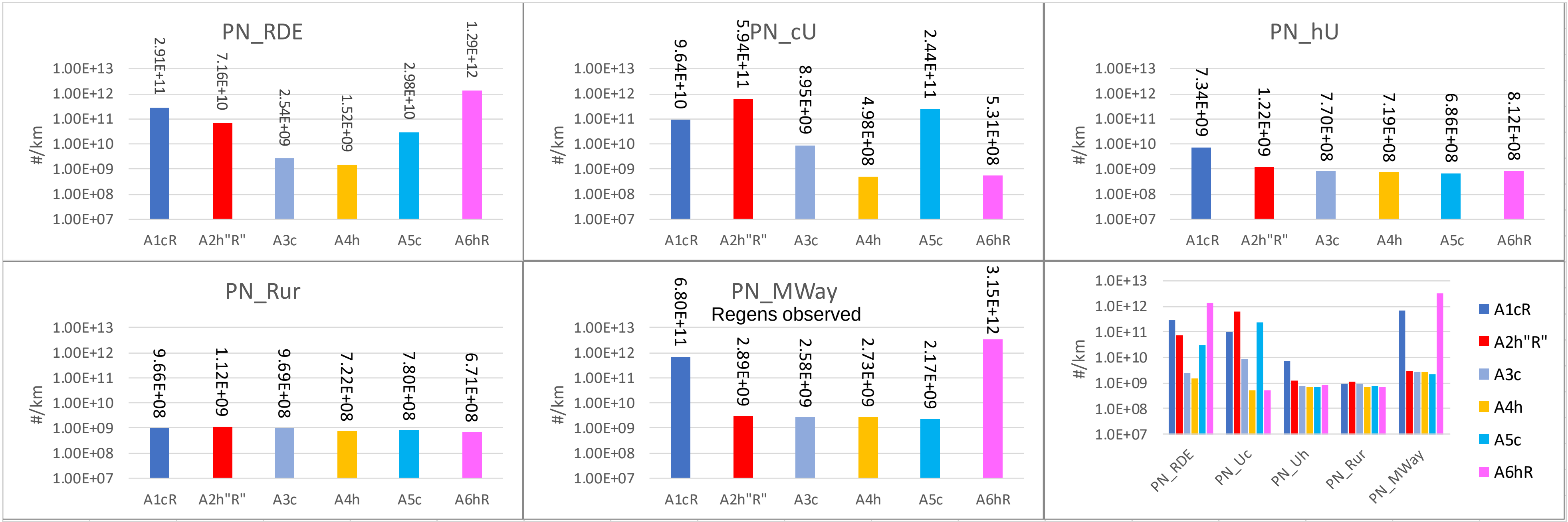
- PM emissions from the whole RDE on the Astra, including cycles containing full or partial regenerations, were ~1mg/km or less (Euro 6d limit value is 4.5mg/km)
- From the regeneration in the MWay section of A6hR, PM emissions were at ~2.7mg/km, similar to levels from Qashqai regenerations
- The impact of the continued regeneration of A2h"R" in reducing filtration efficiency appears evident in elevated PM in during the first bag (PM_cU)

Qashqai Regulatory PN23



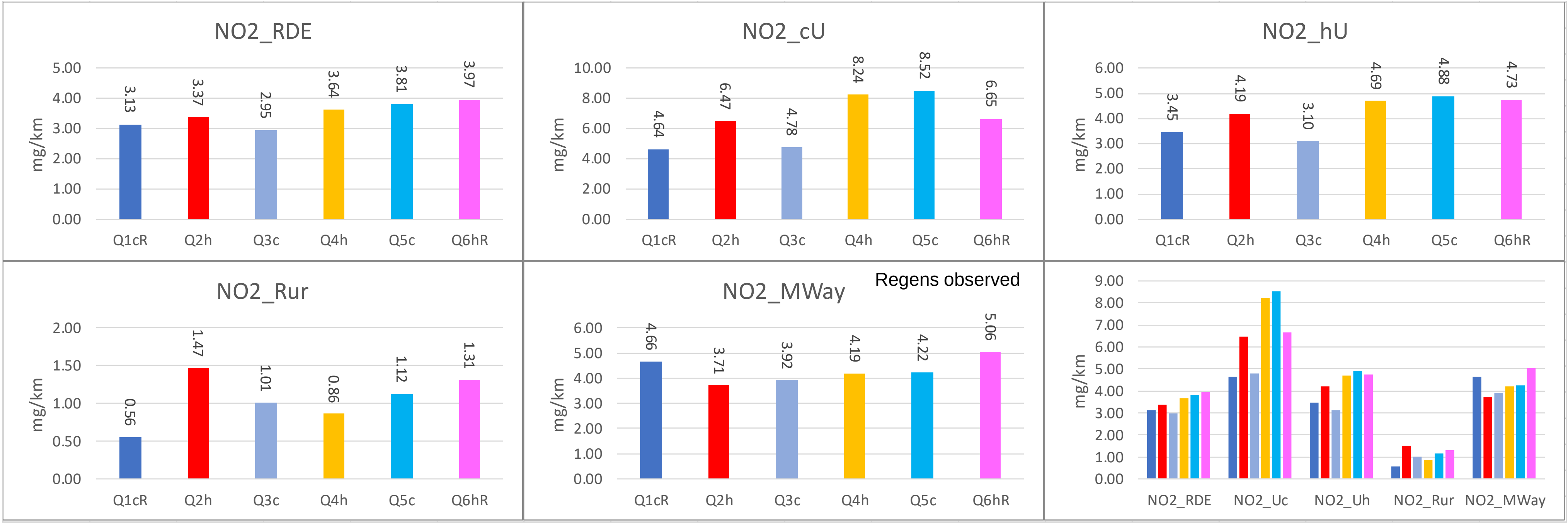
- PN emissions from whole RDE featuring regenerations exceed the $6x10^{11}$ #/km limit by ~40%
- No obvious cold start effect was observed on PN, but a strong follow-on impact of regeneration was observed in the first bag of Q2h following regeneration at the end of Q1cR. PN levels had recovered to close to 10^{10}#/km by the end of bag 2 (PN_hU) in Q2h
- > 1000x increase in MWay PN with regeneration compared to non-regenerating tests

Astra Regulatory PN23



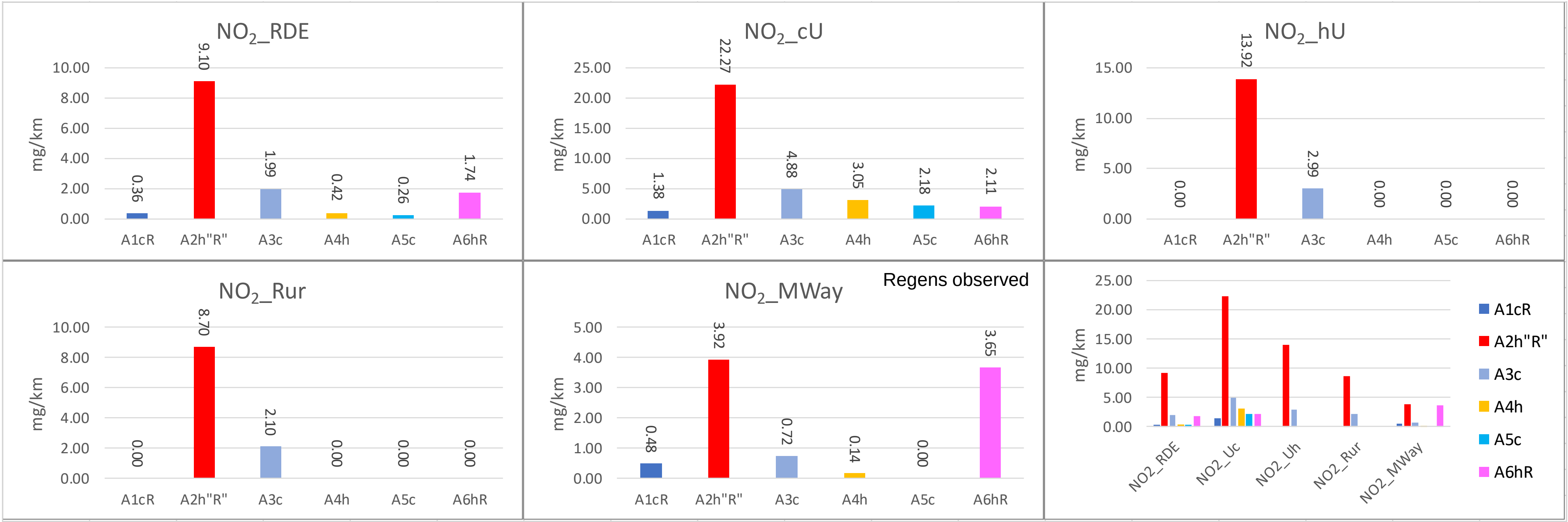
- PN emissions from the whole RDE featuring a complete regeneration (A6hR) exceeded the $6x10^{11}$ #/km limit by ~115%
- No obvious cold start effect was observed on PN, but following incomplete regeneration at the end of A1cR, emissions from bag#1 (PN_cU) approached the $6x10^{11}$#/km limit value. PN levels had recovered to close to 10^{9}#/km by the end of bag 2 (PN_hU) in A2h"R"
- > 1000x increase in MWay PN with regeneration compared to non-regenerating tests

Qashqai NO_2



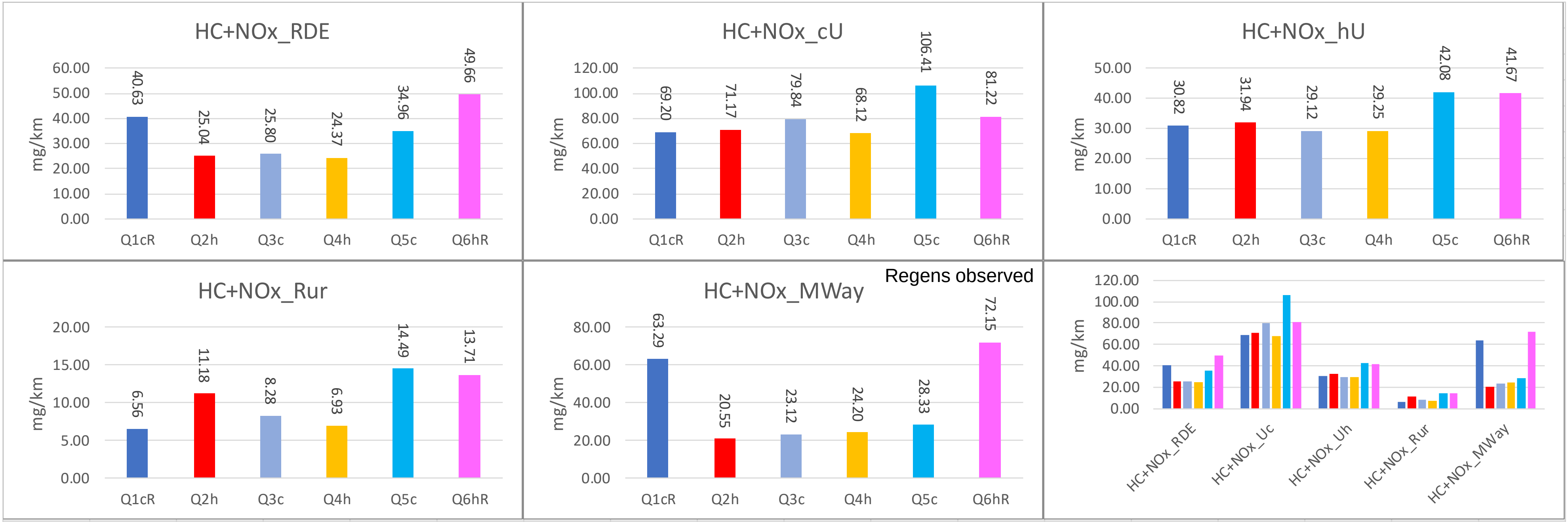
- NO_2 is always < 9mg/km, and consistent between cold and hot start tests
- Highest NO_2 from coldest cycle (possibly indicative of non-aftertreatment NO_2 production in-cylinder)
- A slight increase, of < 1mg/km, is observed during the regeneration in the MWay phase

Astra NO_2



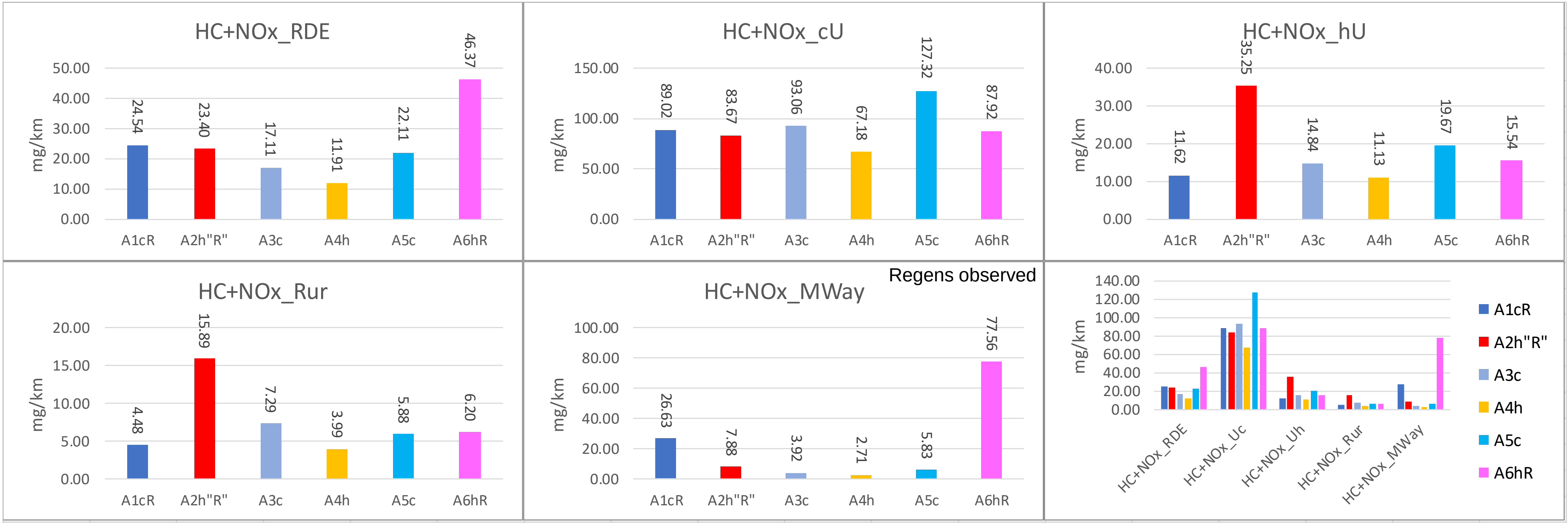
- NO_2 was always < 2mg/km, and consistent between cold and hot start tests, except for A2h"R", where NO_2 was elevated throughout the cycle
- From A2h"R" RDE cycle NO_2 reached 9mg/km, 3x Qashqai emissions levels, though other tests results were lower than comparable Qashqai emissions and over an entire regeneration interval (~420km) only a limited difference between the vehicles would be expected

Qashqai HC + NOx



- When considering the whole RDE and individual bags, HC+NOx is < 110mg/km, so easily compliant with the 170mg/km Euro 6d limit
- Comparing Q3c with Q4h indicates a visible but limited cold start v hot start effect for HC+NOx over both the whole RDE and the first bag
- There is a clear impact of regenerations in motorway phase (+~40mg/km), when comparing Q1cR and Q6hR with the other tests

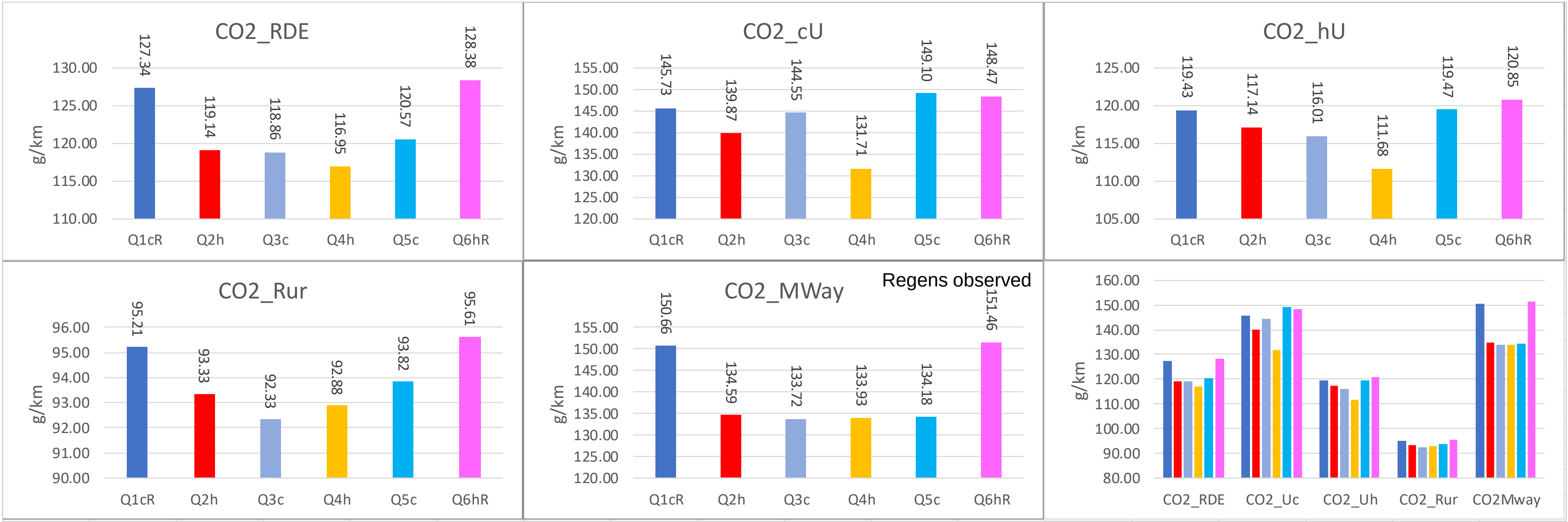
Astra HC + NOx



- When considering the whole RDE and individual bags, HC+NOx is < 130mg/km, so easily compliant with the 170mg/km Euro 6d limit, though slightly (~20mg/km) higher than the Qashqai emissions
- Comparing A3c with A4h indicates a reduction of ~30% from cold start to hot start visible for HC+NOx over the whole RDE, and the first bag
- There is a clear impact of the A6hR regeneration in the motorway phase (+~70mg/km), when comparing Q6hR with A2h"R" and A4h

