

## Characteristics of PN Emission Regarding to Cold start and Hot start on Real Driving Emissions

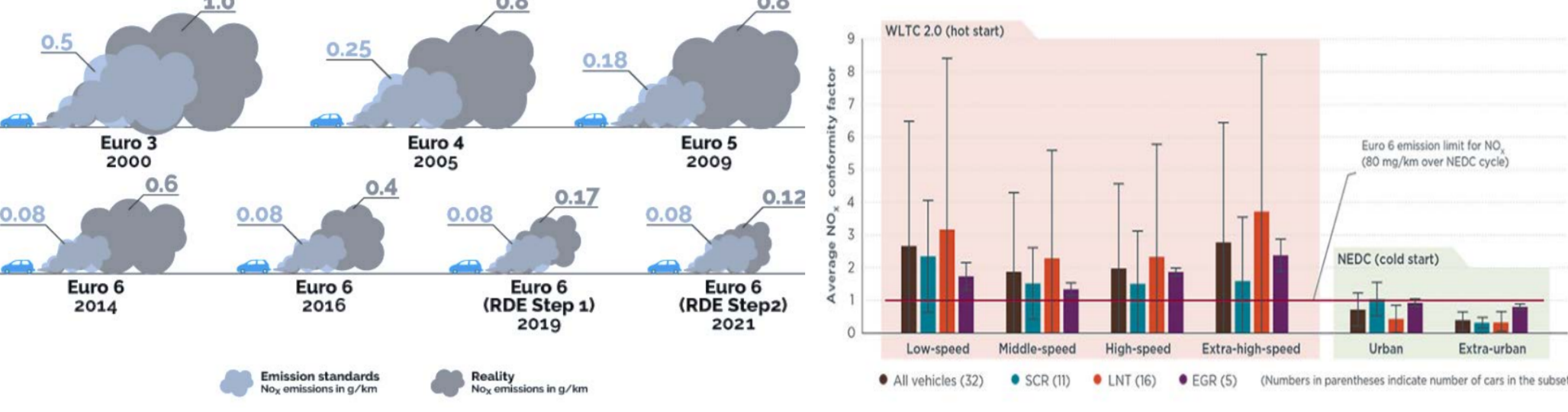
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### Introduction

#### NO<sub>x</sub> standards on the road



(source: T&E, 2017)

(source: ICCT, 2015)

- Exhaust gas regulations of diesel vehicles have been strengthened since 2000. Euro3 to Euro6 has been enhanced by about 84%. However, actual road NO<sub>x</sub> emissions were reduced by about 40% compared to Euro 3.
- Compared with the current certification mode WLTC and NEDC, most vehicles(Euro 6b) meet emissions regulations in NEDC mode, but do not meet emissions regulations in various speed range WLTC modes.
- Characteristics of High NO<sub>x</sub> emissions appear in the low speed phase including cold start and high speed phase including high load operation.
- The one of reason for this phenomenon is that the emissions from certification test mode did not reflect the characteristics of the real driving emissions.
- EU and Korea, which have implemented Euro 6d Temp. regulations(incl. WLTC and RDE), have strengthened cold start conditions and PN regulations in the RDE 3<sup>rd</sup> package since September 2017.

| Pollutant              | Euro 5 Light-Duty |                        | Euro 6 Light-Duty      |                        |
|------------------------|-------------------|------------------------|------------------------|------------------------|
|                        | Gasoline          | Diesel                 | Gasoline               | Diesel                 |
| CO (g/km)              | 1.0               | 0.5                    | 1.0                    | 0.5                    |
| NO <sub>x</sub> (g/km) | 0.06              | 0.18                   | 0.06                   | 0.08                   |
| PN (#/km)              | -                 | 6.0 x 10 <sup>11</sup> | 6.0 x 10 <sup>11</sup> | 6.0 x 10 <sup>11</sup> |

- In this study, PN emission characteristics from light-duty diesel vehicle and gasoline vehicles were evaluated under "cold start" conditions with RDE 3<sup>rd</sup> package

