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In-situ Estimation of Non-Regulated Pollutant Emission Factors in an Urban Area of Nantes, France, with Fleet Composition Characterization

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Abstract

The purpose of this study is to estimate the in-situ emission factors of several pollutants (particle number [PN], black carbon [BC] and several volatile and semi-volatile organic compounds [VOCs and SVOCs]) in an urban area of Nantes, France, with real-world traffic conditions and characterization of the fleet composition. The fleet composition and driving conditions are characterized by the number of vehicles, their speeds and their types (passenger cars [PCs], light commercial vehicles [LCVs], heavy-duty vehicles [HDVs]) as well as their characteristics (make, model, fuel, engine, EURO emission standard, etc.). The number of vehicles passing on the boulevard is around 20,000 per day with about 44% of Euro 5 and Euro 6 vehicles. The impacts of fleet composition on emission were analyzed by ANOVA. The results show that the fleet composition has a significant impact on emissions for different pollutants. Higher percentage of gasoline PCs between Euro 4 to Euro 6 and Euro 4 diesel PCs induces more BC emission. Higher percentage of old gasoline and diesel vehicles (\leq Euro 3) induces higher emission of toluene, ethylbenzene and m+p- and o-xylene. Furthermore, emission factors estimated in this work were compared to those calculated in other in-situ studies that show a good agreement. For the chassis bench comparison, the in-situ PN and BC emission factors are in the same range as those measured for diesel vehicles

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25 without particle filter and gasoline vehicles with direct injection system. These EFs are also
26 comparable with old heavy duty vehicles without particle filter (5×10^{13} - 2×10^{14} #/km).

27 **Keywords**

28 In-situ emission factors; Unregulated pollutants; Fleet composition

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121 **31 1. Introduction**
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124 32 On-road vehicle emissions are the main cause of atmospheric pollution in urban areas.
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127 33 Road transport induces particles, black carbon (BC) and of several VOCs and SVOCs (Volatile
128
129 34 and Semi-Volatile Organic Compounds) emissions, such as carbonyl compounds
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131 35 (formaldehyde, hexanal), and BTEX (benzene, toluene, ethylbenzene, xylene) as well as
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133 36 various alkanes and alkenes. These VOCs and SVOCs are non-regulated compounds that
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135 37 could serve as secondary particle precursors and have serious negative impacts on human
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137 38 health (Sydbom et al., 2001; Lewtas et al., 2007) and air quality in cities.
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140 39 The European Union is imposing emission limits for regulated pollutants in order to
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142 40 reduce road-traffic emissions. Facing on these vehicle emission standards, emission factors
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144 41 are derived from dynamometer bench test (Alves et al., 2015; Yang et al., 2015; Louis et al.,
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146 42 2016; Martinet et al., 2017) or from on-board emissions measurements (O'Driscoll et al.,
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148 43 2016; Ntziachristos et al., 2016). These emission factors constituted an input database with
149
150 44 different vehicle categories using by emission models (e.g., COPERT, HBEFA, PHEM and
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152 45 MOVES) for air quality studies. However, for these emission models, the emission factors
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154 46 inventories for recent Euro 5 and Euro 6 vehicles are quite poor (Rexeis et al., 2013). Only
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156 47 eighty Euro 5 vehicles and twenty Euro 6 vehicles (with 13 different vehicle models, and only
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158 48 one Euro 6 gasoline car) were added to HBEFA Version 3.2 for regulated compounds, which
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160 49 may not be representative of the entire fleet composition. The emissions of non-regulated
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162 50 pollutants are rarely measured and integrated in emission models. As consequence, their
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164 51 emission factors for an entire fleet could not be estimated correctly actually due to this
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166 52 deficiency of database, and their impact on air quality and human health could not be
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168 53 investigated accurately.
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54 Emission factors could be estimated in-situ for a part or an entire fleet using various
55 methods. The first is the chasing method, where pollutant concentrations are measured
56 by driving a mobile measurement platform behind either a single vehicle (Karjalainen et
57 al., 2014; Ježek et al., 2015) or part of the fleet present on the road (Yli-Tuomi et al.,
58 2005; Wang et al., 2009; Westerdahl et al., 2009; Kam et al., 2012; Ning et al., 2012;
59 Hudda et al., 2013). In the second method, traffic pollutant concentrations are collected
60 by a fixed measurement platform placed on the roadside. This method makes it possible
61 to measure emissions for an entire fleet driving near the measurement site (Ketzler et al.,
62 2003; Imhof et al., 2005; Rose et al., 2005; Jones et al., 2006; Bukowiecki et al., 2010).
63 For most of these studies, the number of LDVs, HDVs and buses are counted and the
64 traffic speeds are measured in some cases. However, the fleet compositions with vehicle
65 engine, capacity, combustion, age and Euro emission standard were not fully
66 characterized. As consequence, the impacts of fleet composition on non-regulated
67 pollutant emissions are hardly investigated. Furthermore, the on-road emission factors in
68 these cited studies were mainly calculated for particles and BC. Very few on-road
69 emission factors studies were focused on secondary particle precursors (carbonyl
70 compounds, BTEX and alkanes...). Ning *et al.* (2012) determined on-road emission factors
71 for butane, but only for an HDV/bus fleet.