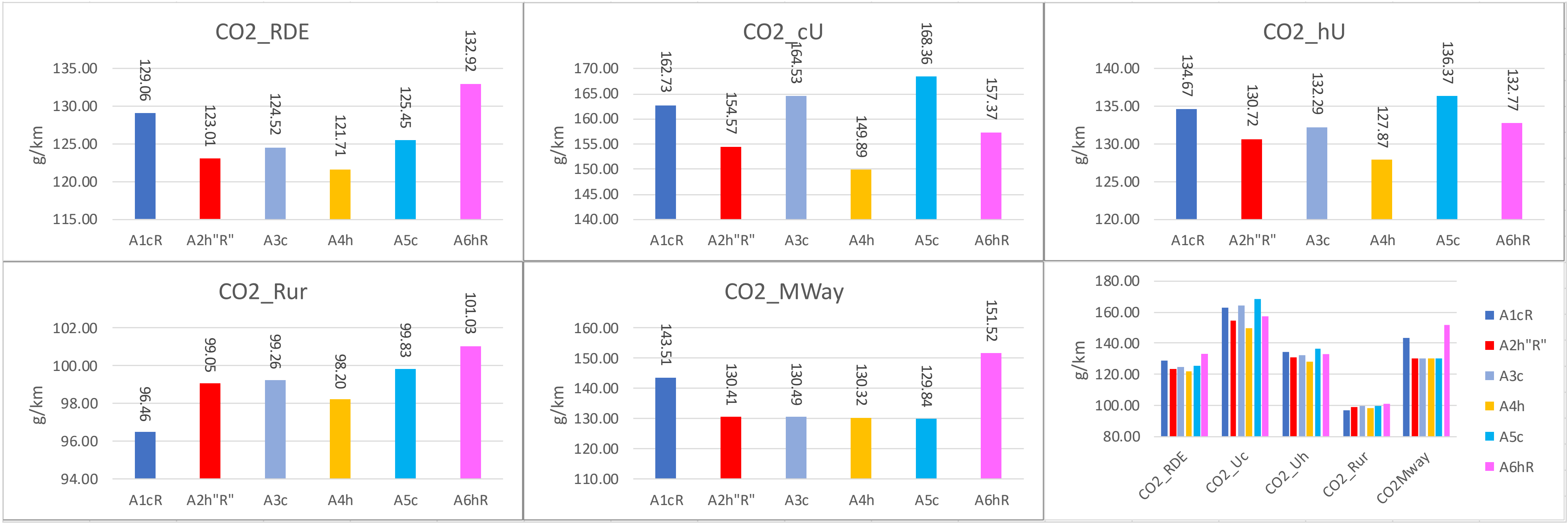
Final

Qashqai CO_2



- RDE CO_2 emissions were ~119g/km from non-regenerating tests compared to the WLTC certification figure of 144 g/km
  - Dyno WLTC certification appears to have been undertaken at a higher road load than the RDE testing, leading to higher CO_2.
- CO_2 increases by 8 - 9g/km (6-7%) compared to non-regenerating tests, while the impact of the regeneration in the motorway phase in isolation is a ~12.5% increase
- A cold start v hot start effect on CO_2 is apparent when comparing the RDE result of Q3c and Q4h, where a reduction of ~1.6% is seen with the hot start

Astra CO_2



- RDE CO_2 emissions were ~123 g/km from non-regenerating tests compared to the WLTC certification figure of 133 g/km. As with the Qashqai, the certification WLTC appears to have been tested at slightly higher load than the RDE.
- From the regenerating test, A6hR, CO_2 increases by 10 g/km (~7.5%) compared to non-regenerating tests, while the impact of the regeneration in the motorway phase in isolation is a ~16.5% increase
- A cold start v hot start effect on CO_2 is apparent when comparing the RDE result of A3c and A4h, where a reduction of ~2.2% is seen with the hot start

Emissions Results Sub-sections

- Regeneration occurrences and identification
- Regeneration duration, regeneration periodicity/cycle
- Bagged Emissions Results
- Additional gaseous and particle emissions
- Quantifying regeneration impact

Additional Gaseous and Particle Emissions Results

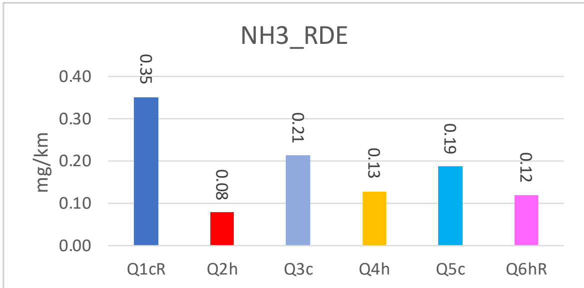
- The following section presents RDE, and sub-phase, emissions results from selected species measured raw by QCL and DMS, and dilute (from the CVS) by the DownTo10 PN system
- Results are shown for the Qashqai and Astra and include:
  - The whole RDE cycle result (RDE)
  - The first bag / initial part of urban (cU)
  - The second bag / final part of urban (hU)
  - The third bag / rural (Rur)
  - The fourth bag / Motorway (MWay)
- Emissions species shown are: NH_3, DMS nucleation mode integral, DMS accumulation mode integral; *PN4, *PN10 and *PN23 data

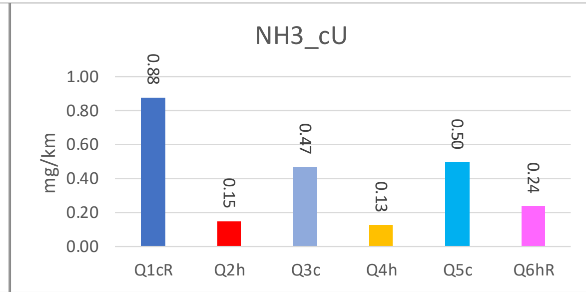
*PN4, PN10 and PN23 data are collected simultaneously from the DownTo10 (DTT) system. DTT data are uncalibrated, so PN23 results are scaled to the Horiba SPCS 23nm data, but with only dilution correction applied to SPCS data. PN10 and PN4 are then also corrected by that scaling factor

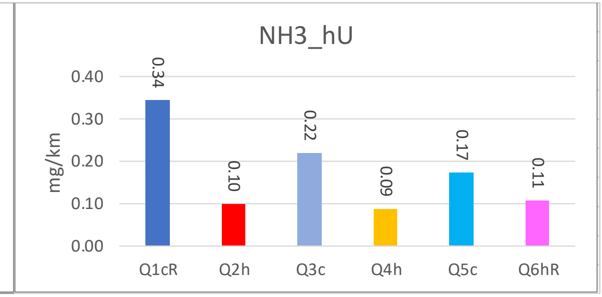
Final

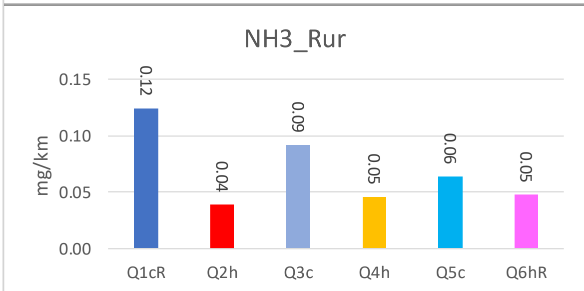
Ammonia Emissions: Qashqai and Astra

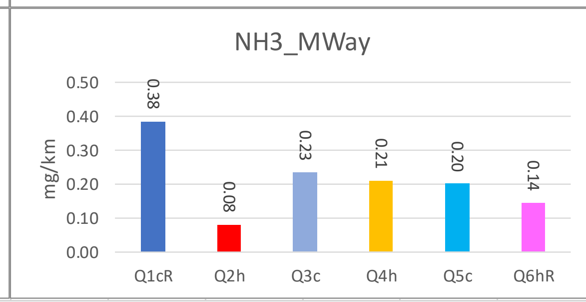
Qashqai





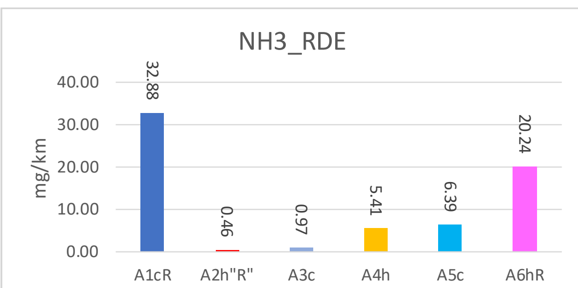


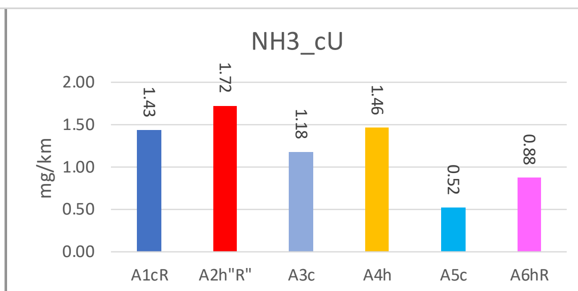


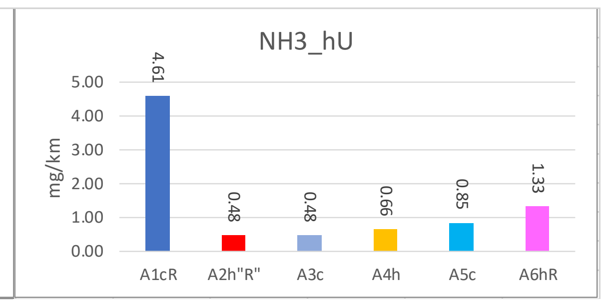


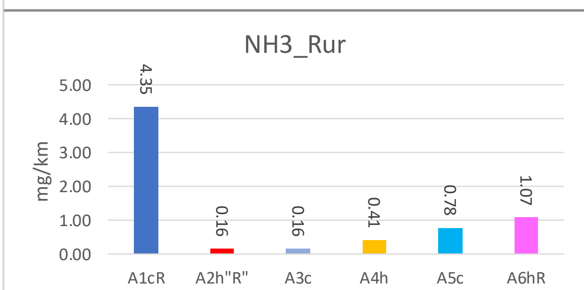
- Qashqai ammonia emissions are well controlled at < 1mg/km across all bags and the whole RDE, including during regenerations
- This indicates a mature urea dosing strategy including clean-up catalyst and closed-loop NOx control, probably aimed at Euro 6d final

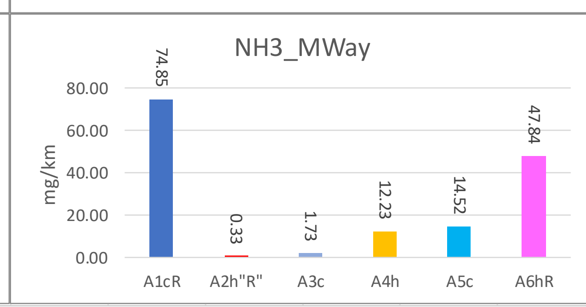
Astra





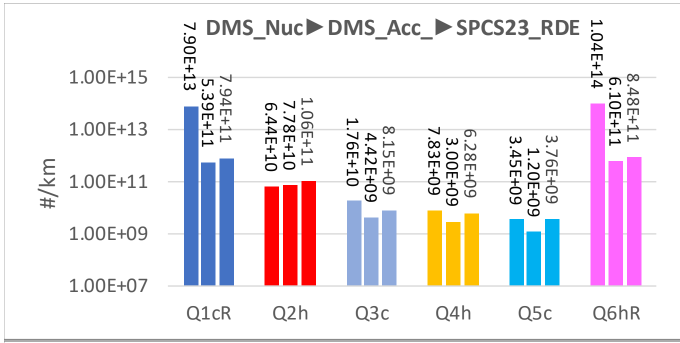


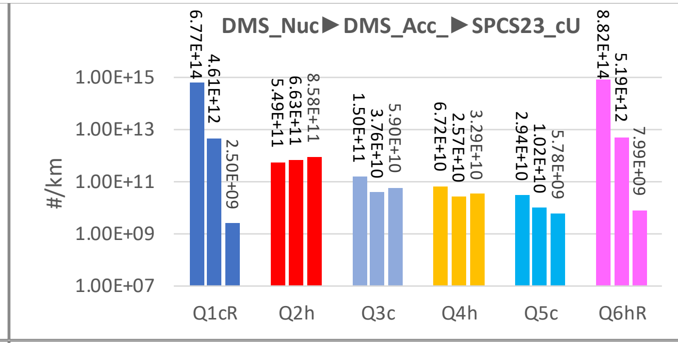


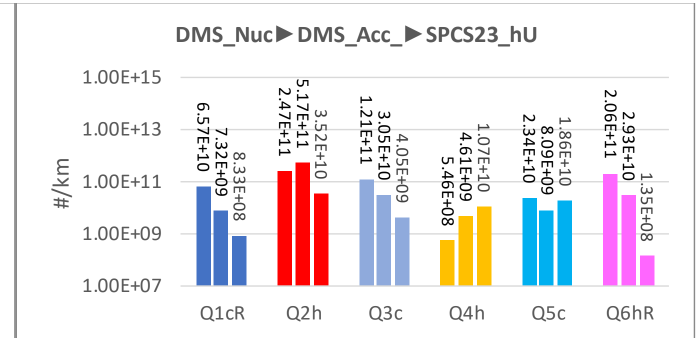


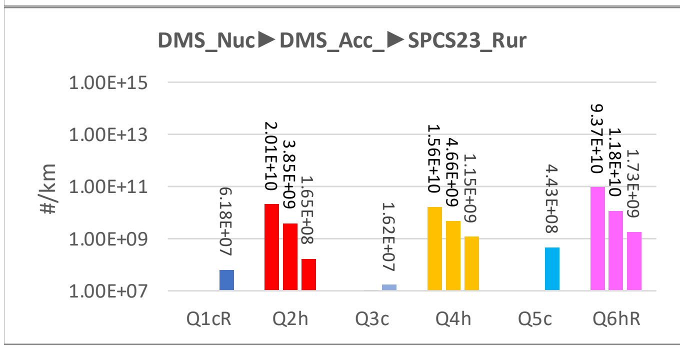
- Astra ammonia emissions from the RDE cycle are in the range 20-30mg/km from regenerating cycles and ~0.5 to ~6.5mg/km from other cycles. Emissions are dominated by the motorway phase (up to almost 75mg/km with regeneration)
- This indicates a less mature emissions control approach, probably an interim 6d-temp solution

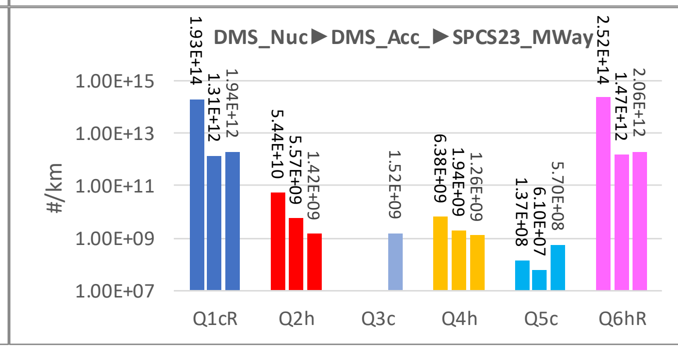
Qashqai: DMS Nucleation Mode and Accumulation Mode Integrals Compared with regulatory PN23 (SPCS) data