### Test Result and Conclusions

- As a result of PN correlation test Vehicle 1 showed a tendency to satisfy the PEMS error range of 50% with CVS equipment. Vehicle 2 showed a tendency that the absolute error of CVS equipment and PEMS satisfied  $1 \times 10^{11}$  and below.
- As a result of MAW
  - Vehicle 1 satisfied the regulation of  $2.3 \times 10^{11}$  in the cold start condition and  $2.1 \times 10^{11}$  in the hot start condition. However, emissions characteristics are the same order as PN regulation ( $6 \times 10^{11}$ ).
  - Vehicles 2 satisfied the regulation of  $1.1 \times 10^{10}$  in the cold start condition and  $4.2 \times 10^9$  in the hot start condition. Vehicle 2 has less PN emission characteristics than Vehicle 1.
- As a result of comparing the Cold start condition and the Hot start condition based on the coolant temperature of 70°C
  - For Veh.1(GDI), the PN emission is about 30% of the urban part and about 17% of the total trip in the cold start condition.
  - For Veh.2(light-duty diesel veh.), the PN emission is about 93% of the urban part and about 86% of the total trip in the cold start condition. Compared with Veh.1, Veh.2 has a more sensitive PN emission characteristic in cold start condition
- PN emissions characteristics by Vehicle
  - Veh.1 shows high PN emission characteristics under cold start and high load operating (high RPM and acceleration) conditions.
  - Veh.2 shows high PN emission characteristics. under low-temperature cold start conditions where the engine is not sufficiently warm-up
  - Veh. 2 controls PN emissions in the DPF after-treatment system, so PN emissions are relatively low compared to Veh.1(GDI).
- Conclusions
  - PN emissions of total are higher for gasoline vehicles(GDI) than for DPF-equipped diesel vehicles.
  - The effects of cold start conditions during the total test are significant both in diesel and gasoline vehicles.
  - High PN emission characteristics are shown in high acceleration and high RPM region.

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### Test Vehicle



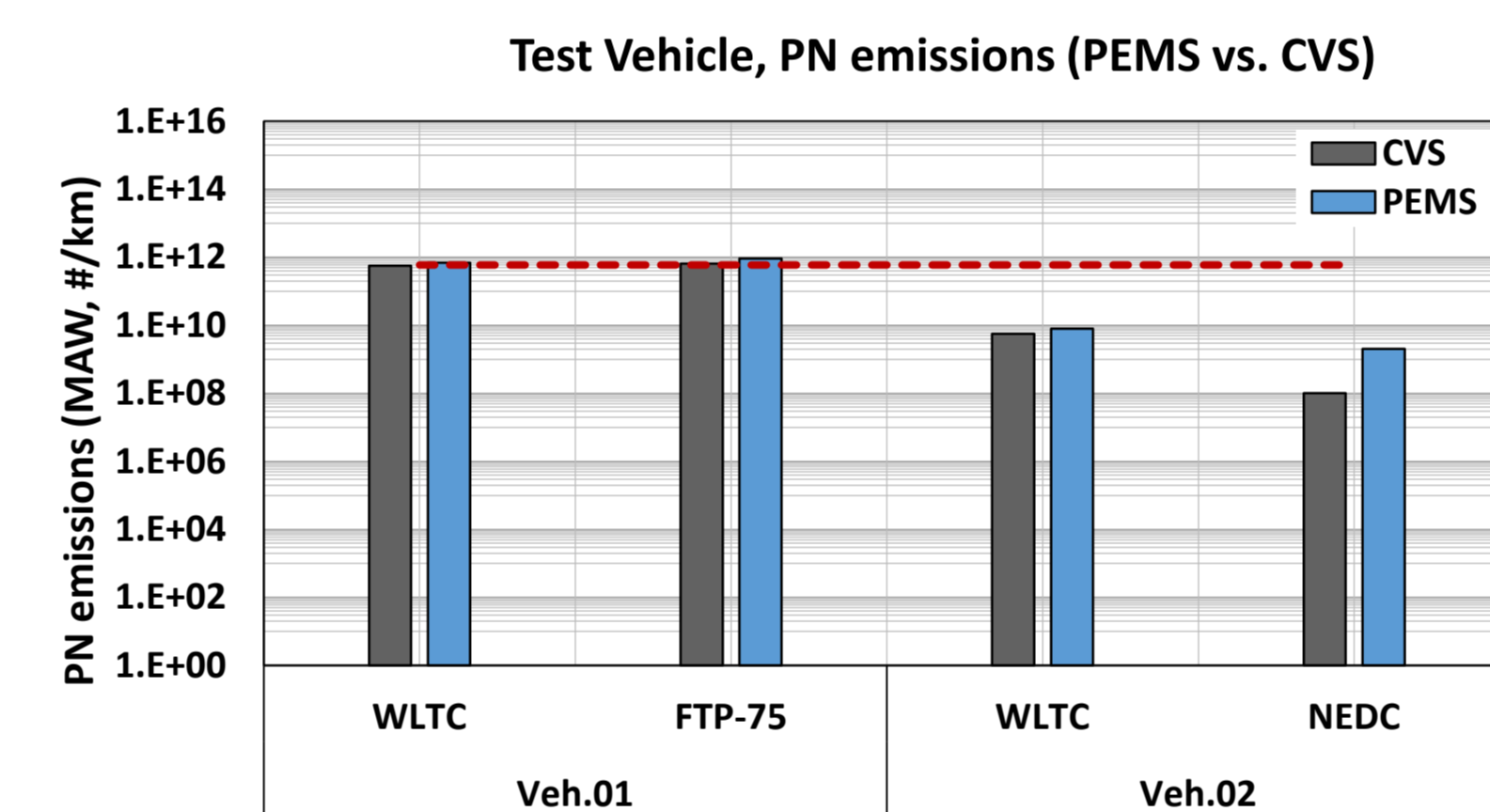
| Vehicle | EngineType | Disp.   | Max. Power | Max. Torque | Fuel     | After-Treat. | Unloaden Weight |
|---------|------------|---------|------------|-------------|----------|--------------|-----------------|
| Veh.1   | GDI I4     | 2,359cc | 139.84kW   | 24.6kg·m    | Gasoline | TWC          | 1,701kg         |
| Veh.2   | CRDI I4    | 1,995cc | 134.69kW   | 41kg·m      | Diesel   | LNT+DPF      | 1,930kg         |