72 In this paper, the emission factors of particle number (PN), BC, and several aliphatic,
73 aromatic and carbonyl compounds were estimated using the different concentrations of NO_x
74 and a pollutant between a background measurement site and a traffic measurement site
75 with the fleet composition observed during the measurements campaign. Furthermore, the
76 fleet composition was characterized based on the vehicle type, make, model, fuel, engine,
77 age, Euro emission standard, as well as the traffic conditions, traffic speed, and congestion.

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239 78 ANOVA statistical analyses were performed to characterize the impact of fleet composition
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241 79 on emissions. Furthermore, the emission factors estimated in this study were compared to
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244 80 other emission factors calculated in previous in-situ studies and those measured on a
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246 81 dynamometer bench.
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249 82 **2. Experimental Method**

250 251 252 253 83 **2.1 Measurement Sites**

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256 84 The measurements were conducted at two sites in the city of Nantes, France, between
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259 85 April 19 and 30, 2017. The first site was an urban background (47°13'20.3"N 1°32'15.2"W)
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261 86 site to measure urban background pollutant concentrations over a period of four days. The
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263 87 second site was a traffic site in the city center (47°12'16.0"N 1°33'10.9"W). It is an urban
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265 88 boulevard with two lanes of traffic in each direction, a speed limit of 30 km/h, and traffic
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268 89 lights (Fig. 1). The number of vehicles passing on the boulevard is around 20,000 per day.
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270 90 Trucks and buses pass on the boulevard but with a low frequency. Measurements were
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272 91 conducted over a period of seven days.
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275 92 **2.2 Traffic Characterization**

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278 93 The fleet composition and traffic conditions on the traffic site were characterized by
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281 94 AlyceSofreco (a private company specialized in the field of traffic measurement). These data
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283 95 were recorded in both directions of traffic and over a period of seven days using two video
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285 96 cameras and pneumatic-tube automatic traffic counters. The counters determined the
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287 97 number of vehicles and the driving conditions (speed, traffic congestion, etc.) and the video
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289 98 cameras collected the license plate numbers of each vehicle. Using these license plate
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99 numbers, AAAData (a private company) provided the characteristics of each vehicle,
100 including its make, model, vehicle type, fuel, engine, date of entry into circulation and Euro
101 emission standard according to the vehicle type (LDV and HDV).

2.3 Sampling Devices

102 The sampling devices were installed in a truck that been specially fitted with an array of
103 analyzers to sample the ambient air. The truck was placed along the edge of the road on the
104 traffic site and the sampling was carried out around at a height about two meters and at a
105 distance of 0.5 m of the road (Fig. 1). A Fast Mobility Particle Sizer (FMPS™; TSI) was used to
106 measure the distribution and total particle number ranging from 5.6 to 560 nm with 1 scan/s
107 at a flow rate of 8 L/min, with a concentration range from 0 to 10⁷ particle/cm³. An
108 Aethalometer® (AE-33-7, Magee Scientific) was used to measure the BC concentration. The
109 data are collected once a second and at a flow rate of 5 L/min. The concentration ranges
110 from 10 to 10⁵ ng/m³ with a detection limit of 5 ng/m³ for 1 hour. The device measures the
111 light attenuation for seven wavelengths from UV to IR (370, 470, 525, 590, 660, 880 and 940
112 nm). The 880 nm wavelength corresponding to the maximum amount of BC was used for the
113 quantification in this study.

114 VOCs and SVOCs were sampled on different cartridges with 1 sample per hour. DNPH
115 and Tenax® cartridges were used to collect respectively carbonyl compounds and BTEX and
116 five majority alkanes with a flow rate of 1 L/min and 0.1 L/min. A private laboratory, TERA
117 Environnement, analyzed the cartridges (78 TENAX and 78 DNPH, including 28 for the
118 background site, 49 for the traffic site and 1 for the transport blank for each type of
119 cartridge) using standardized analytical methods (ISO-16000-6, ISO 16000-3, NIOSH 2549,
120

121 NIOSH 5506 and NF X 43-025). The complete list of compounds (six BTEX, five alkanes and 11
122 carbonyl compounds) analyzed on the cartridges is given below.