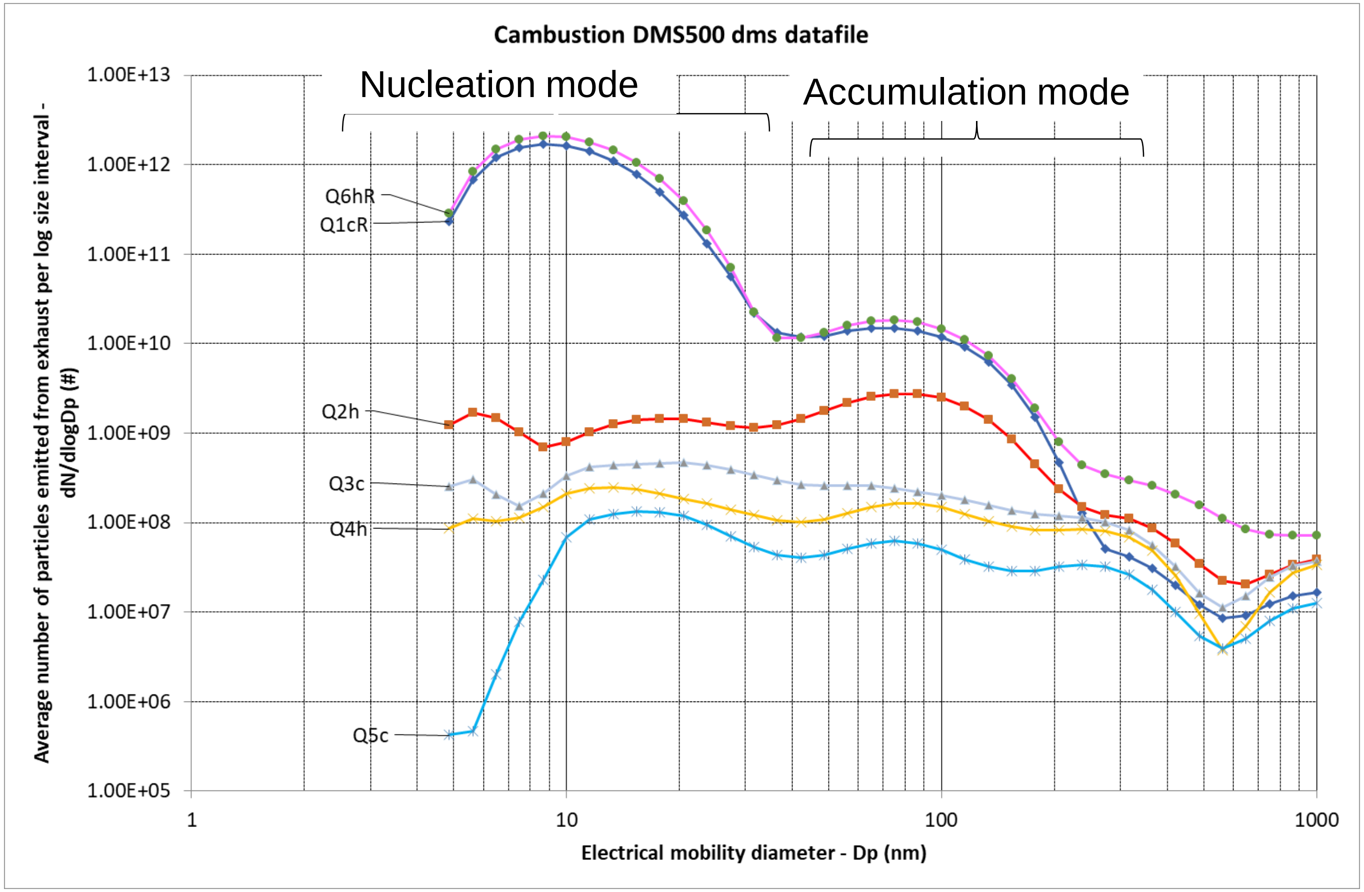


Data shown compare the DMS nucleation and accumulation mode integrals with the regulatory PN result from the SPCS, including PCRF. The order of the data in the three columns is, left to right:

DMS_Nuc ▶ DMS_Acc_ ▶ SPCS23

- Highest emissions are observed in the DMS nucleation mode from A1cR and A6hR, with elevated emissions in both the motorway section, related to the regenerations, and (of uncertain origin) in the cold urban phase#1 (cU) prior to the regenerations. It appears that engine starts that precede DPF regenerations have higher emissions of nucleation mode/volatile particles than the regenerations themselves. Emissions from both these bags were in the range >10^{13}#/km to almost 10^{15}#/km.
- Generally the accumulation mode integral from the DMS was similar to the SPCS PN23 result, especially during regenerations, which is expected as both the SPCS and DMS accumulation mode generally identify solid / carbon particles. However, in the cU phase the DMS_Acc integral is almost 1000x greater than the SPCS result (5x10^{12}#/km v 8x10^{9}#/km) indicating that the high level of nucleation mode particles observed is derived from a large volatile particle mode that also significantly overlaps the accumulation mode region. The SPCS eliminates volatile particles as part of the sample conditioning process, and so does not indicate the presence of these particles.
- [Note that Some DMS data are “missing” / below the detection limit]

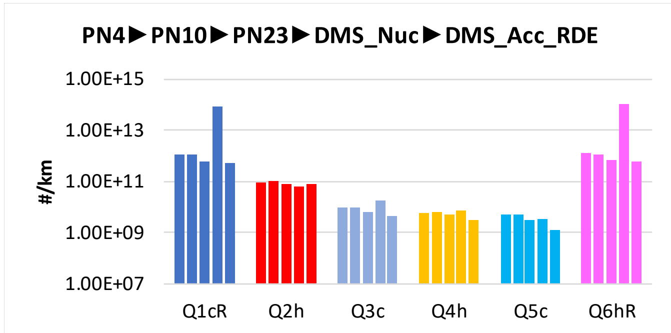
Qashqai Particle Size Distributions (#/s)

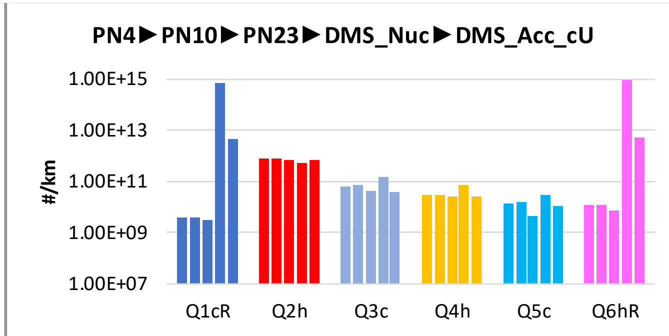


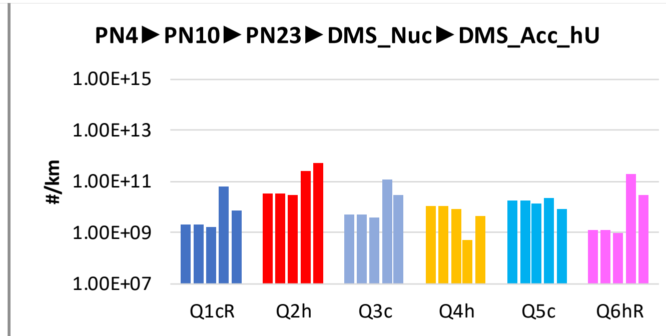
- DMS particle size distributions show:
  - Highest nucleation mode particle numbers from tests associated with regenerations, and the peak of the size distribution is largest with the highest PN levels
  - Highest nucleation mode PN were seen from the completed regenerations Q1cR and Q6hR
  - Highest soot (accumulation mode) levels were seen from regenerating tests, and levels were highest from Q1cR and Q6hR, and the test that follows a regeneration (Q2h) where the soot cake of the DPF is recovering
  - Lowest particle numbers from hot start test (A4h) and Q5c immediately before the regeneration in Q6hR

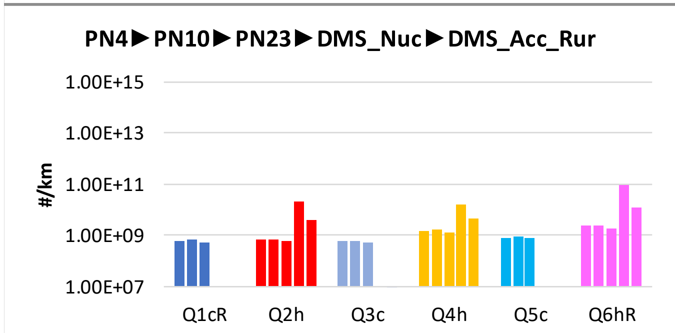
Final

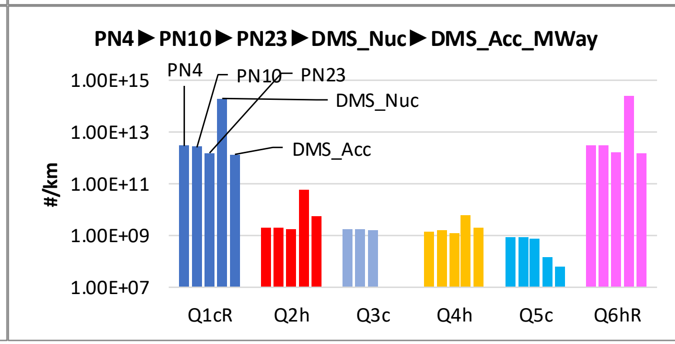
Qashqai: DMS Nucleation Mode and Accumulation Mode Integrals Compared with PN4, PN10 and PN23 DownTo10 data











Data shown compare the DMS nucleation and accumulation mode integrals with the >4nm, >10nm and >23nm PN DownTo10 system data which is subject only to dilution correction (no correction for losses is applied). The order of the data in the five columns is, left to right:

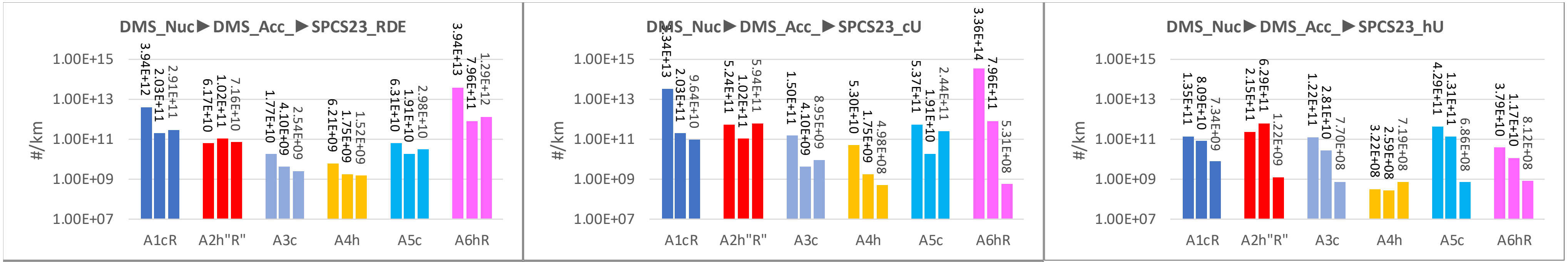
PN4►PN10►PN23►DMS_Nuc►DMS_Acc

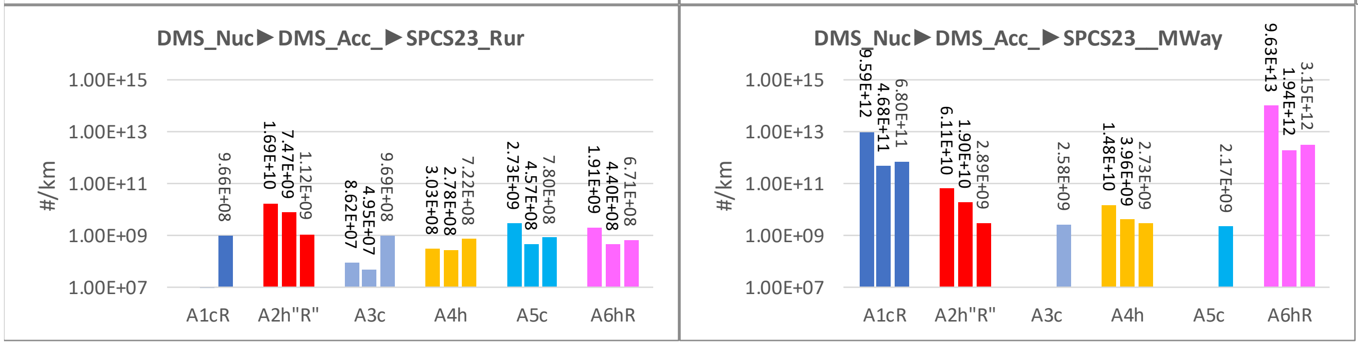
- Comparing the first two columns shows that there is minimal difference between PN4 and PN10, this likely indicates that the are few, if any PN present below 10nm, even during regenerations on the Qashqai.
- PN levels from the 3rd column (PN23) are a little lower than PN10, indicating that there are particles present between 10nm and 23nm. The most likely explanation for this effect is that the size distribution of particles being measured begins, at its lower end, around 10nm. These particles do not massively increase the overall particle number.
- Considering the DMS data, the cU, hU and Rur cycles indicate elevated nucleation and accumulation mode particles in several RDE cycles, but these increases are not indicated in the DTT data, which uses a catalytic stripper to eliminate volatiles. Therefore the PN observed by the DMS, but not in the DTT data, must be volatiles.

[Note that Some DMS data are “missing” / below the detection limit]

Final

Astra: DMS Nucleation Mode and Accumulation Mode Integrals Compared with regulatory PN23 (SPCS) data

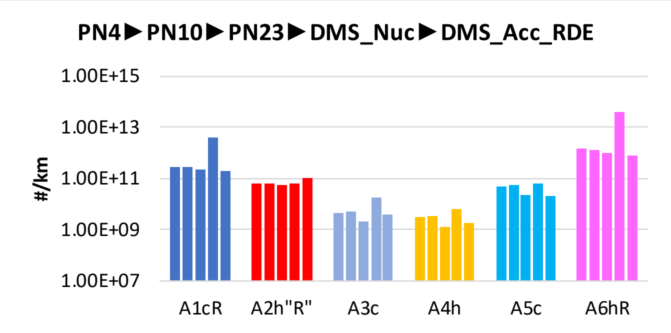


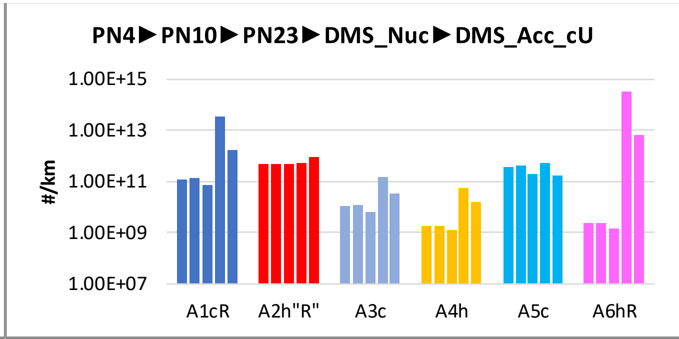


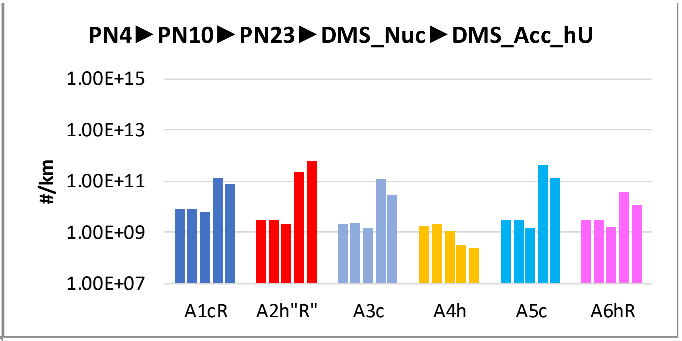
Data shown compare the DMS nucleation and accumulation mode integrals with the regulatory PN result from the SPCS, including PCRF. The order of the data in the three columns is, left to right:
DMS_Nuc▶DMS_Acc_▶SPCS23

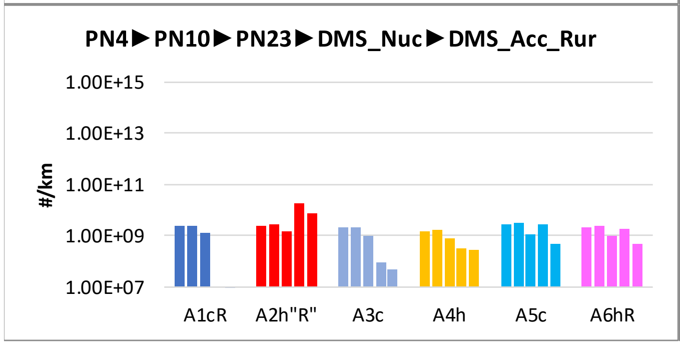
- Highest emissions are observed in the DMS nucleation mode from A1cR and A6hR, with elevated emissions in both the motorway section, related to the regenerations, and in the cold urban phase#1 (cU) prior to the regenerations. Emissions from both these bags were in range 10^{13}#/km to >10^{14}#/km.
- Generally the accumulation mode integral from the DMS was similar to the SPCS PN23 result, including during regenerations, which is expected as both the SPCS and DMS accumulation mode generally identify solid / carbon particles. However, in the cU phase the DMS_Acc integral is >1000x greater than the SPCS result ($8x10^{11}$#/km v $5x10^{8}$#/km) indicating that the high level of nucleation mode particles is derived from a large volatile particle mode that also overlaps the accumulation mode region. The SPCS eliminates volatile particles as part of the sample conditioning process, and so does not indicate the presence of these particles.