### Test Equipment (PEMS)

| Item                         | Principle   | Range                                    |
|------------------------------|---|--|
| CO                           | Heated NDIR (Non-Dispersive Infrared Detection)   | 0 ~ 5 vol. %                             |
| CO <sub>2</sub>              | Infrared Detection  | 0 ~ 20 vol. %                            |
| NO, NO <sub>2</sub>          | UV (Ultra-Violet)   | 0 ~ 5,000 ppm<br>0 ~ 2,500 ppm           |
| PN                           | DC (Diffusion Charger)  | Approx. 0.5 [L/min]                      |
| Exhaust flow                 | Pitot flow meter  | 100°C: 18~810 kg/h<br>400°C: 23~610 kg/h |
| Standard Signal Measurements | Exhaust temperature, Exhaust pressure, Atmospheric pressure, Atmospheric temperature, Atmospheric humidity, GPS signal, Speed |  |



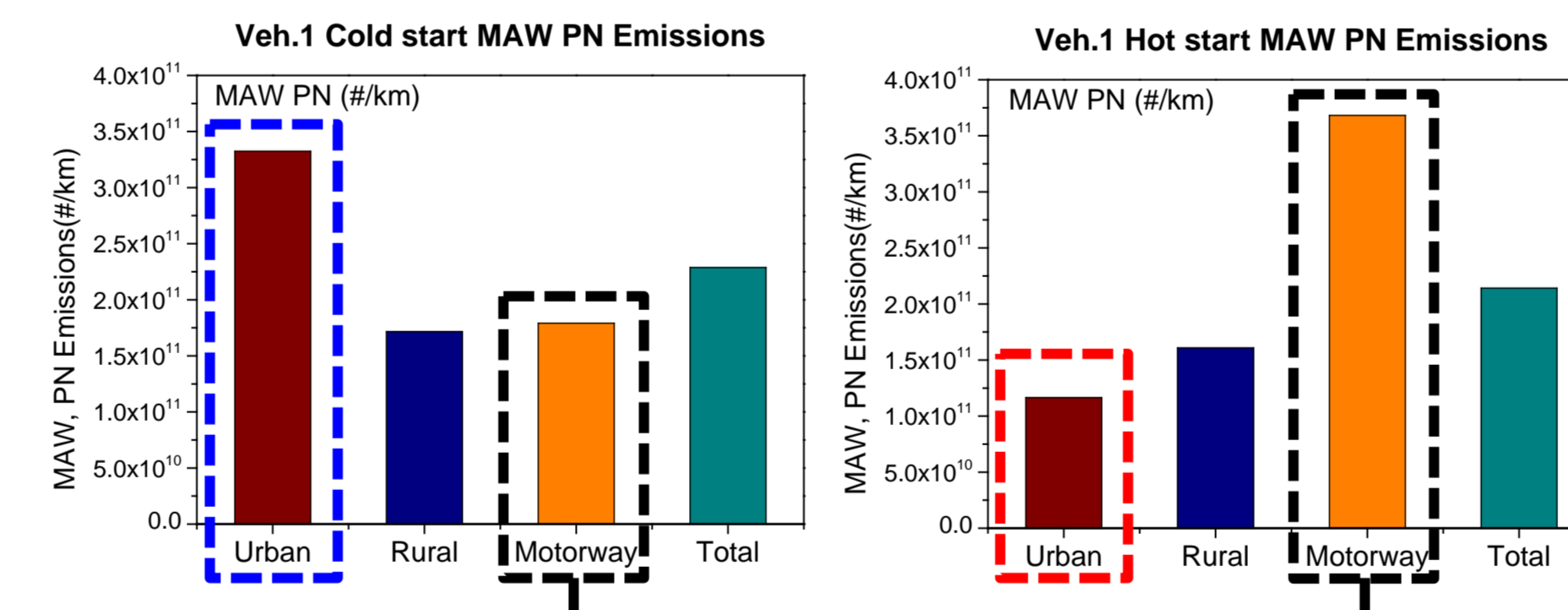
### Correlation test (CVS vs. PEMS)



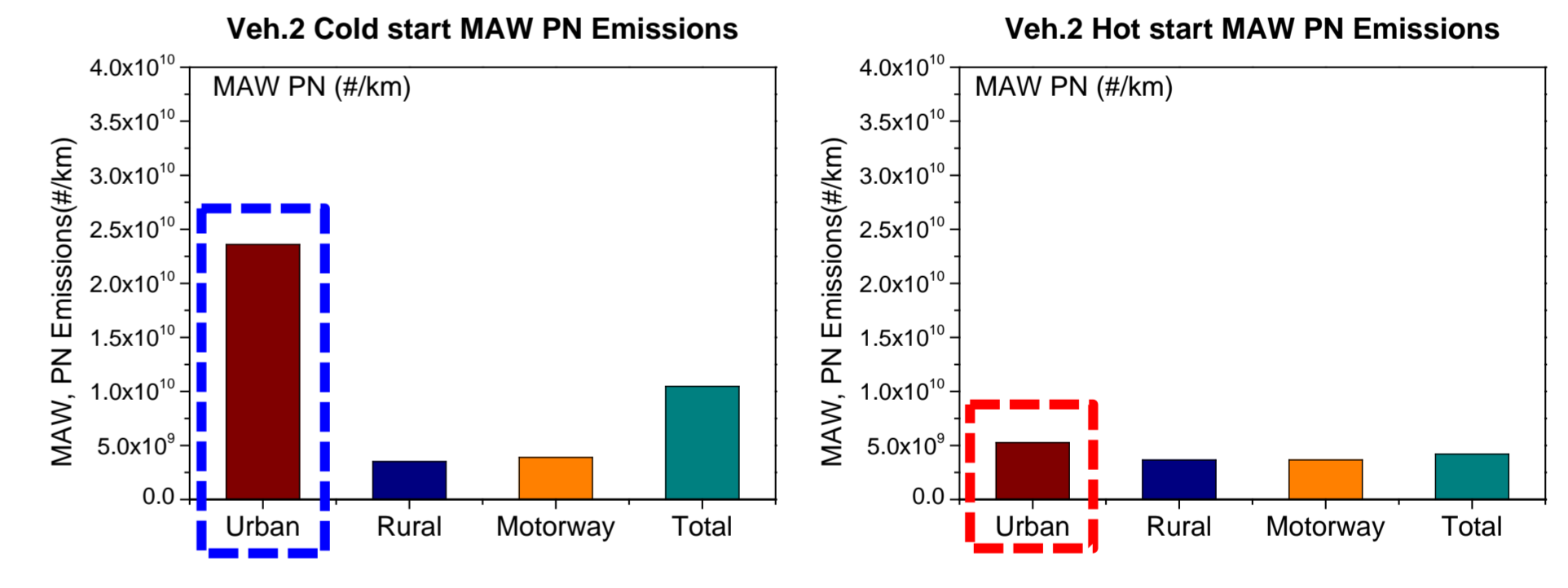
| Veh.   | Mode   | CVS      | PEMS     | Diff. %  | Diff. abs |
|--------|--------|----------|----------|----------|-----------|
|        |        | WLTC     | 5.62E+11 | 6.92E+11 | 18.8%     |
| Veh.01 | FTP-75 | 6.51E+11 | 9.20E+11 | 29.2%    | 2.69E+11  |
|        | WLTC   | 5.61E+09 | 8.05E+09 | 30.3%    | 2.44E+09  |
| Veh.02 | NEDC   | 1.02E+08 | 2.05E+09 | 95.0%    | 1.95E+09  |