- 123 • BTEX: benzene, toluene, ethylbenzene, m-xylene, p-xylene, o-xylene.
- 124 • Alkanes: nonane, decane, undecane, cyclopropane, ethyl, cyclohexane, ethyl.
- 125 • Carbonyl compounds: formaldehyde, acetaldehyde, acetone, acrolein, propionaldehyde,
126 crotonaldehyde, methacrolein, butanal, benzaldehyde, pentanal, hexanal.



127
128 **Fig. 1.** Diagram of the traffic site used for the measurements.

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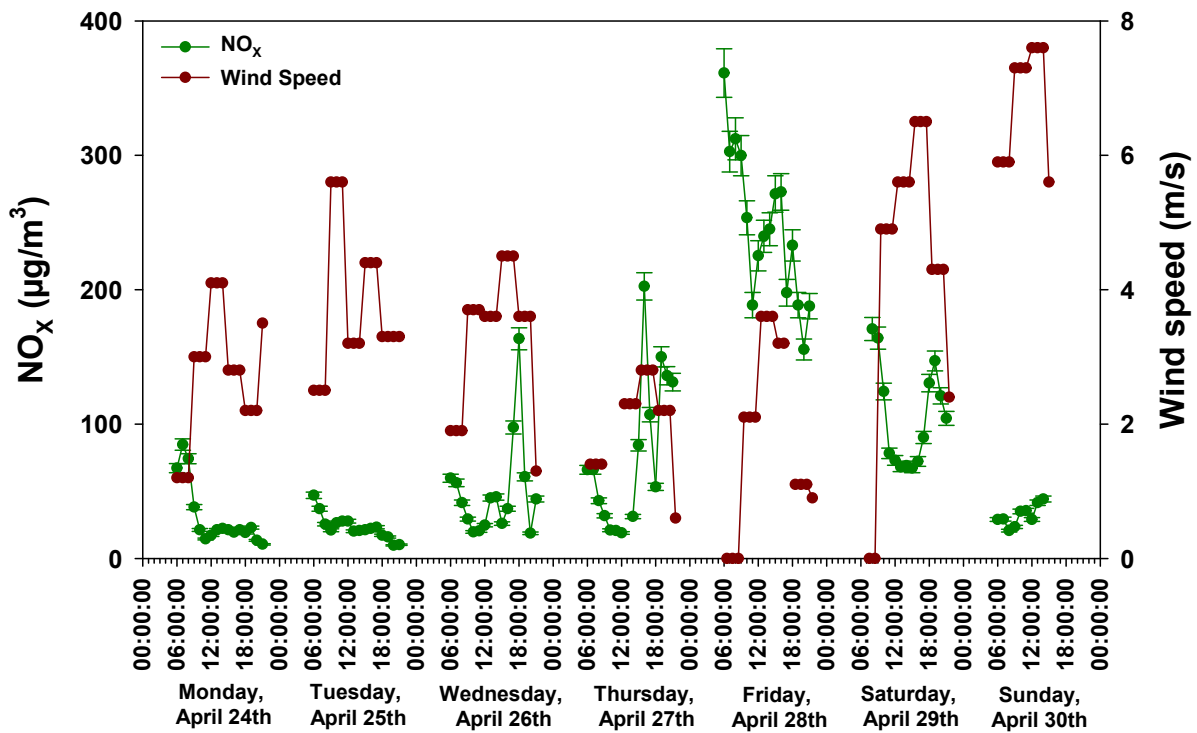
2.4 Emission Factors

The variation of NO_x and pollutant concentrations between the background site and the traffic site were used for estimating road-traffic emission factors (Imhof et al., 2005; Jones et al. 2006; Johansson et al., 2009; Krecl et al., 2017). This method is based on the assumption that the dilution of the pollutant between the exhaust outlets of vehicles and the sampler device inlets and the behavior in the atmosphere are comparable for NO_x and the other pollutants (Lohmeyer et al., 2002; Amato et al., 2010; Bukowiecki et al., 2010; Gietl et al., 2010). Using this assumption, it is considered that the dilution of other pollutants may be approximated by the dilution of NO_x . The wind speed (Fig. 2) and directions during the campaign varied between 0 and 7.6 m/s, with principally the north direction and few times the south and west direction. The temperature varied between 0 and 19 °C with relative humidity at about 30-99%. The following equation is used to calculate the emission factor for a given pollutant:

$$EF_P = \Delta P \times \frac{EF_{NO_x}}{\Delta NO_x} \quad (1)$$

where EF_P and EF_{NO_x} are the emission factor for pollutant P and NO_x , respectively, given in mass or number of particles per vehicle per kilometer (#/veh/km or $\mu\text{g}/\text{veh}/\text{km}$). ΔP and ΔNO_x are the difference of concentrations between background and traffic sites for pollutant P and NO_x respectively. The emission factors for NO_x used in the equation (1) were obtained using COPERT 4 (COmputer Programme to calculate Emissions from Road Transport) for each time step (one-hour period) with the corresponding fleet composition characterized at the same time step. For urban driving conditions, COPERT 4 estimates a NO_x emission that takes into account cold and hot emissions.