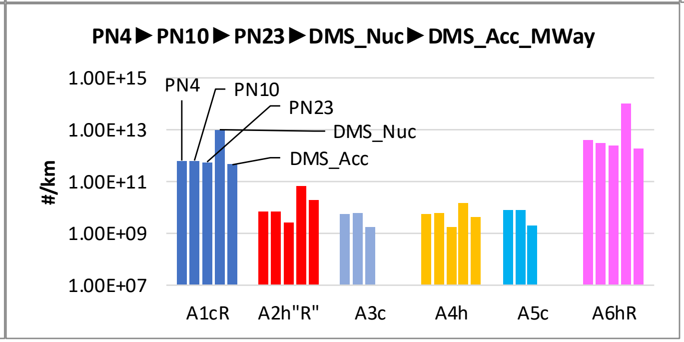
Astra: DMS Nucleation Mode and Accumulation Mode Integrals Compared with PN4, PN10 and PN23 DownTo10 data









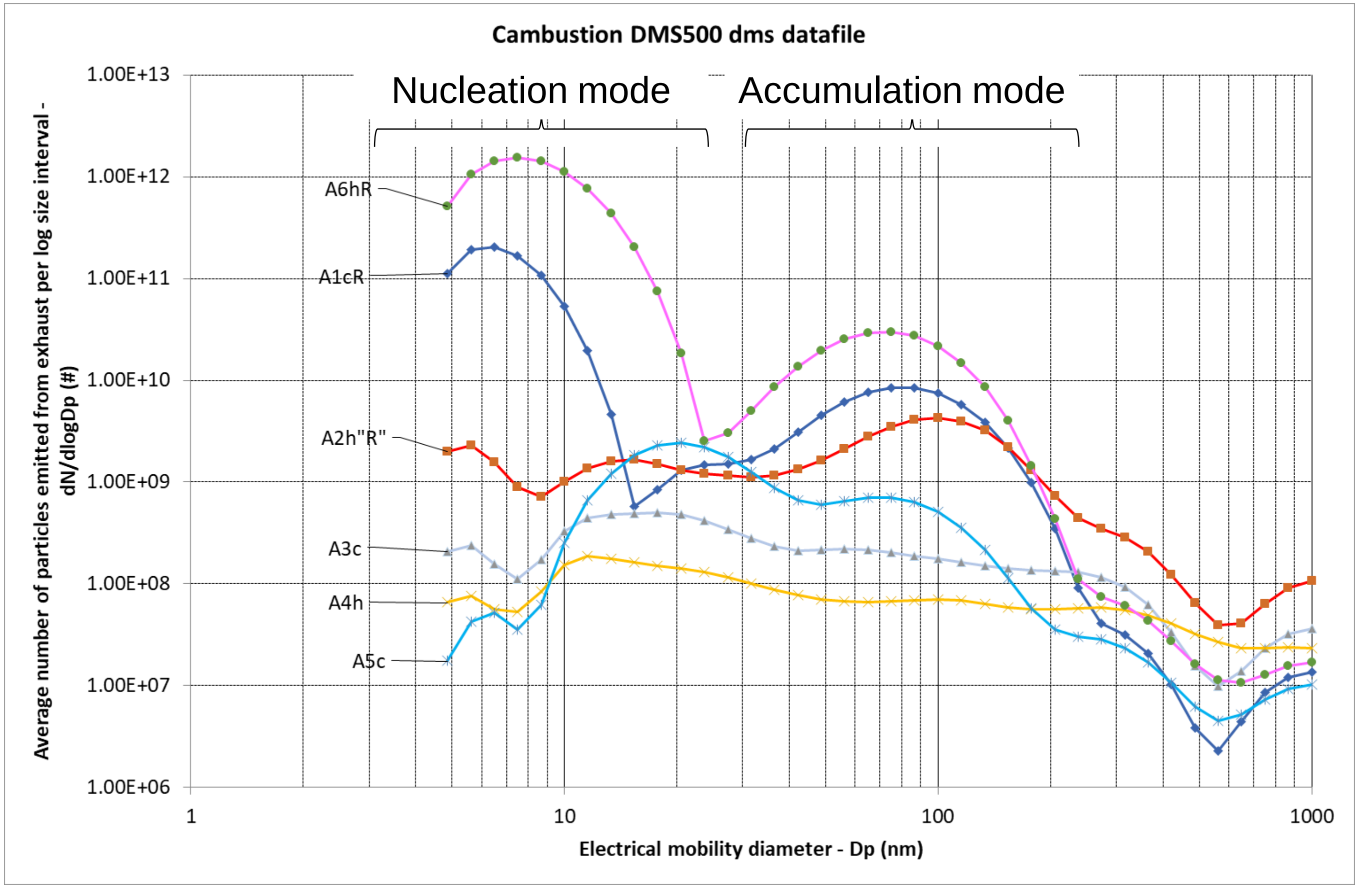


Data shown compare the DMS nucleation and accumulation mode integrals with the >4nm, >10nm and >23nm PN DownTo10 system data which is subject only to dilution correction (no correction for losses is applied). The order of the data in the five columns is, left to right:
PN4▶PN10▶PN23▶DMS_Nuc▶DMS_Acc

- Comparing the first two columns indicates that there is minimal difference between PN4 and PN10, this likely indicates that the are few, if any PN present below 10nm, even during regenerations on the Astra
- PN levels from the 3rd column (PN23) are a little lower, indicating that there are particles present between 10nm and 23nm. The most likely explanation is that the size distribution of particles being measured begins, at its lower end, around 10nm. These particles do not massively increase the overall particle number.
- Considering the DMS data, the cU and hU cycles indicate elevated nucleation and accumulation mode particles in several RDE cycles, but these increases are not indicated in the DTT data, which uses a catalytic stripper to eliminate volatiles. Therefore the PN observed by the DMS must be volatiles.

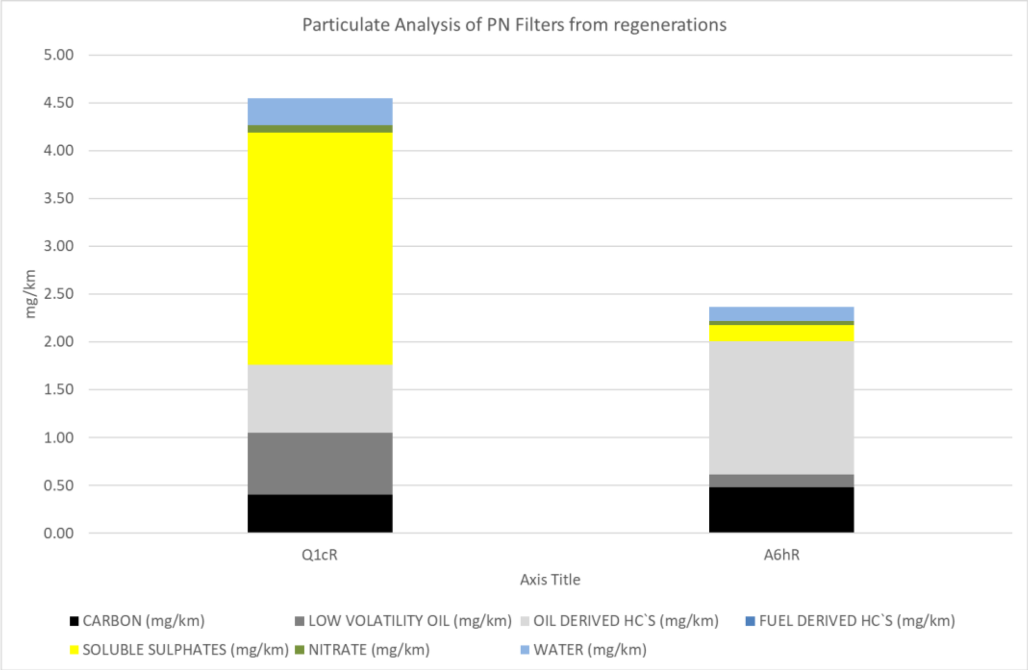
Final

Astra Particle Size Distributions (#/s)



- DMS particle size distributions show:
  - Highest nucleation mode particle numbers from tests associated with regenerations, and the peak of the size distribution is largest with the highest PN levels
  - Highest nucleation mode PN were seen from the completed regeneration A6hR
  - Highest soot (accumulation mode) levels with seen from regenerating tests, and again levels were highest from A6hR
  - Lowest particle numbers from hot start test (A4h)

Chemical analysis of PM from DPF regenerations



- Chemical analyses were performed on PM filters from regenerating and non-regenerating tests
- From the non-regenerating tests, analyses were indistinguishable from those of blank filters due to low masses
  - typical filter masses were <20µg and in most cases zero
- From the regenerating tests on both vehicles regeneration occurred in the 4th phase of the RDE and the filter associated with this phase was analysed
  - Major chemical components could be clearly identified, although the oil derived HC levels were high in the blank filter and these may be over-stated in the results

- The PM emission from Q1cR was higher than that of A6hR, due to a large release of sulphates from the Qashqai that was not present in in the Astra sample. It is mostly likely that this is related to a higher PGM loading in the Qashqai aftertreatment, meaning that its ability to trap, store and release sulphate at high temperatures (>600°C) is greater. It's also possible that the Qashqai could be running of a higher sulphur lubricant, which could also affect stored sulphate, but this is considered unlikely. The mass of sulphate released from the Qashqai was ~2.43mg/km over the 34.7km phase, which equates to ~0.2mg/km over the entire regeneration interval.
- Similar amounts of carbon were present in the PM from the two vehicles equating to 30 to 40µg/km over the regeneration interval.
- Lubricant-derived materials were present in the PM. Low volatility oil, which indicates the presence of oil polymers such as viscosity improvers, could be seen at levels similar to or below that of carbon. Oil basestock HCs were also identified, but confidence in quantifying these accurately is low due to the presence of similar volatility HC in the blank filters. Minimal fuel HC were present
- Low levels of nitrate were present in the sample along with some water
- Low volatility HC from the lubricant, along with sulphates, will contribute to a nucleation mode during regeneration

Emissions Results Sub-sections

- Regeneration occurrences and identification
- Regeneration duration, regeneration periodicity/cycle
- Bagged Emissions Results
- Additional gaseous and particle emissions
- Quantifying regeneration impact

WLTP regulatory approach to regeneration impact, and Ki factor

RICARDO

(1) $$M_{si} = \frac{\sum_{j=1}^{n} M'_{sij}}{n} \qquad n \geq 2$$

(2) $$M_{ri} = \frac{\sum_{j=1}^{d} M'_{rij}}{d}$$

(3) $$M_{pi} = \left\{ \frac{M_{si} \cdot D + M_{ri} \cdot d}{D + d} \right\}$$

where for each pollutant (i) considered:

M'_{sij} = mass emissions of pollutant (i) in g/km over one Type I operating cycle (or equivalent engine test bench cycle) without regeneration

M'_{rij} = mass emissions of pollutant (i) in g/km over one Type I operating cycle (or equivalent engine test bench cycle) during regeneration (if **d** > 1, the first Type I test is run cold, and subsequent cycles are hot)

M_{si} = mean mass emission of pollutant (i) in g/km without regeneration

M_{ri} = mean mass emission of pollutant (i) in g/km during regeneration

M_{pi} = mean mass emission of pollutant (i) in g/km

n = number of test points at which emissions measurements (Type I operating cycles or equivalent engine test bench cycles) are made between two cycles where regenerative phases occur, ≥ 2

d = number of operating cycles required for regeneration

D = number of operating cycles between two cycles where regenerative phases occur

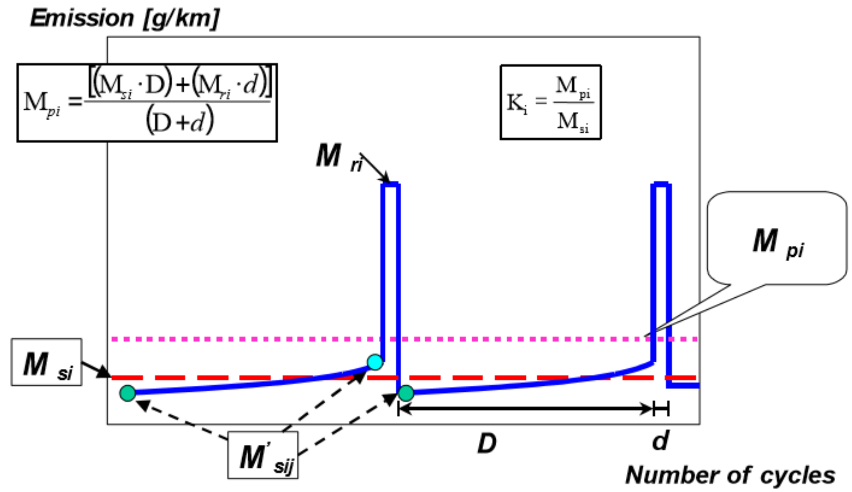


Figure 8/1: Parameters measured during emissions test during and between cycles where regeneration occurs (schematic example, the emissions during 'D' may increase or decrease)

Calculation of the regeneration factor K for each pollutant (i) considered

$K_i = M_{pi} / M_{si}$

M_{si}, M_{pi} and K_i results shall be recorded in the test report delivered by the technical service.

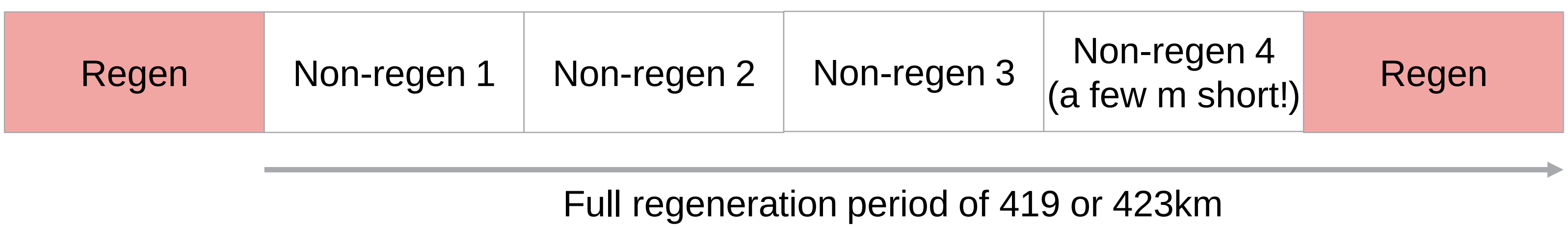
K_i may be determined following the completion of a single sequence.

Notes: there is currently no regulatory Ki factor for PN; Ki factor cannot be < 1

Quantifying the regeneration impact

- The impact of DPF regenerations on emissions is considered in the following section. The regulatory approach (see slide 99 entitled "Regulatory approach to regeneration impact, and Ki factor") has been applied to entire cold start RDE cycles. Increases in emissions, on a per km basis, between non-regenerating driving and regenerating driving are calculated along with the Ki.
- For the Qashqai
  a) The regulatory approach has been applied to the entire cold start RDE cycle featuring a regeneration (Q1cR), the average cold start emissions of tests Q3c and Q5c, regeneration interval of 423km, and setting the number of cycles between regenerations to 4* (calculated as 3.995, but 4.0 was used). This approach is applied all regulated gases, unregulated gases, PM and PN, including DMS integrals.
- For the Astra
  b) The regulatory approach has been applied to the entire hot start RDE cycle featuring a complete regeneration (A6hR), the hot start emissions of test A4h, regeneration interval of 419km, and setting the number of cycles between regenerations to 3.94* (the distance between regenerations equates to just less than 4 complete RDEs). This approach is applied all regulated gases, unregulated gases, PM and PN, including DMS integrals. A2h"R" was excluded as the impact of the prior regeneration on the early part of this cycle would have led to unrepresentative "weighted" results.
  – A "pseudo-cold start regenerating RDE" result has been calculated by adding the difference between the non-regenerating cold start RDE emissions results (average A3c, A5c) and the non-regenerating hot start RDE emissions result (A4h) to the A6hR result. This "AcR" result and the mean of A3c and A5c are then used in the regulatory approach, as with the Qashqai cold RDE (a, above) and Astra hot RDE (b, above) results

Ki factor employs regeneration cycle distance and number of tests between regenerations

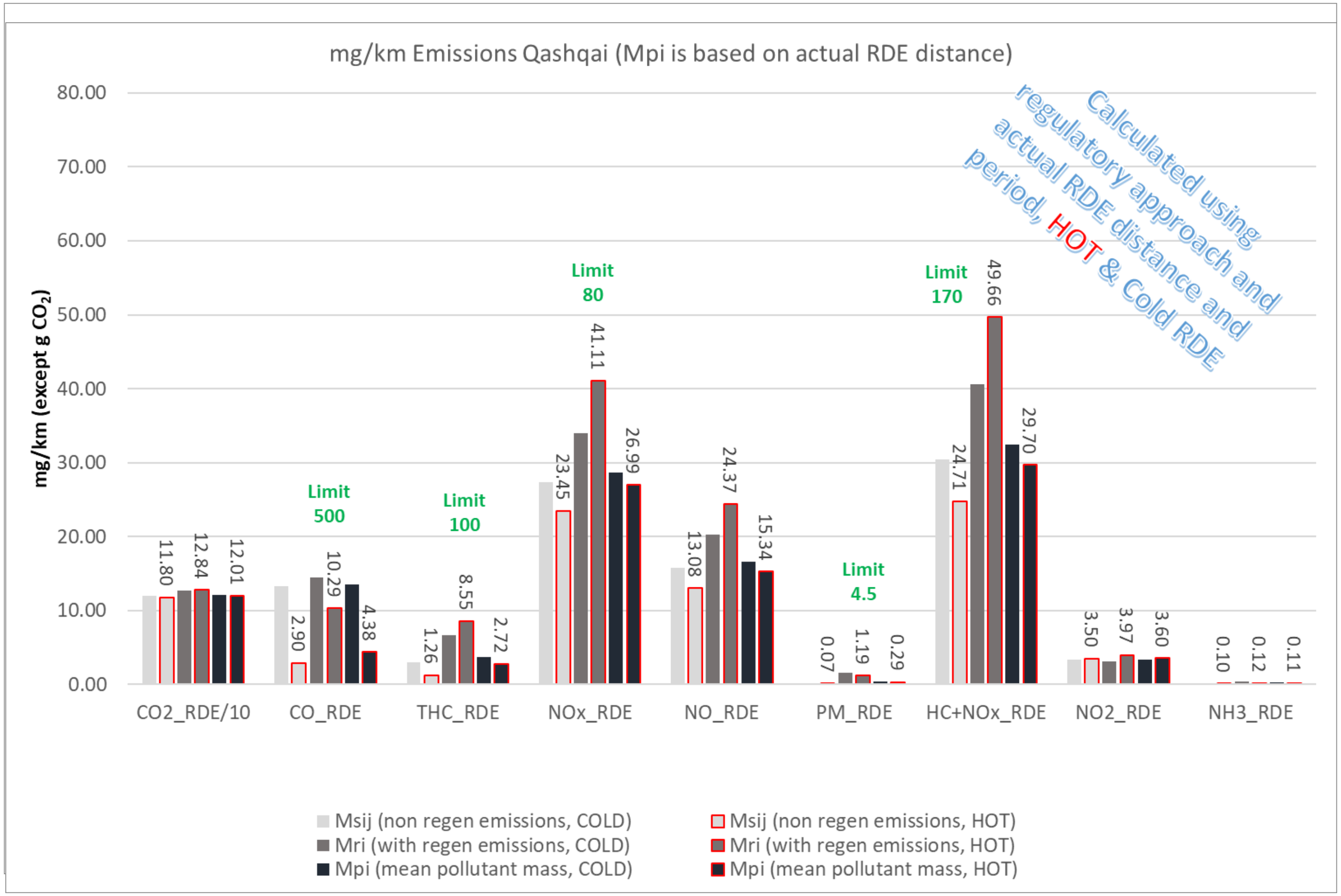


* Actually the number of cycles between regenerations is supposed to be the number of ***complete*** cycles, so properly this should be 3 cycles. However, values are extremely close to 4 and given the length of the RDE, and thus limited number of cycles possible in even a long regeneration period, 4 is reasonable for the Qashqai, slightly lower for the Astra.. Note that for the regeneration intervals (~420 km) both vehicles would experience almost exactly 17 WLTC cycles, leading to much less scope for difference if one WLTC more (or less) is used for calculations.