- Currently, the PN correlation test between CVS and PEMS equipment shall be such that the error of the measured value is less than 50% or the absolute value is less than  $1E + 11$ .

### MAW Result

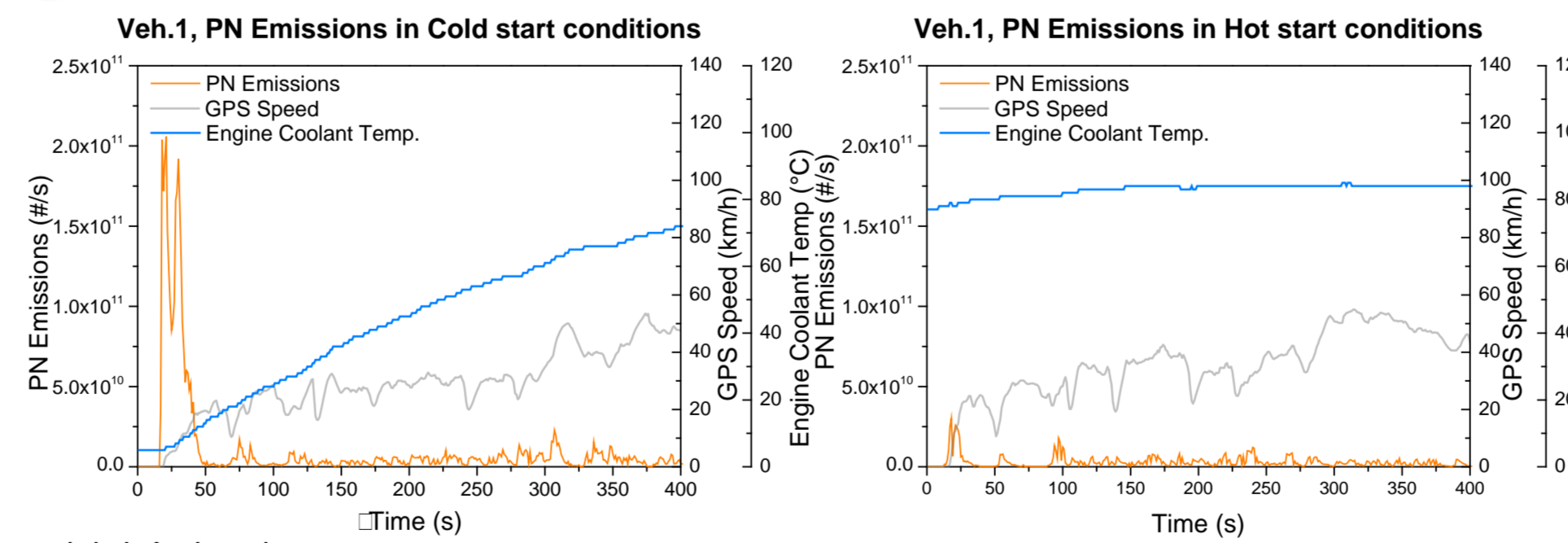


| Veh.   | Start Condition | MAW PN Emission (#/km) |         |          |         | C.F. PN |
|--------|-----------------|------------------------|---------|----------|---------|---------|
|        |                 | Urban                  | Rural   | Motorway | Total   |         |
| Veh.01 | Cold            | 3.3E+11                | 1.7E+11 | 1.8E+11  | 2.3E+11 | 0.38    |