152 For all cartridges, the sampling time is one hour to have enough material for chemical
 153 analysis. For PN and BC, the data resolution is 1 second. However, in order to be able to
 154 analyze the emission factors with the fleet for all measured pollutants, the PN and BC
 155 measurement were averaged in one-hour period, corresponding to the cartridge sampling
 156 time. In addition, the NO_x concentrations used for ΔNO_x in Equation 1 are given as a 15-
 157 minute average concentration. It is therefore impossible to go below this 15-minute time
 158 step for calculating emission factors.



160 Fig. 2. Time profiles of NO_x concentration and wind speed on the measurement week.

161 2.5 ANOVA Analysis

162 The analysis of variance (ANOVA) is a statistical technique for assessing the differences
 163 between the dependent variables, which are the emissions, of a nominal variable with
 164 several categories (composition of the fleet). The null hypothesis (H0) for the analysis
 165 represents the fact that there is no significant difference between the groups. The

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534 166 alternative hypothesis considers that there is at least one significant difference among the
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536 167 groups. For the ANOVA test, the F-ratio and associated probability value (p-value) are
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539 168 calculated. If the p-value associated with the F is smaller than 0.05, then the H0 is rejected
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541 169 and the alternative hypothesis (H1) is retained (Fanelli et al., 2018) and this implies that the
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543 170 groups have a significant impact on emissions (Wildt and Ahtola, 1978). It can be concluded
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545 171 that the means of all groups are not equal and we can determine which groups are different
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548 172 from others.

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550 173 In this work, ANOVA was performed by SPAD (data analysis and data mining software) to
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552 174 determine impact of fleet composition on emission factors. The nominal-level variables used
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554 175 are the number of HDVs, the percentage of diesel vehicles between pre-Euro and Euro 3, the
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556 176 percentage of Euro 4 diesel, the percentage of diesel between Euro 5 and Euro 6, the
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558 177 percentage of gasoline vehicles between pre-Euro and Euro 3 and the percentage of gasoline
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560 178 between Euro 4 and Euro 6.

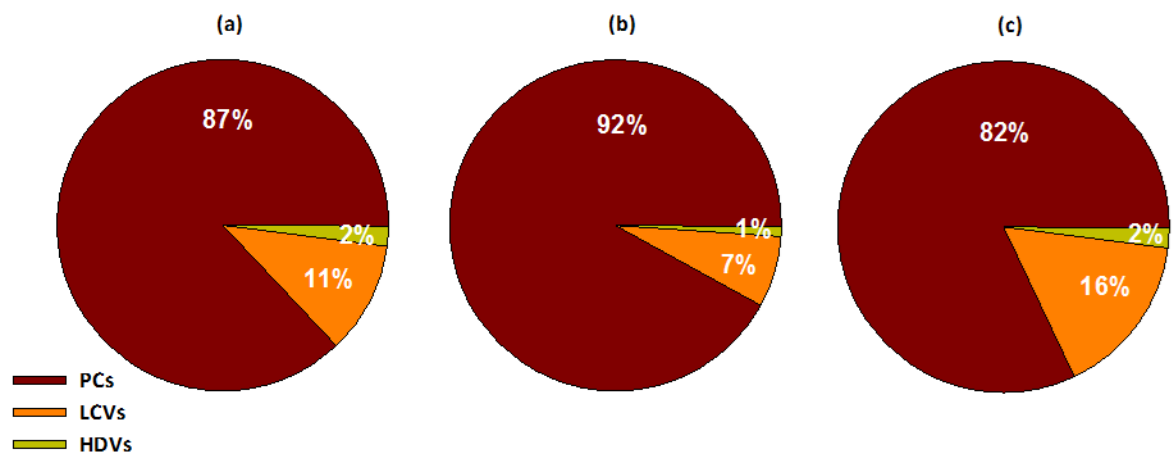
565 179 **3. Results and Discussion**

568 180 **3.1 Fleet Composition**

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571 181 The number of vehicles was characterized during the measurement on the traffic site. A
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573 182 total of 140,076 vehicles drove along the boulevard during the seven-day measurement
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575 183 period. Many vehicles were registered twice or more times during the week. The number of
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577 184 unique vehicles after removing these duplicates is 57,220. The number of vehicles varied
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579 185 between 21,147 and 23,401 from Monday to Friday. On Saturday and Sunday, 18,763
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581 186 vehicles and 9,860 vehicles were counted, respectively. The number of vehicles per hour was
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583 187 between 600 and 1800 with an average number of 1400/h for all five weekdays and
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188 between 200 and 1600 on the weekend with an average number of 900/h. The traffic speed
189 was characterized for each 5 minutes. The average traffic speed for one hour was between
190 16 and 34 km/h on all five weekdays and 21 and 38 km/h on the weekend (



191
192 **Fig. 3.** Weekdays (a) and weekend (b) characterization of the fleet composition during the measurement campaign. 2017
193 composition of the French fleet (c).