Quantifying the regeneration impact: sub-menu

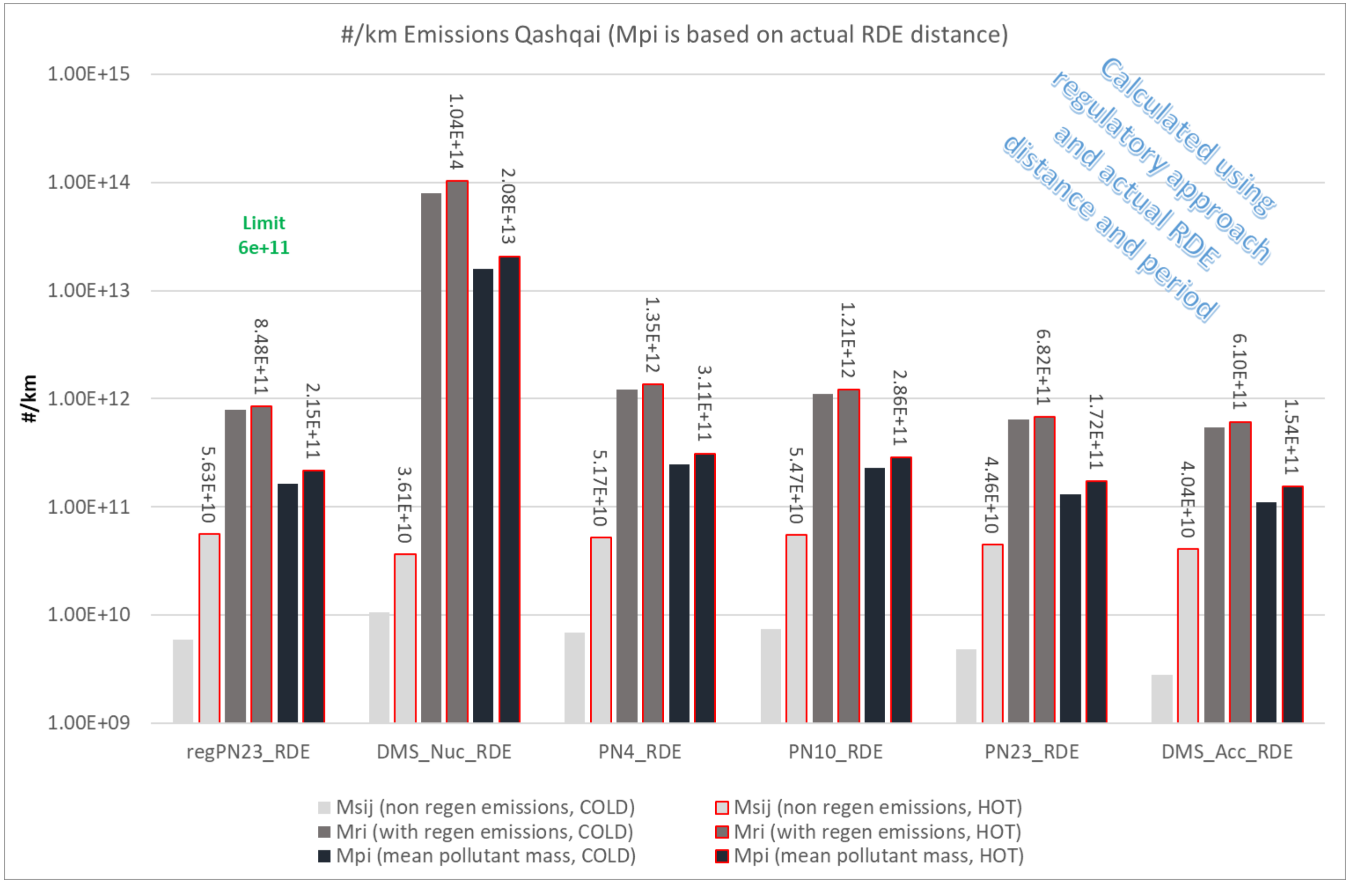
- Qashqai
- Astra
- Regeneration impact of vehicles compared

Qashqai: mg/km emissions from non-regenerating, regenerating and weighted RDE cycles



- All regulated gaseous emissions and PM are compliant with Euro 6 limits
- Emissions increases during regeneration are only substantial for gaseous HC emissions (and therefore effecting a shift in HC+NOx), plus an increase in PM. A slightly greater NOx increase is observed with the hot regeneration (Q6hR) than with Q1cR
- Weighted cycle emissions for all gases show limited increases relative to non-regenerating results, anticipating low Ki factors
  - PM increases by a significant factor but from a very low initial level to well below the limit value

Qashqai: #/km emissions from non-regenerating, regenerating and weighted RDE cycles (cold and hot RDE)



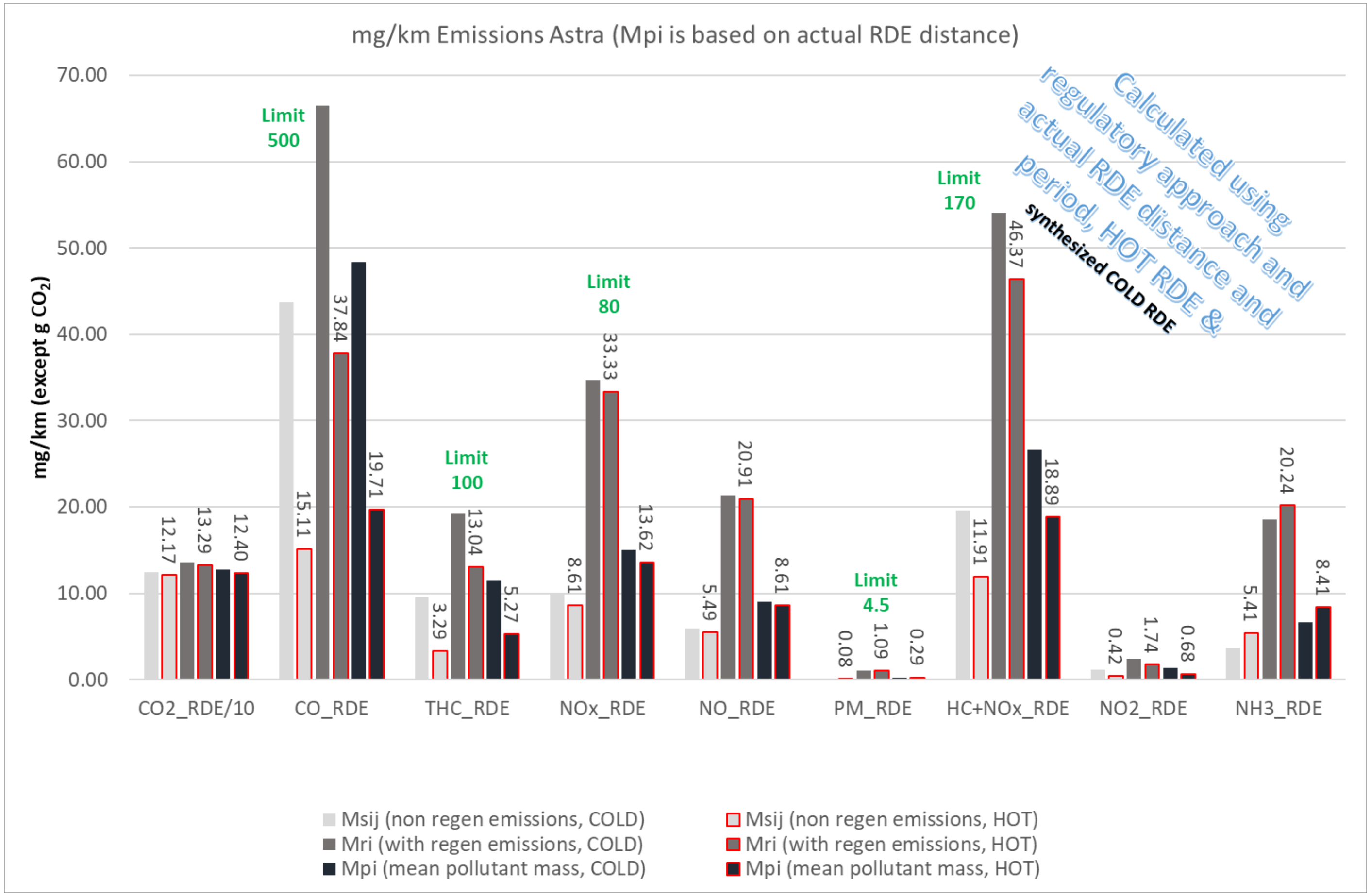
Non-regenerating hot cycle PN emissions were substantially higher (~5x10^{10}#/km) than cold cycle PN (< 10^{10}#/km), this is likely to have a large impact on Ki factors, limiting hot factors compared to cold

- Regulatory PN23 emissions are fully compliant with the Euro 6d limit value from the weighted RDE, but exceed the limit during regeneration
- The same is true for PN4, PN10 and PN23 from the DownTo10 system. Particle losses at 10nm may mean that 20-30% of PN10 may be missed by the quantification, but even so, the weighted RDE result would still be comfortably below the emissions limit of 6x10^{11}#/km. Elevated PN10 levels may contain ash particles as well as <23nm soot
- Nucleation mode PN levels from the DMS increase dramatically during cycles that include regenerations – as shown previously at start-up (cU phase) - and during the active regeneration (in the Mway phase). The number of particles observed is dependent on the dilution conditions and environment (temperature, dilution ratio, saturation ratio, humidity, residence time during dilution) and so will not be representative of real world effects on volatile PN production (one reason why we do not currently regulate these particles). However, it is clear that the regeneration releases substantial amounts of condensable species that are not present during non-regenerating operation. It is worth noting that volatile PN emissions levels during regeneration are similar to those of soot particles in non-DPF diesel applications
- DMS accumulation mode effects are similar to regPN23

Quantifying the regeneration impact: sub-menu

- Qashqai
- Astra
- Regeneration impact of vehicles compared

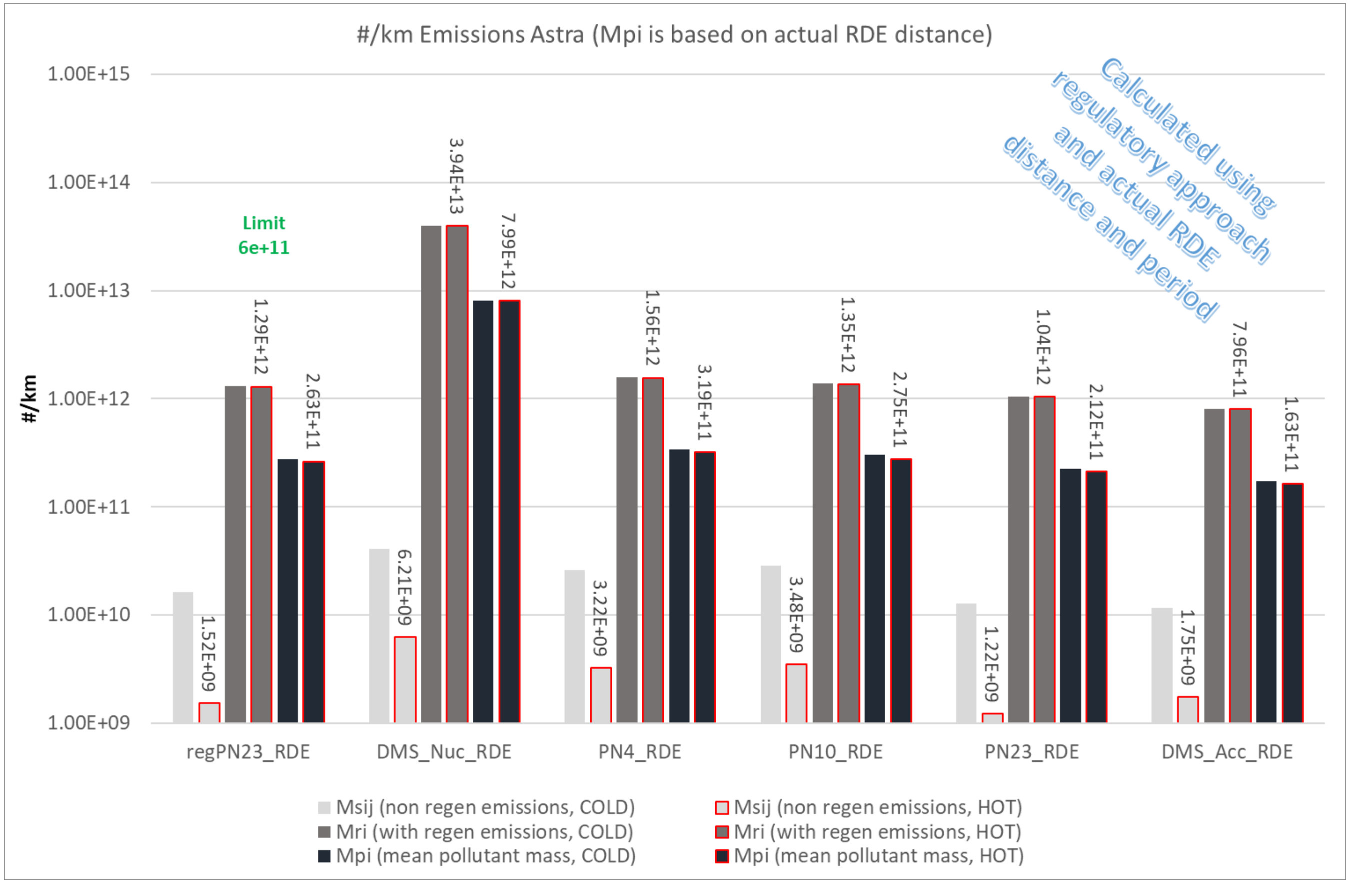
Astra: mg/km emissions from non-regenerating, regenerating and weighted HOT & Synthesized COLD RDE cycles



- All regulated gaseous emissions and PM are compliant with Euro 6 limits for both hot and cold RDE results
- Emissions increases from cold to hot start are most substantial in gaseous CO & HC emissions (and also HC+NOx), plus an increase in PM, possibly related to cold start warm-up strategy and generally poorer fuel air homogeneity on cold start.
- Emissions increases between hot and cold RDE results during regeneration are apparent in almost all emissions (though small in CO_2 and NO_2).
- Largest regeneration effects are due to fuel-derived and partial combustion derived species (HC, HC + NOx, CO and PM). Ammonia also increases substantially with regeneration, probably due to slip through the SCR.