|        | Hot             | 1.2E+11                | 1.6E+11 | 3.7E+11  | 2.1E+11 | 0.36    |

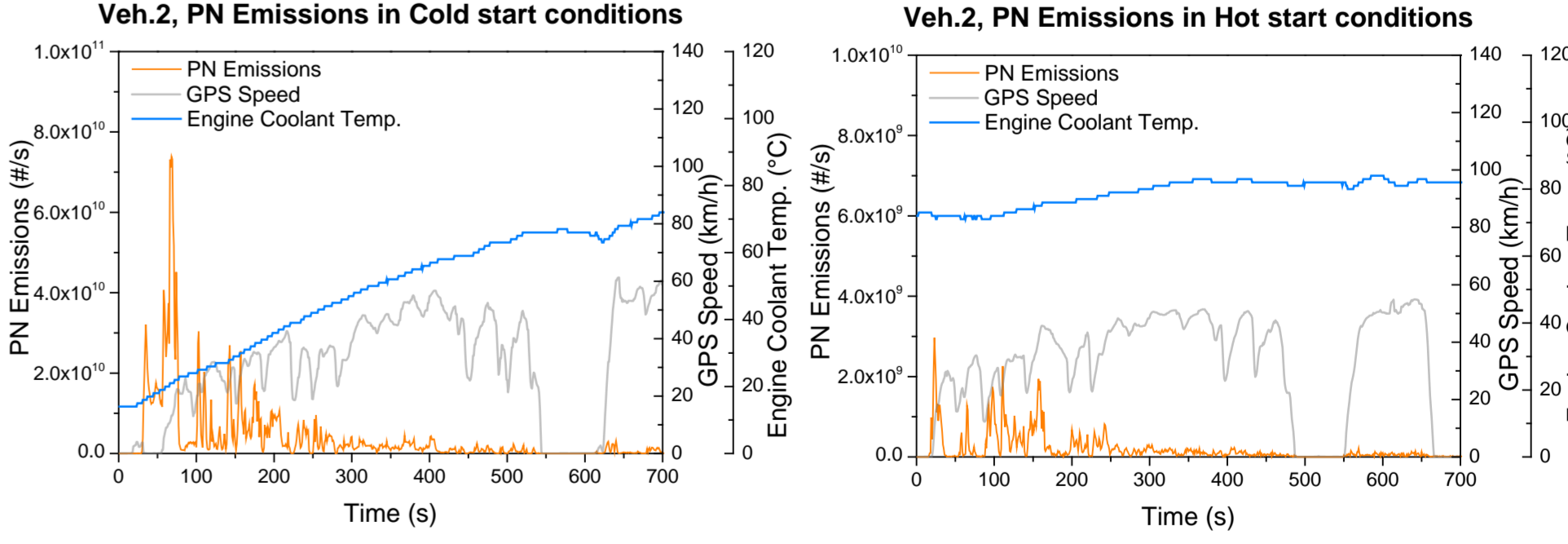


| Veh.   | Start Condition | MAW PN Emission (#/km) |        |          |         | C.F. PN |
|--------|-----------------|------------------------|--------|----------|---------|---------|
|        |                 | Urban                  | Rural  | Motorway | Total   |         |
| Veh.02 | Cold            | 2.4E+10                | 3.5E+9 | 3.9E+9   | 1.1E+10 | 0.02    |
|        | Hot             | 5.3E+9                 | 3.7E+9 | 3.7E+9   | 4.2E+9  | 0.01    |