194 Furthermore, the fleet composition characterized during the measurement campaign
195 was composed of 87% passenger cars (PCs), 11% light commercial vehicles (LCVs), and 2%
196 heavy-duty vehicles (HDVs) on weekdays. On the weekend, it consisted of 92% PCs, 7% LCVs,
197 and 1% HDVs. The number of LCVs and HDVs decreased over the weekend, particularly on
198 Sundays. According to André *et al.* (2014), the entire French fleet was composed of 82% PCs,
199 16% LCVs, and 2% HDVs in 2017 (Fig. 3). The comparison between this study and the French
200 fleet composition shows the slightly higher percentage of PCs and the slightly lower
201 percentage of LCVs. These differences are explained by the fact that the measurements
202 were conducted in an urban environment, where LCV and HDV traffic is generally lower.

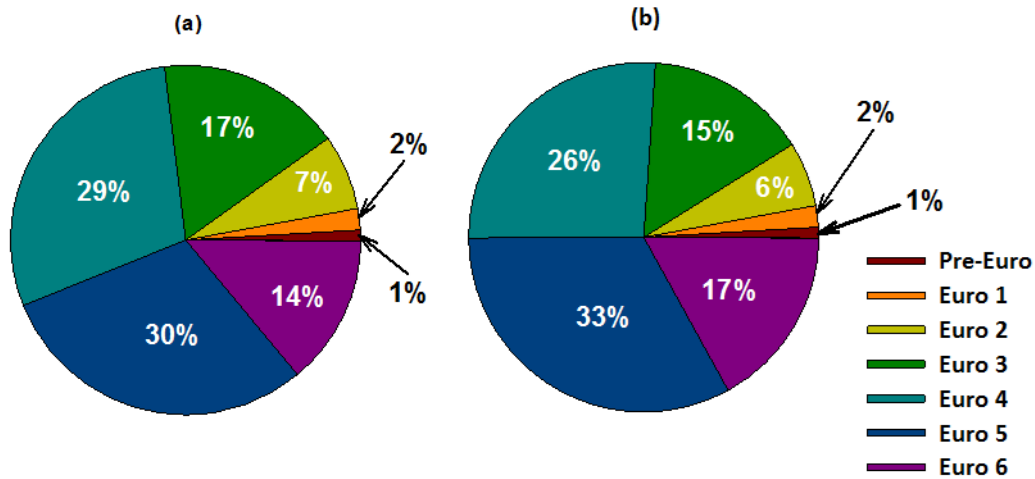


Fig. 4. Distribution of the various Euro emission standards for PCs (a) during the measurement campaign and (b) for the 2017 French fleet.

The distribution of the various Euro emission standards for PCs during the measurements was 14% Euro 6, 30% Euro 5, 29% Euro 4, 17% Euro 3, 7% Euro 2, 2% Euro 1, and 1% pre-Euro vehicles (Fig. 4a). This distribution is consistent with André et al. (2014), who estimated the PCs French fleet composed 17% Euro 6, 33% Euro 5, 26% Euro 4, 15% Euro 3, 6% Euro 2, 2% Euro 1, and 1% pre-Euro in 2017 (Fig. 4b). As regards drive technology systems, the observed PC fleet was composed of 68% diesel vehicles, 30% gasoline vehicles, and 2% other such as gasoline or diesel hybrid vehicles, electric vehicles, gasoline/compressed natural gas and gasoline/liquefied petroleum gas vehicles. The LCV fleet was composed of 97% diesel vehicles. For the HDVs, all the trucks were powered by diesel engines and all the buses were natural gas combustion or other gaseous hydrocarbons.

3.2 Estimation of Global Fleet Emission Factors

The global fleet emission factors for PN, BC, carbonyl compounds, BTEX, alkanes, NO_x concentrations, number of vehicles, and traffic speeds are presented in Fig. 5 as a function of the measurement time and day on the traffic site. The average emission factor of one