Final

Astra: #/km emissions from non-regenerating, regenerating and weighted HOT & Synthesized COLD RDE cycles



- PN emissions effects from the Astra were broadly the same as observed for the Qashqai.
- One interesting observation is the impact of the cold start on PN: this shows~10x as many solid, accumulation mode and nucleation mode PN than from the hot start test, and is in line with the higher PM shown previously
- However, since the weighted PN from all instruments is dominated by the regeneration contribution, the impact of this change (from 10^9 to 10^{10}) is minimal

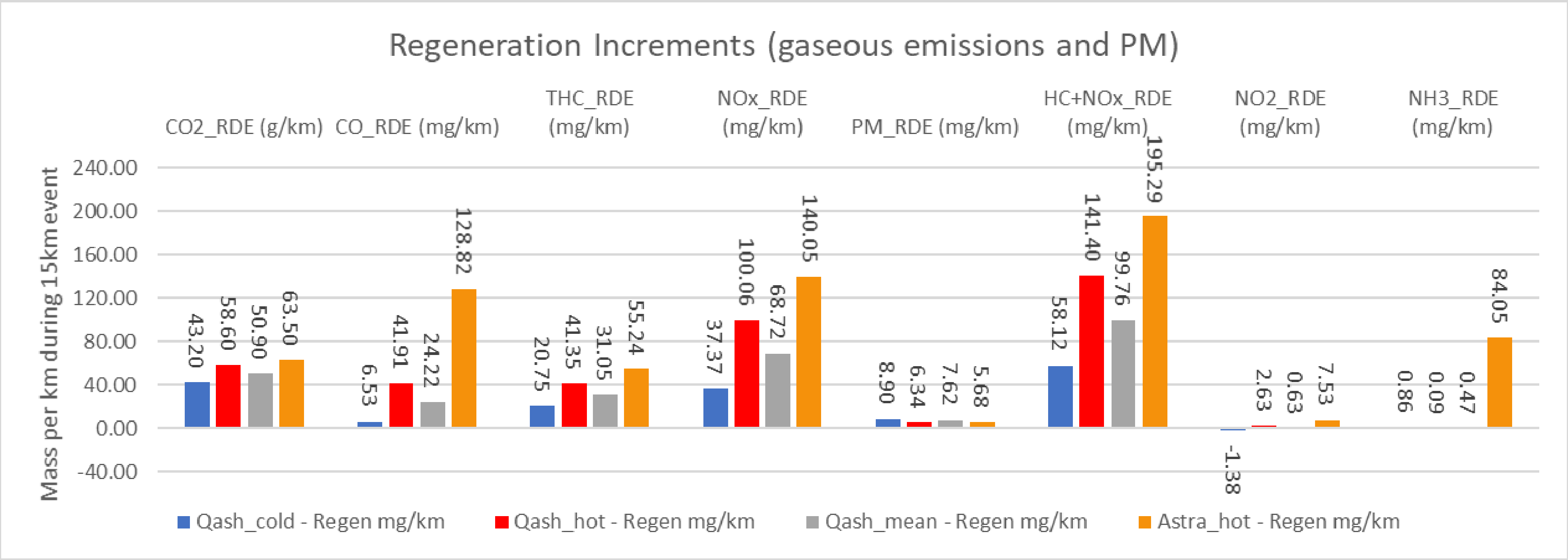
Quantifying the regeneration impact: sub-menu

- Qashqai
- Astra
- Regeneration impact of vehicles compared

Elevation in emissions/km during regeneration

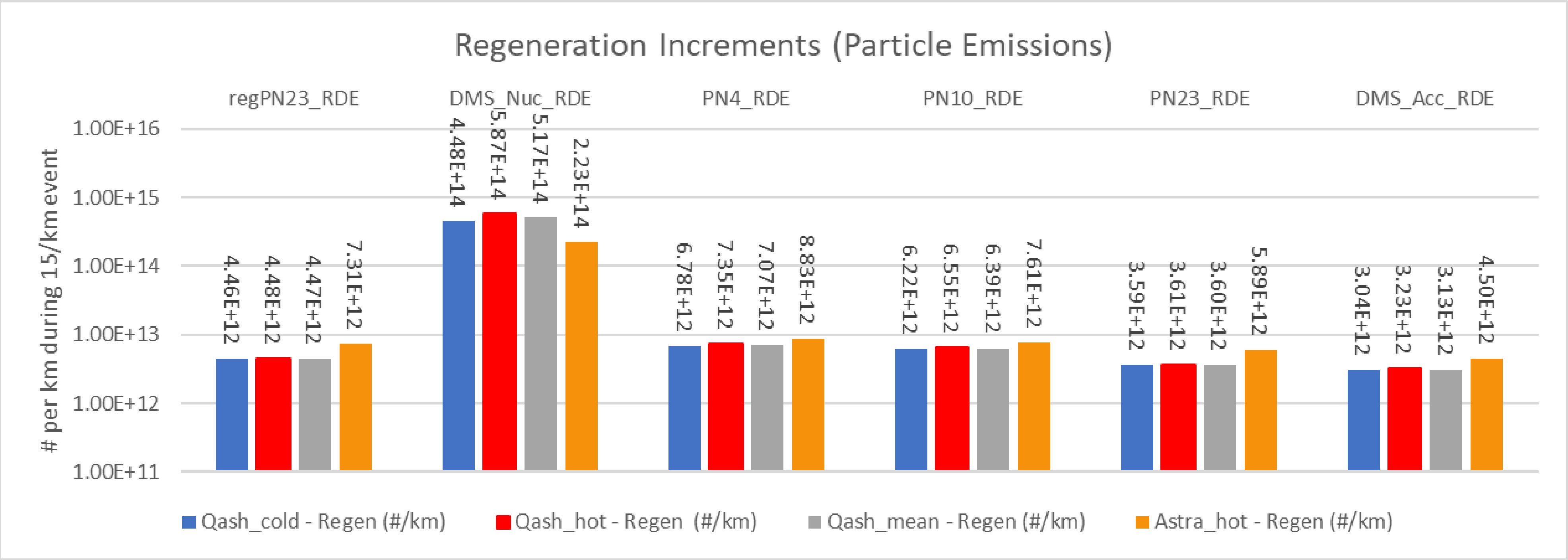
- Emissions per km increases during regeneration were determined by subtracting the non-regenerating emissions from an RDE cycle from the emissions determined from a similar (i.e. hot or cold) regenerating RDE cycle. This gives the extra emissions (mass or number) across the RDE cycle, approximately 85km in length.
- As stated previously, the actual distance during which the regeneration's instantaneous impact is observed differs between emissions. The longest period of the three pollutants studied: HC, CO and PN, was observed from PN and that equated to ~15km. A 15km period has therefore been assumed for the "active period of the regeneration" during the 85km cycle.
- The mass or number per km emissions during the regeneration period are therefore calculated as [85/15] * [regen RDE emission – non-regen RDE emission]. These data represent the additional emissions contributed by the regeneration, on a mass or number per km basis, during the nominal 15km period.
- For the Qashqai, these data are presented for cold and hot RDE, while for the Astra these are presented for hot RDE only

Elevation in mass/km emissions during the regeneration event



- In general, emissions increases during the regeneration event appear larger from the Astra than from the Qashqai, and from the Qashqai appear larger from hot start RDE than cold start RDE. More entire regeneration cycles would need to be tested to evaluate whether these are meaningful differences.
- During the regeneration event CO_2 is observed to increase by ~50 to 65g/km, while CO increases by 25-40mg/km (Qashqai) and ~130mg/km (Astra). Higher CO from the Astra may indicate a less active DOC (which aligns with the lower sulphate observed in the PM analysis). The HC increase from the Astra (~55mg/km) is ~35% higher than the Qashqai.
- The NOx emissions increase approaches 200mg/km from the Astra hot RDE, around 45% higher than the Qashqai hot RDE
- PM emissions increase by ~6-9 mg/km during the regeneration event, and NO_2 increases are at worst of a similar magnitude, despite the observed NOx increases.

Elevation in particles/km during the regeneration event

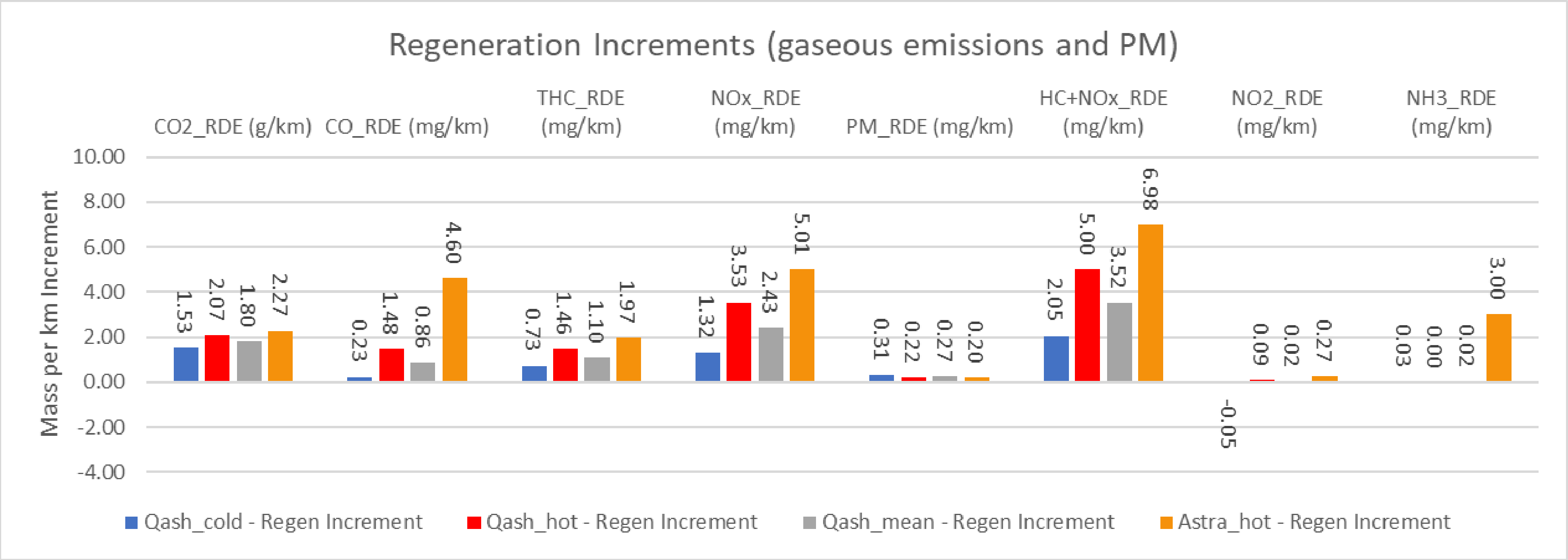


- In general, particle emissions increases during the regeneration event appear larger from the Astra than from the Qashqai, and from the Qashqai appear similar from hot start RDE than cold start RDE. The regeneration increment for particles dominates the overall emissions of both vehicles
- During the regeneration event non-volatile PN emissions are 5-10x the limit value ($6x10^{11}$#/km), though correcting the PN4 and PN10 data for losses would increase this slightly.
- The largest impact is seen with the DMS nucleation mode data, where PN emissions exceed 10^{14}#/km. It is important to note that formation of these particles is highly dependent on dilution conditions, and it is unlikely that the levels observed in these tests will be representative of real-world particle formation as the low dilution ratios of the CVS (3-30x approximately, >1s residence) do not compare well with the real-world dilution of the exhaust plume (>1000x after ~1s)

Regeneration impact of vehicles compared

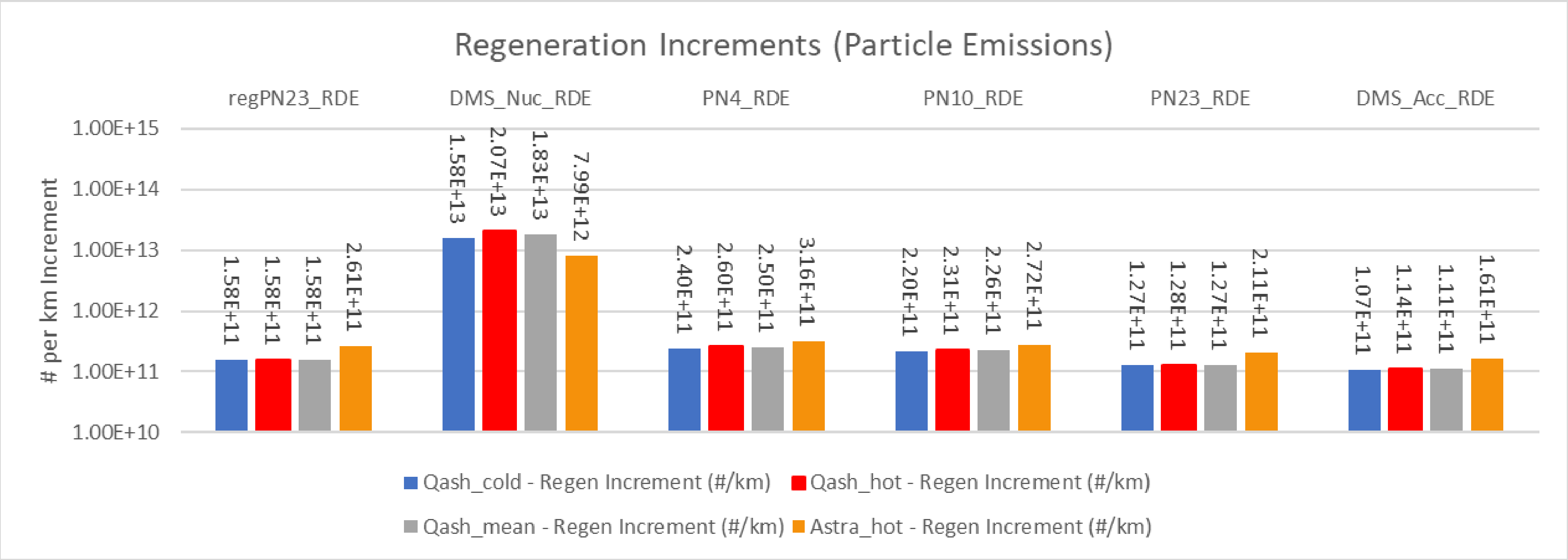
- The impact of regenerations on the increase in mass emissions throughout all driving is provided in this section
  - The impact is calculated by subtracting the per km non-regenerating pollutant mass (Msij - non regen emissions) from the weighted pollutant emissions result (Mpi -mean pollutant mass)
  - The resultant "Regeneration Increment" is the extra mass or number per km released on average in every km driven, due to the active regeneration frequency determined in this study
  - It should be noted that for the Qashqai both cold and hot Regeneration Increments can be generated from actual test results, but from the Astra only the hot Regeneration Increment data can be directly derived, and so only these 3 results are shown

Regeneration increments, mass/km



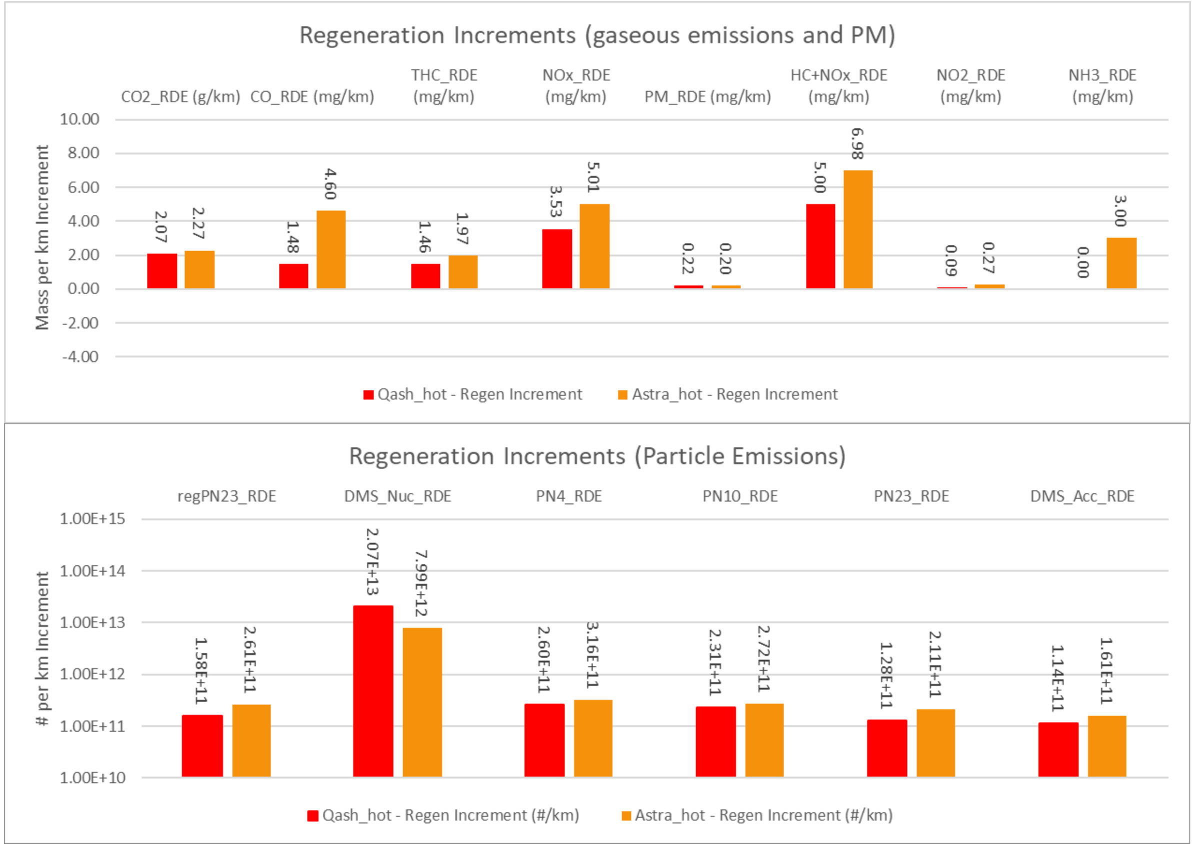
- From the data obtained in this study, the resulting effect of DPF regeneration is to add ~2g of CO_2, ≤ 4.5mg of CO, ≤ 5mg of NOx, but only < 300µg of NO_2 and ≤ 300µg of PM for each km driven through the life of the vehicle. The additional ammonia from the Astra is ~3mg/km, but the Qashqai adds only 1% of this.

Regeneration Increments, particles/km



- From the data obtained in this study, the resulting effect of DPF regeneration is to increase non-volatile PN emissions by 25% to 50% of the Euro 6d PN limit for each km driven.
- As non-regenerating PN emissions are generally so low, this is the main determinant of PN emissions from diesels that have DPFs with the characteristics and which use the same regeneration strategy as the Astra and Qashqai, but it is not clear if there are applications on the market with much lower regeneration PN emissions. There is no disproportionate impact on the emissions of <23nm PN.
- Nucleation mode PN levels are orders of magnitude higher than non-volatile particles, but while these can be measured repeatably, there is no current approach to measuring them representatively. On this basis it is difficult to know how significant this observation is, but it is clear that regenerations do emit substantial amounts of the precursors for volatile particle formation.

Regeneration Increments: Qashqai v Astra



- Comparing results from hot-start regenerations on both vehicles, incremental mass emissions are almost always higher from the Astra than from the Qashqai. This may reflect the more mature emissions control approach of the latter vehicle.
- A similar observation can be made for non-volatile particles
- Exceptions are PM, where levels are similar and volatile/nucleation mode particles, where emissions from the Qashqai are almost 3x as high. This increase may be linked to increased sulphate storage on the precious metals of the aftertreatment system, and its release during the regeneration.