### Real-Time Result

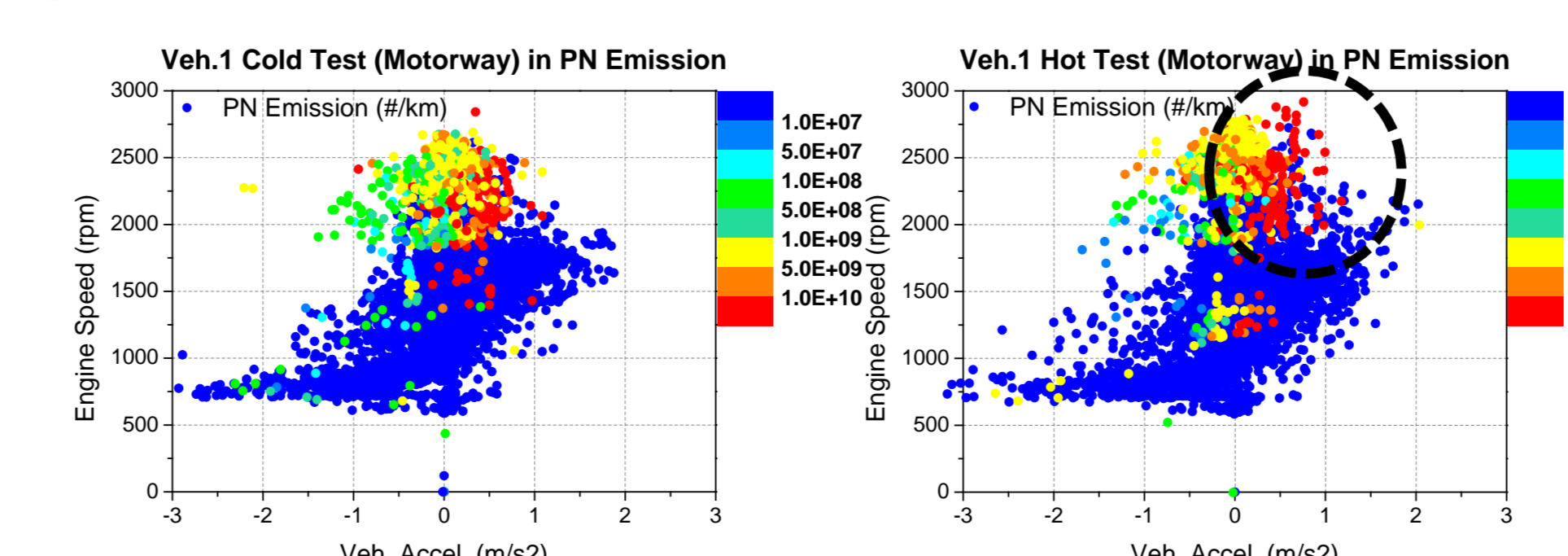


| PN (#) | Coolant Temp. by 70°C (388s) | PN Emission (#/km) |         |          |         | by 388s / by 388s / Total |       |
|--------|------------------------------|--------------------|---------|----------|---------|---------------------------|-------|
|        |                              | Urban              | Rural   | Motorway | Total   | Urban                     | Total |
| Cold   | 3.9E+12                      | 1.3E+13            | 4.8E+12 | 4.7E+12  | 2.3E+13 | 29%                       | 17%   |
| Hot    | 1.2E+12                      | 4.6E+12            | 6.3E+12 | 8.6E+12  | 2.0E+13 | 25%                       | 6%    |



| PN (#) | Coolant Temp. by 70°C (687s) | PN Emission (#/km) |         |          |         | by 687s / by 687s / Total |       |
|--------|------------------------------|--------------------|---------|----------|---------|---------------------------|-------|
|        |                              | Urban              | Rural   | Motorway | Total   | Urban                     | Total |
| Cold   | 2.3E+12                      | 2.5E+12            | 1.0E+11 | 1.2E+11  | 2.7E+12 | 93%                       | 86%   |
| Hot    | 1.4E+11                      | 2.5E+11            | 1.1E+11 | 5.9E+10  | 4.1E+11 | 54%                       | 33%   |

### PN emission characteristics of Veh.1



### PN emission characteristics of Veh.2