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711 220 vehicle (equation (1)) has been multiplying by the vehicle number that gives us the pollutant
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713 221 emission factors for a global fleet, over the one-hour measurement period. This allows us to
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716 222 study the pollutant emissions in relation with the current traffic.
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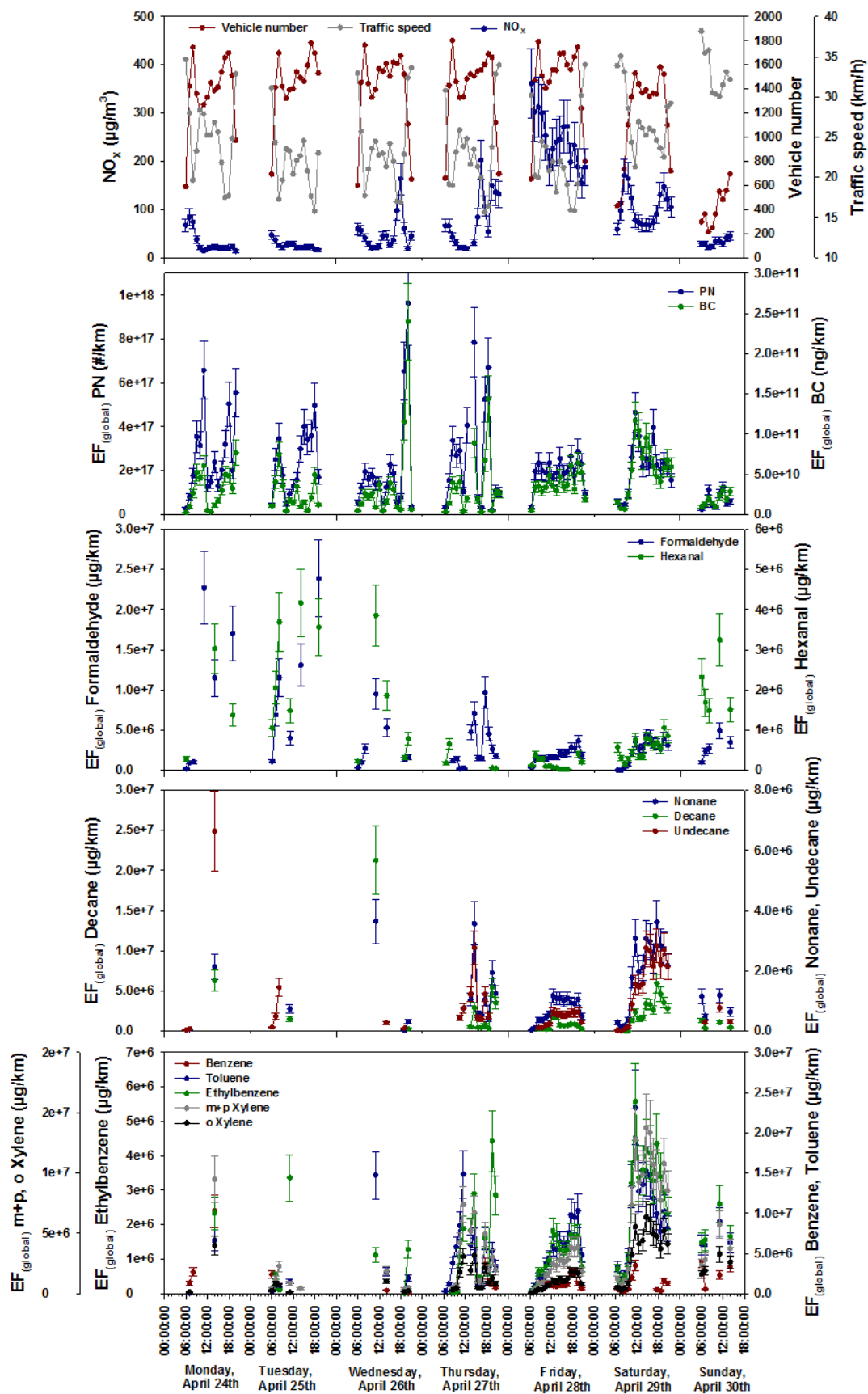
718 223 The particle number emission factors varied between 2×10^{16} and 9.6×10^{17} #/km on five
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720 224 weekdays and between 2.3×10^{16} and 4.6×10^{17} #/km on the weekend. The BC emission
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722 225 factors varied between 2.4×10^9 and 2.4×10^{11} ng/km on weekdays and between 6.6×10^9 and
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724 226 1.2×10^{11} ng/km on the weekend. The emission factors for carbonyl compounds varied
725
726 227 between 2×10^4 and 2.4×10^6 $\mu\text{g}/\text{km}$ on weekdays and between 2.7×10^3 and 4.9×10^5 $\mu\text{g}/\text{km}$
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728 228 on the weekend. The hexanal emission factors ranged between 2.3×10^3 and 4.1×10^5 $\mu\text{g}/\text{km}$
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730 229 on weekdays and between 1.5×10^4 and 3.2×10^5 $\mu\text{g}/\text{km}$ on the weekend. For the three
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732 230 alkanes, the emission factors were between 1.2×10^4 and 7.1×10^6 $\mu\text{g}/\text{km}$ on weekdays and
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734 231 between 5.3×10^3 and 2×10^6 $\mu\text{g}/\text{km}$ on the weekend. The BTEX emission factors ranged
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736 232 between 5.4×10^3 and 3.3×10^6 $\mu\text{g}/\text{km}$ on weekdays and between 6.3×10^4 and 5.1×10^6 $\mu\text{g}/\text{km}$
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738 233 on the weekend. The missing points for VOCs are either pollutant quantities sampled on the
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740 234 cartridges below their quantification limit; or negative values by subtracting the background
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742 235 value.
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747 236 The urban background concentrations for the pollutants used in the equation (1) were
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749 237 measured on the urban background site used by the air quality association "Air Pays de la
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751 238 Loire". This background site is not affected by road traffic emissions, the measured NO_x , PN
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753 239 and BC concentrations vary little on the different measurement time (16h/day during 4 days)
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755 240 (between 3200 and 4800 #/cm³ for PN, between 400 and 700 ng/m³ for BC, and between 5
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757 241 and 50 $\mu\text{g}/\text{m}^3$ for NO_x) and provides a general background concentration with all different
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759 242 sources. The subtraction in the equation (1) allows removing only the general back ground