Contents

Conclusions#1: Vehicles and on-dyno RDE

- An on-dyno RDE cycle, from a valid drive on a D-Class diesel, was employed for on-dynamometer RDE testing of two Euro 6d-temp certified diesel vehicles, an Opel Astra and a Nissan Qashqai. This cycle was employed at the request of T&E rather than drive on-road RDE tests with each test vehicle and use those as the bases of the dyno tests. This RDE replicated road speed, time and gradient of an on-road drive. Six on-dyno RDE tests were completed on each vehicle. These were tested in pairs, with the first test a 23°C "cold start" and the second a hot start later the same day

Conclusions#2: Regeneration Detection

- From both vehicles regenerations commenced in the motorway section at the end of the first cold start on-dyno RDE (Q1cR & A1cR) and in the motorway section of the sixth (hot start) on-dyno RDE (Q6hR & A6hR)
- DPF regenerations were detected on the two project vehicles in a number of ways: by OBD (Qashqai only) using a binary data flag and using exhaust temperature; by emissions of CO, HC and PN; by a surface thermocouple (Astra)
- From the Qashqai it was determined that regeneration periods determined from emissions were similar to the binary data flag, but from CO and PN onset and/or completion were subject to a time delay. HC emissions were near synchronous with the binary flag (at just less than 500s duration) which is not unexpected as HC post-injection initiates the regeneration and so is the regeneration cause, while CO and PN emissions increases are regeneration effects that can be attributed to both fuel and soot burning. PN emissions were both delayed in rising after regeneration initiation, and slow to fall, indicating some degree of self-sustaining soot combustion.
- Since regenerations impact on emissions for different durations depending on the particular species studied, the distance driven during the period, when the emissions effect is observed, varies. In this study that distance was between ~11.5km and ~15km.
- Regeneration periodicity for the Qashqai (start of regeneration #1 to start of regeneration #2) was ~420km. Astra periodicity, based upon HC, was also ~420km. While these two vehicles demonstrated similar regeneration periods, it is not necessarily the case that approaches to regeneration employed on these vehicles are representative of all Euro 6d-temp/6d diesels on the market.
- Analysis of real-time exhaust flow and DPF delta-pressure data indicated that increases in PN are not correlated with exhaust flow spikes, and thus are not related to particles ‘blowing off’ the DPF, but that there was a clear indication of reduced delta-pressure as DPF regenerations progressed and soot was removed from the filter.

Conclusions#3.1: Emissions levels and regeneration contributions

- From both the Qashqai and the Astra
  - Hydrocarbons from the RDE (and individual bags from cold urban [cU], hot urban [hU], rural [Rur] and motorway [Mway]) were less than 15% of the Euro 6d 100mg/km limit. Highest emissions were in cU phase due to the catalyst light-off impact, and from the MWay phase when regenerations were observed. HC emissions from regenerating MWay cycles were ~20x the <1mg/km levels seen from non-regenerating MWay cycles
  - CO emissions results showed similar trends to those observed for HC, although Astra CO emissions in cold start and during regenerations were substantially higher (although still below the 500mg/km limit value) than from the Qashqai. It is proposed that this is due to a less mature catalyst heating strategy and less active oxidative emissions control system.
  - In comparison with an 80mg/km limit, NOx emissions from the RDE were at ~40mg/km or below from both vehicles, with Astra levels slightly lower than the Qashqai. During MWay operation, the presence of a DPF regeneration added ~30mg/km to that phase's result from the Qashqai (~25mg/km to ~55mg/km) and ~55mg/km to that phase's result from the Astra (~3mg/km to ~58mg/km). There was minimal difference between urban NOx emissions levels from cold and hot start RDE cycles on either vehicle, indicating good cold start NOx control.
  - PM emissions from the whole RDE, including cycles containing regenerations are <2mg/km for the Qashqai, <1mg/km for the Astra (Euro 6d limit value is 4.5mg/km). From the regenerations in the MWay section, independent of vehicle, PM emissions were ≤ 3.6mg/km, and while there was noticeable increment in PM in the cU phase of RDE tests following an MWay cycle with a regeneration, this increment disappeared during the subsequent hU phase, and the impact on overall PM was negligible.

Conclusions#3.2: Emissions levels and regeneration contributions

- From both the Qashqai and the Astra
  - HC+NOx emissions from whole RDE and individual bags, were < 110mg/km from the Qashqai and < 130mg/km from the Astra: comfortably compliant with the 170mg/km Euro 6d limit. There is a clear impact of regenerations in the Mway leading to increases of ~40mg and ~70mg/km in this phase from the Qashqai and Astra respectively – the effect being dictated by NOx emissions levels.
  - Regulatory PN23 emissions (using Horiba SPCS) from the whole RDE featuring a complete regeneration (A6hR, Q1CR and Q6hR) exceeded the $6x10^{11}$ #/km limit by ~40% (Qashqai) and ~115% (Astra). Non regenerating RDE emissions ranged from $\sim 2x10^{9}$ #/km to $\sim 10^{11}$ #/km. There was no obvious cold start impact on PN, but following incomplete regeneration at the end of A1cR, emissions from bag#1 approached the $6x10^{11}$ #/km limit value. PN levels had recovered to close to 10^{9}#/km by the end of bag#2 (PN_hU) in A2h"R", indicating that the DPF very quickly recovers filtration efficiency. When compared to non-regenerating MWay operation, PN increased by ~1000x during regenerations. These PN then dominate the emissions from the specific RDE and entire ~420km regeneration cycles.
  - Excepting test A2h"R" (the run-on regeneration following the Mway regeneration in the preceding A1cR) phase-specific NO_2 emissions levels were always < 9mg/km on the Qashqai and <2mg/km on the Astra, and consistent between cold and hot start tests. Maximum whole RDE NO_2 was <4mg/km on both vehicles (so <5% of the Euro 6d NOx limit). On the Qashqai, highest NO_2 was observed from the coldest cycle, cU, which is possibly indicative of non-aftertreatment NO_2 production in-cylinder. Small increases, of < 1mg/km (Qashqai) and ~3.5mg/km (Astra) were observed during the regeneration in the MWay phase. From the A2h"R" RDE cycle NO_2 reached 9mg/km, with urban cycle NO_2 exceeding 20mg/km.

Conclusions#3.3: CO_2 emissions levels and regeneration contributions

- From the Qashqai, dyno RDE CO_2 emissions were ~119g/km from non-regenerating tests compared to the WLTC certification figure of 144 g/km, with RDE certification CO_2 of 133 g/km
  - Dyno WLTC certification appears to have been undertaken at a higher road load than the RDE testing, leading to higher CO_2.
  - It should also be noted that the on-dyno RDE does not replicate transient increases in road load experienced while cornering, and any wind / weather effects will also tend towards higher on-road CO_2 than on-dyno CO_2.
  - From regenerating tests, CO_2 increased by 8 – 9 g/km (6-7%) compared to non-regenerating tests, while the impact of the regeneration in the motorway phase in isolation was a ~12.5% increase
  - A cold start v hot start effect on CO_2 is apparent when comparing the RDE result of Q3c and Q4h, where a reduction of ~1.6% is seen with the hot start
- Similar comparisons on the Astra showed dyno RDE CO_2 emissions at ~123 g/km from non-regenerating tests compared to the WLTC certification figure of 133 g/km, and road RDE CO_2 of 144 g/km. From the regenerating test, A6hR, CO2 increased by 10 g/km (~7.5%) compared to non-regenerating hot tests, while the impact of the regeneration in the motorway phase in isolation was a ~16.5% CO_2 increase. A reduction of ~2.2% is seen with the hot start dyno RDE relative to the cold start dyno RDE.

Conclusions#4: Additional pollutants and regeneration contributions

- Ammonia (NH_3): Qashqai ammonia emissions were well controlled at < 1mg/km across all bags and the whole RDE, including during regenerations, but Astra emissions from the RDE cycle were in the range 20-30mg/km from regenerating cycles and ~0.5 to ~6.5mg/km from other cycles. Astra RDE emissions were dominated by the motorway phase, where they approached 75mg/km with regeneration.
  - These difference between Qashqai and Astra emissions may be indicative of a mature urea dosing strategy including clean-up catalyst (CuC) and closed-loop NOx control in the Qashqai, probably aimed at Euro 6d final. The Astra approach may be less mature, lacking an ammonia slip / clean-up catalyst, an interim step aimed beyond Euro 6d-temp compliance, but with scope for further improvement.

Conclusions#5: Nucleation mode / Volatile Particle Emissions from the DMS500

- Nucleation mode particle emissions were generally similar to accumulation mode levels excepting during the DPF regenerations experienced in the MWay phases on both vehicles. During regenerations, levels of the nucleation mode increased by >1000 times, with highest emissions observed from the Qashqai (approaching 10^{15}#/km). Astra nucleation mode emissions peaked above 10^{14}#/km. These levels are similar to those observed from pre Euro 5 diesels without DPFs.
- Elevated nucleation mode particle levels were also observed in the cold start (cU) phases of all dyno RDEs that ended with regenerations in the MWay phase. It is not clear what creates this phenomenon, but the particle production effect also contributes to increases in the DMS accumulation mode.
- Size distribution data indicated a 6-10nm nucleation mode peak from both Qashqai and Astra from RDE cycles that feature regenerations, with lower modal diameters observed with lower particle numbers. This is indicative of the presence of less volatile/semi-volatile materials in the dilution tunnel restricting particle growth.
  - Particle formation and growth is highly dependent on dilution characteristics such as temperature, dilution ratio, dilution rate and the presence and partial pressures of particle precursors. The CVS dilution tunnel is an ideal place for forming particles, but is not representative of tailpipe dilution conditions, so volatile particle levels measured in this work will not necessarily reflect real-world emissions.

Conclusions 6: Particulate filter analyses

- Chemical analysis of PM filters collected from MWay phase tests during DPF regenerations indicated a significant difference between the Qashqai and the Astra. The Qashqai filter contained a significantly higher level of sulphates (~2.4 mg/km over the Mway) than the Astra (0.1mg/km). It is mostly likely that this is related to a higher PGM loading in the Qashqai aftertreatment, meaning that its ability to trap, store and then release sulphate at the high temperatures experienced in the regeneration (>600°C) is greater. It's also possible that the Qashqai could be running of a higher sulphur lubricant, which could also increase stored sulphate, but this is less likely.
  - Sulphates provide 1-5 nm nuclei that encourage nucleation modes to form through condensation of hydrocarbons (unburned fuel and lubricant) in the dilution tunnel. This explains why higher nucleation mode levels are observed from the Qashqai than from the Astra

Conclusions 7: Non-volatile PN emissions; solid and volatile PN in the <23nm range

- From both the Qashqai and the Astra, there is minimal difference between PN4 and PN10 emissions, this likely indicates that there are limited levels of PN present below 10nm, even during regenerations. This is consistent with current understanding that the wall-flow particle filters fitted to both vehicles are more efficient for <20nm PN than for >20nm PN. It should be noted that as particle size decreases sampling losses increase, so levels of PN4 and PN10 would increase if a loss correction applied. Even so, it is anticipated that differences between PN4 and PN10 would be limited.
- PN23 levels are a little lower than PN10, indicating that there are particles present between 10nm and 23nm. The most likely explanation is that the size distribution of particles being measured begins, at its lower end, around 10nm, and extending the size measured to 10nm includes the leading edge of the size distribution. These particles do not substantially increase the overall particle number.
- Considering the DMS data, the cU and hU cycles indicate elevated nucleation and accumulation mode particles in several RDE cycles, but these increases are not indicated in the DTT data, which uses a catalytic stripper (effectively an oxidation catalyst) to eliminate hydrocarbons. Therefore the elevated PN observed concurrently in both nucleation mode and accumulation mode by the DMS, are likely to be volatiles.

Conclusions 8.1: Weighted RDE Emissions according to the regulatory approach*, Qashqai

- After weighting the results, all regulated gaseous emissions and PM were comfortably compliant with Euro 6 limits. Emissions increases during regeneration were only substantial for gaseous HC emissions (and therefore effecting a shift in HC+NOx), plus an increase in PM. A slightly greater NOx increase is observed with the hot regeneration (Q6hR) than with Q1cR
- Weighted cycle emissions for all gases show limited increases relative to non-regenerating results, anticipating low Ki factors
- PM increases by a significant factor but from a very low initial level to just over 1mg/km, still less than 20% of the limit value
- Weighted PN emissions results from PN4, PN10 and the DMS accumulation mode were all well below $6x10^{11}$#/km. Conversely, nucleation mode emissions were ~30 times that level, due mainly to the influence of sulphate emissions driving nucleation mode formation in the CVS and so will not be representative of real world effects on volatile PN production (one reason why we do not currently regulate these particles). However, it is clear that the regeneration releases substantial amounts of condensable species that are not present during non-regenerating operation, even if these did not to form as many particles under more realistic dilution conditions.

*As described on slide 99

Conclusions 8.2: Weighted RDE Ki factors according to the regulatory approach*, Qashqai

- The Ki factors for the majority of gaseous species are below 1.05 from cold cycles, with only fuel HC-related species (HC and HC+NOx) and ammonia (from urea injection to manage the elevated engine-out NOx from regeneration) higher than this
- NO_2 emissions were reduced from the cold regeneration Q1cR (and thus weighted RDE results) compared to non-regeneration tests, and have Ki <1.
- PM from the Q1cR has a Ki factor of ~6.5 indicating a large increase in material collected on the filter during regeneration. This has been shown to be derived from released sulphates and other volatile materials, as well as soot that escapes the DPF
- In general Ki factors from hot start RDE cycles are similar to or higher than from cold start cycles, in particular for the fuel related components (CO, THC), since the baseline emissions of these species are lower
- The cold cycle Ki factors for non-volatile PN (reg PN23, PN4, PN10, PN23 and DMS accumulation mode) are all broadly similar, since they address the same metric. The 27 to 40 range reflects the 1-2 orders of magnitude reduction in filtration efficiency for solid particles that the DPF experiences as the soot cake is consumed in the regeneration

**As described on slide 99*

Conclusions 8.3: Weighted RDE Emissions according to the regulatory approach*, Astra

- After weighting the results with the contribution from DPF regeneration, all regulated gaseous emissions and PM were comfortably compliant with Euro 6 limits. Emissions increases during regeneration were obvious for gaseous CO and HC emissions (and also HC+NOx), plus there was an increase in PM.
- Weighted cycle emissions for all gases from the Astra show larger increases over non-regenerating emissions levels than the Qashqai, suggesting higher Ki factors.
- Weighted PM increases by a significant factor but from near zero to ~0.3mg/km, a level similar to PM background.
- Weighted PN emissions results from PN4, PN10 and the DMS accumulation mode were all well below $6x10^{11}$#/km. PN emissions effects from the Astra were broadly the same as observed for the Qashqai. Cold start PN produces ~10x as many solid, accumulation mode and nucleation mode PN than from the hot start test. However, since the weighted PN from all instruments is dominated by the regeneration contribution (at ~$1.3x10^{12}$#/km), the impact of this change (from 10^9 to 10^{10}) is minimal

*As described on slide 99

Conclusions 8.4: Weighted RDE Ki factors according to the regulatory approach*, Astra

- PM has Ki factors of ~3.5 (hot) and ~5.7 (cold) indicating a large increase in material collected on the filter during regeneration. This has been shown to be derived from released sulphates and other volatile materials as well as soot that escapes the DPF. However, sulphate levels were much lower than the Qashqai, and nucleation mode PN were also reduced.
- Compared to these data, type-approval Ki factors are lower than the RDE factors determined in this work (CO = 1.0351, NOx = 1.014, THC = 1.086 and PM = 1.0245). The low number of non-regenerating cycles, and the fact that the regeneration distance/time is less than 1 WLTC would suggest lower Ki would be determined from a WLTC-based calculation
- The Ki factors for non-volatile PN (reg PN23, PN4, PN10, PN23 and DMS accumulation mode) are all broadly similar, since they address the same metric. The 10 to 17 range reflects the order of magnitude reduction in filtration efficiency for solid particles that the DPF experiences as the soot cake is consumed in the regeneration.
- The ~1300 times Ki for the DMS nucleation mode from the Astra is not associated with the release of as much sulphates (these were not detected substantially in the PM analysis) during the DPF regeneration. An alternative source could be ash escaping from the DPF providing nuclei for fuel and oil HCs to condense upon, or a release of oil HC that can self-nucleate.

*As described on slide 99

Conclusions 8.5: Increase in mass emissions per km of the discrete regeneration events on the Qashqai and Astra

- Throughout the duration of the regeneration event (~500 seconds) almost all pollutants were elevated when emissions were compared with the same period in a non-regenerating RDE, and emissions increases from regenerations in hot RDE cycles were greater than emissions increases in cold RDE cycles
  - During hot start RDE cycles the following additional emissions were determined per km of the regeneration event (corresponding to the ~500s period of the regeneration and ~11.5 to ~15km)
    - ~ 50 to ~ 65g of CO_2
    - ~ 40 to ~ 130mg of CO
    - ~ 100 to ~ 140mg of NOx
    - ~ 6mg of PM
    - ~2.5 to ~7.5mg of NO_2
    - ~84 mg NH_3 (Astra only)
  - Non-volatile PN emissions were increased by 3 – 9×10^{12} per km of the regeneration event (corresponding to the ~500s period of the regeneration and ~11.5 to ~15km), while total particles were increased by ~2 to ~6 x 10^{14}#/km.

Conclusions 8.6: Increase in mass/km emissions effected by regeneration events on all driving, from the Qashqai and Astra

- The increment in emissions observed during the regeneration event has been averaged across all driving to indicate the impact on overall emissions. On average, for each km driven by the Qashqai / Astra, the DPF regeneration adds:
  - ~ 2g CO_2
  - ≤ 4.5mg CO
  - ≤ 5mg NOx
  - ≤ 300µg of NO_2 and a similar amount of PM
  - ~3mg/km of ammonia on the Astra, but ~30µg on the Qashqai
  - Non-volatile >23nm PN emissions are increased by ~1.5 to ~2.5×10^{11} while >4nm and >10nm show slightly higher increases
  - Nucleation mode / volatile particle emissions increase by ~10^{13}/km, but the formation of the very high levels of these particles observed is driven by the dilution conditions present in the CVS, and these levels are not necessarily representative of real-world emissions.

Appendix 1

Tabulated Emissions Results (selected)

Appendix 1: Tabulated Emissions Results
Test facility, standard analyzers

Qashqai	Total									
Whole RDE	CO2	CO	THC	NOx	NO	HC+NOx	NO2	PM	PN	Fuel Cons.
	(g/km)	(mg/km)	(mg/km)	(mg/km)	(mg/km)	(mg/km)	(mg/km)	(mg/km)	(#/km)	(l/100km)
20190726_Qashqai_On-dyno RDE_1	127.34	14.422	6.649	33.984	20.230	40.633	3.134	1.627	7.94E+11	4.843
20190726_Qashqai_On-dyno RDE_2	119.14	1.614	1.631	23.413	13.126	25.044	3.368	0.073	1.06E+11	4.530
20190729_Qashqai_On-dyno RDE_3	118.86	9.873	2.473	23.323	13.336	25.796	2.947	0.045	8.15E+09	4.520
20190729_Qashqai_On-dyno RDE_4	116.95	4.181	0.883	23.491	13.027	24.373	3.641	0.068	6.28E+09	4.447
20190806_Qashqai_On-dyno RDE_5	120.57	16.668	3.503	31.454	18.145	34.957	3.808	0.070	3.76E+09	4.586
20190806_Qashqai_On-dyno RDE_6	128.38	10.293	8.553	41.109	24.368	49.662	3.969	1.189	8.48E+11	4.883

Astra	Total									
Whole RDE	CO2	CO	THC	NOx	NO	HC+NOx	NO2	PM	PN	Fuel Cons.
	(g/km)	(mg/km)	(mg/km)	(mg/km)	(mg/km)	(mg/km)	(mg/km)	(mg/km)	(#/km)	(l/100km)
20190731_Astra_On-dyno RDE_1	129.06	66.752	14.313	10.231	6.610	24.544	0.358	0.331	2.91E+11	4.913
20190731_Astra_On-dyno RDE_2	123.01	7.013	4.685	18.719	6.218	23.404	9.098	0.148	7.16E+10	4.678
20190801_Astra_On-dyno RDE_3	124.52	39.549	7.865	9.244	4.732	17.109	1.991	0.087	2.54E+09	4.738
20190801_Astra_On-dyno RDE_4	121.71	15.105	3.293	8.614	5.486	11.907	0.415	0.083	1.52E+09	4.629
20190807_Astra_On-dyno RDE_5	125.45	47.918	11.295	10.812	7.079	22.107	0.256	0.234	2.98E+10	4.774
20190807_Astra_On-dyno RDE_6	132.92	37.839	13.042	33.329	20.914	46.370	1.744	1.085	1.29E+12	5.058

Appendix 1: Tabulated Emissions Results
NOx speciation via QCL

Qashqai	QCL Cumulative NO	QCL Cumulative NO2	QCL Cumulative NH3
yyyymmdd_vehicle_cycle_fuel_test#	(mg/km)	(mg/km)	(mg/km)
20190726_Qashqai_On-dyno RDE_1	16.36	2.48	0.35
20190726_Qashqai_On-dyno RDE_2	9.40	3.12	0.08
20190729_Qashqai_On-dyno RDE_3	11.32	3.27	0.21
20190729_Qashqai_On-dyno RDE_4	10.23	3.97	0.13
20190806_Qashqai_On-dyno RDE_5	13.14	3.74	0.19
20190806_Qashqai_On-dyno RDE_6	19.24	3.43	0.12

Astra	QCL Cumulative NO	QCL Cumulative NO2	QCL Cumulative NH3
yyyymmdd_vehicle_cycle_fuel_test#	(mg/km)	(mg/km)	(mg/km)
20190731_Astra_On-dyno RDE_1	4.59	0.13	32.88
20190731_Astra_On-dyno RDE_2	3.08	10.16	0.46
20190801_Astra_On-dyno RDE_3	2.93	2.88	0.97
20190801_Astra_On-dyno RDE_4	3.42	0.39	5.41
20190807_Astra_On-dyno RDE_5	5.33	0.12	6.39
20190807_Astra_On-dyno RDE_6	16.13	1.09	20.24

Appendix 1: Tabulated Emissions Results DMS500

yyyymmdd_vehicle_cycle_fuel_test#	Nucleation Mode PN (#/km)	Accumulation Mode PN (#/km)
20190726_Qashqai_On-dyno RDE_1	7.90E+13	5.39E+11
20190726_Qashqai_On-dyno RDE_2	6.44E+10	7.78E+10
20190729_Qashqai_On-dyno RDE_3	1.76E+10	4.42E+09
20190729_Qashqai_On-dyno RDE_4	7.83E+09	3.00E+09
20190806_Qashqai_On-dyno RDE_5	3.45E+09	1.20E+09
20190806_Qashqai_On-dyno RDE_6	1.04E+14	6.10E+11

yyyymmdd_vehicle_cycle_fuel_test#	Nucleation Mode PN (#/km)	Accumulation Mode PN (#/km)
20190731_Astra_On-dyno RDE_1	3.94E+12	2.03E+11
20190731_Astra_On-dyno RDE_2	6.17E+10	1.02E+11
20190801_Astra_On-dyno RDE_3	1.77E+10	4.10E+09
20190801_Astra_On-dyno RDE_4	6.21E+09	1.75E+09
20190807_Astra_On-dyno RDE_5	6.31E+10	1.91E+10
20190807_Astra_On-dyno RDE_6	3.94E+13	7.96E+11

Appendix 1: Tabulated Emissions Results
PN via DTT system

Qashqai	Total - Scaling factor applied		
	DTT >4nm	DTT >10nm	DTT >23nm
yyyymmdd_vehicle_cycle_fuel_test#	(#/km)	(#/km)	(#/km)
20190726_Qashqai_On-dyno RDE_1	1.20E+12	1.11E+12	6.38E+11
20190726_Qashqai_On-dyno RDE_2	9.74E+10	1.03E+11	8.41E+10
20190729_Qashqai_On-dyno RDE_3	9.07E+09	9.79E+09	6.57E+09
20190729_Qashqai_On-dyno RDE_4	5.96E+09	6.29E+09	5.04E+09
20190806_Qashqai_On-dyno RDE_5	4.76E+09	5.13E+09	2.98E+09
20190806_Qashqai_On-dyno RDE_6	1.35E+12	1.21E+12	6.82E+11

Astra	Total - Scaling factor applied		
	DTT >4nm	DTT >10nm	DTT >23nm
yyyymmdd_vehicle_cycle_fuel_test#	(#/km)	(#/km)	(#/km)
20190731_Astra_On-dyno RDE_1	2.70E+11	2.75E+11	2.34E+11
20190731_Astra_On-dyno RDE_2	6.02E+10	6.32E+10	5.69E+10
20190801_Astra_On-dyno RDE_3	4.48E+09	4.85E+09	2.03E+09
20190801_Astra_On-dyno RDE_4	3.22E+09	3.48E+09	1.22E+09
20190807_Astra_On-dyno RDE_5	4.77E+10	5.27E+10	2.36E+10
20190807_Astra_On-dyno RDE_6	1.56E+12	1.35E+12	1.04E+12

Creating a world
fit for the future

Appendix 2

Measurement Equipment

Final

Fourier Transform Infra-red Spectroscopy (FTIR)

FTIR

- Provides highly resolved absorption spectra of exhaust gas in the mid infra-red (IR) region of the EM spectrum on a second-by-second basis
- Rotations, stretches and bends of chemical bonds in polyatomic molecules all have characteristic absorbances
- This spectral data of compounds in exhaust gas is collected simultaneously and deconvoluted by Fourier Transform
- Detailed analysis of such spectra yields simultaneous compositional information for up to 25 compounds including some regulated emissions and a selection of important low molecular weight compounds

NOTE: *work at Ricardo has indicated an interference in diesel samples that leads to over-estimation of formaldehyde relative to DNPH-HPLC-UV*

FTIR used for:

- Real-time determination of NOx species critical for catalyst calibration and function, and relevant to health and environmental impacts
- NO, NO_2, NH_3 and N_2O
- Other compounds can also be measured, ethanol, formaldehyde etc
- Compounds without dipole moments cannot be measured

Final

Quantum Cascade Laser (QCL)

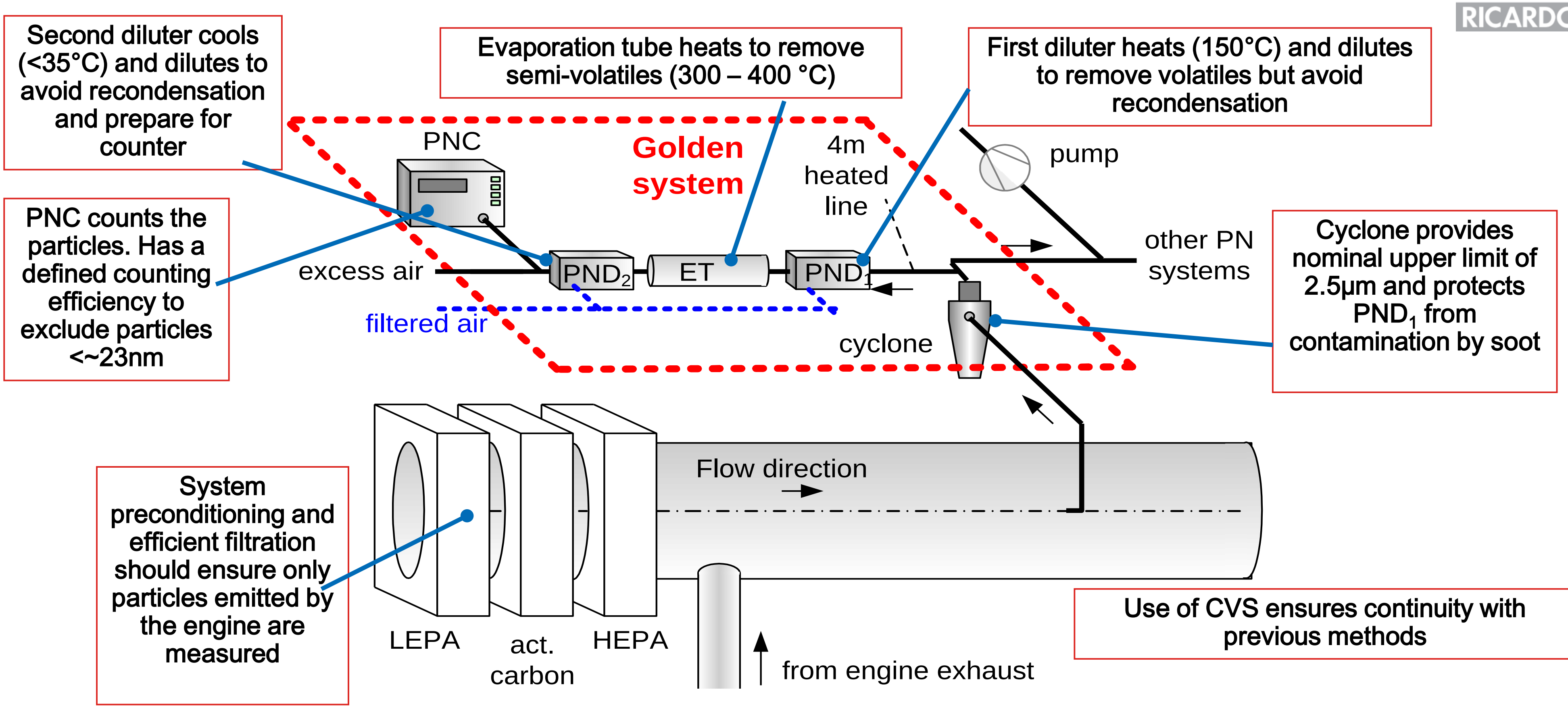
QCL

- Provides highly resolved absorption spectra of exhaust gas in the mid infra-red (IR) region of the EM spectrum on a second-by-second basis
- Rotations, stretches and bends of chemical bonds in polyatomic molecules all have characteristic absorbances
- QCL can generate mid-infrared (Mid-IR) where many gases exhibit strong absorption tendency.
- QCL wavelength is tunable in narrow region.
- High resolution spectrum (~0.005 nm) can minimize interference
- High accuracy for a limited number of dedicated compounds: currently limited to nitrogenous species

QCL used for:

- Real-time determination of NOx species critical for catalyst calibration and function, and relevant to health and environmental impacts
- NO, NO_2, NH_3 and N_2O
- WLTP reference method

PN23 – Horiba SPCS 2000



- Measurement employs a condensation nucleus counter, but uses sample pre-conditioning to eliminate the most volatile particles which may contributesignificantly to variability
- Solid particles defined by the measurement equipment
  - ~23nm to 2.5µm and surviving evaporation in the range 300°C to 400°C (350°C)
  - Analogous to heated FID hydrocarbon method
- System sufficiently sensitive to determine differences in fill-state of DPF; repeatability as low as 2% with non-DPF

Final

Non-volatile Particle Number Measurement (PN23)

SPCS

- Heating and dilution are used to exclude volatile particles from measurement
- Particles are counted with a condensation nucleus counter (~50% efficiency at 23nm)
- Sampling from CVS for regulations

MEXA-2000SPCS

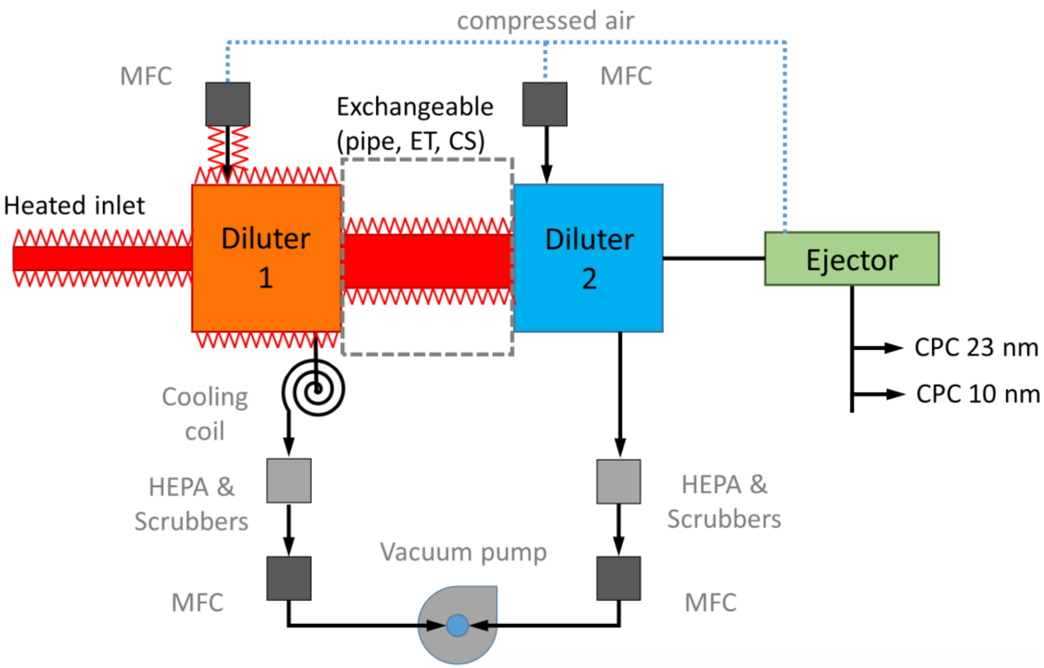
PN used for:

- Certification of PN emissions at type approval
- Ensures fitment of efficient DPF to diesel
- Current transition to stricter limits from GDI, but 23nm cut-point may allow smaller particles to escape effective control
- Study of >23nm PN can also be undertaken

Final

PN10 measurement

- DownTo10 prototype system
  - One of three Horizon 2020 projects aiming at creating optimised system for measuring particles >10nm (or lower)
  - Approach includes minimisation of losses of small particles (and limit correction factors and uncertainty)
  - Use 23nm particle counter and 10nm particle counter in tandem



On-line Mass Spectrometry (OLMS)

OLMS

- Gaseous compounds are fragmented into a fingerprint pattern of ions
- One ‘parent’ ion is selected and this is monitored in real-time during emissions cycles or transient events
- Strength of the signal / number of ions is proportional to the amount of the component present in the exhaust gas sampled
- Raw gas is sampled
- Small (methane RMM ~16) to moderately sized molecules (RMM ~200) can be measured

OLMS used for:

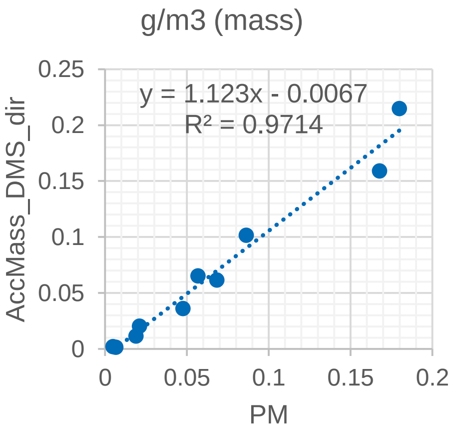
- Determination of species not easily quantified using FTIR
- Aromatics (such as benzene)
- Sulphur species: SO_2, H_2S, CS_2, COS derived from fuel and lubricant sulphur during rich and lean engine operation
- Nitrogen species: NH3, HCNO

Differential Mobility Particle Sizer (DMS)

DMS500

- Multifunctional particle measurement instrument
- Determines particle size distribution and number concentration by separating particles according to their electrical mobility and their number by the cumulative charge carried
- Can sample from raw exhaust and from a reasonable depression
- Data provided includes particle size distribution of volatile and soot particle modes, plus integrated particle numbers
- Data can be used to estimate soot and PM emissions
- Real time and cumulative data are available, readable by STARS – often included in Design of Experiments projects
- Data shown by Ricardo and others to correlate with SPCS

Relationship between DMS mass estimate and filter PM



DMS required for:

- Development for soot and PM emissions, solid particle number emissions
- 5nm -1000nm size distributions