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761 243 levels but not the local background levels. This might induce a potential bias with an over
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770 244 estimation of EF for PN and other pollutants if the local background levels are higher than
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772 245 general background levels. The local background levels could also be measured when there
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775 246 is no traffic. However, depending on the weather conditions, especially the wind speeds, the
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777 247 accumulation phenomena under no traffic condition might also induce a potential bias on
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779 248 our measurement. The first point in the morning (at around 6:00 a.m.) was taken as the
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781 249 background level at the traffic site. Using this local background levels, the emission factors of
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783 250 PN and BC are respectively between 5×10^{15} and 9×10^{17} #/km and 1.2×10^8 and
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785 251 2.3×10^{11} ng/km. The local background values induce an underestimation of 4 and 20 times
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787 252 for PN and BC comparing to the 'Air Pays de la Loire' background site, but only for low
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789 253 emission period. These background values do not induce a significant difference at high
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791 254 emission period for both PN and BC. Overall, if we use the local background value, it induced
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793 255 an average underestimation around 30% for all period of measurement.
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797 256 In general, the highest emission factors were measured between 7:00 a.m. and
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799 257 10:00 a.m. and between 5:00 p.m. and 8:00 p.m. on all five weekdays. For the Saturday, the
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801 258 highest emission factors were measured between 10:00 a.m. and 1:00 p.m. and between
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803 259 5:00 p.m. and 8:00 p.m. For the Sunday, between 6:00 a.m. and 3:00 p.m., high emission
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805 260 factors were measured for carbonyl compounds, BTEX and alkanes. The higher emission
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807 261 factors measured in the morning can be explained by vehicle cold start, which emits large
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809 262 amounts of pollutants such as BC, PN, BTEX, and carbonyl compounds (Westerholm et al.,
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811 263 1996; Jourmard et al., 2000; Sluder et al., 2000; Caplain et al., 2006; Louis et al., 2016;
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813 264 Martinet et al., 2017).
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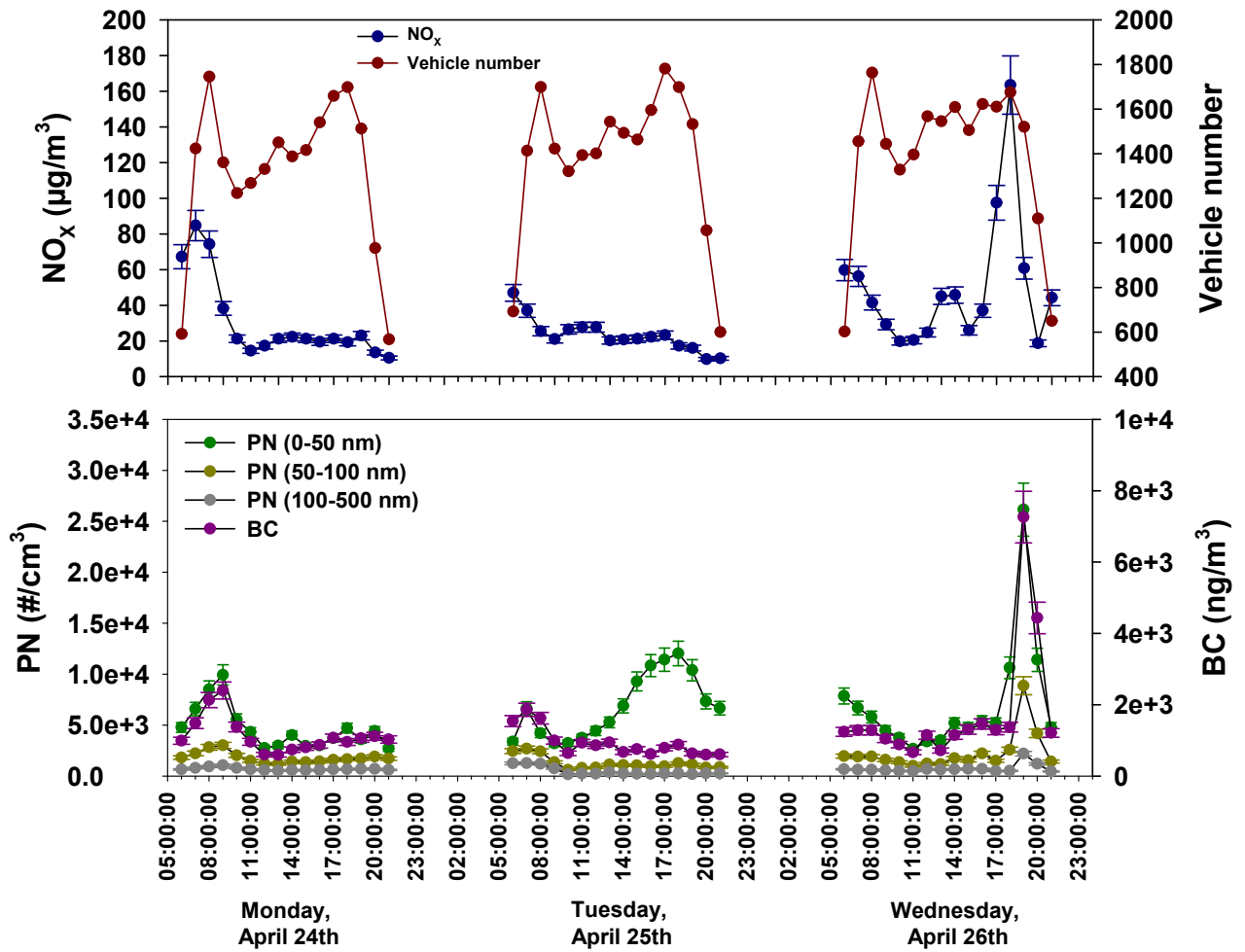
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Fig. 5. Global fleet emission factors for PN, BC, carbonyl compounds, BTEX, alkanes, NO_x concentrations, number of vehicles, and traffic speeds as a function of the time and day of measurement on the traffic site.

886
887
888 268 The PN and BC emission factors showed a good correlation, following the same tendency
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890 269 during the week of measurements (Fig. 5). Apart from Tuesday afternoon between 2:00 p.m.
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893 270 and 8:00 p.m., the PN emission factors did not follow the same tendency as the BC emission
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895 271 factors. The emission factor values for BC decreased while those for PN increased sharply.
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897 272 This could imply that the particle number emissions measured during this afternoon were
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900 273 not due to road traffic (See Section below).
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902

903 274 3.3 PN Concentration and Size Distribution Time Profiles 904 905

906 275 The number of vehicles, BC, NO_x and PN for three size ranges ([0-50] nm, [50-100] nm,
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908 276 and [100-500] nm) concentrations were followed from Monday (April 24th) to Sunday (April
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910 277 30th), which show the similar results in general for the five weekdays, except for Tuesday
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913 278 afternoon. Fig. 6 shows the time profiles of NO_x, BC, PN concentrations and vehicles number
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915 279 on Monday, Tuesday and Wednesday. Concentration peaks of BC, PN and NO_x was observed
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917 280 over a short period between 7:00 a.m. and 9:00 a.m. on weekdays corresponding to morning
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920 281 rush-hour traffic (See Section 3.2).
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922 282 Moreover, Fig. 6 shows a large peak for PN with size range [0-50] nm between 2:00 p.m.
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924 283 and 8:00 p.m. on Tuesday that is not correlated with BC, NO_x and PN size ranges [50-100] nm
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927 284 and [100-500] nm. Since NO_x and BC are considered as traffic tracers (Pant et al., 2013),
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929 285 which might indicates that the [0-50] nm PN on Tuesday afternoon is not generated by the
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932 286 road traffic.
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288 Fig. 6. Time profiles of NO_x concentration and number of vehicles and PN and BC concentrations on Monday, Tuesday and
289 Wednesday.

290 3.4 ANOVA Analysis of Global Fleet Emission Factors

291 The pollutant emission factors for a global fleet, over the one-hour measurement period,
292 have been analyzed by ANOVA statistical analysis to investigate impact of fleet composition
293 on measured pollutant emissions (Table 1). The emission factors were analyzed with 6
294 categories: number of HDVs (0 to 43 with groups of every 10 HDVs), percentage of diesel PCs
295 between pre-Euro to Euro 3 (5 to 25% with 5% interval), percentage of Euro 4 diesel PCs (10
296 to 30% with 5% interval), percentage of diesel PCs Euro 5 and Euro 6 (15 to 35% with 5%
297 interval), percentage of gasoline PCs between pre-Euro and Euro 3 standard (5 to 15% with

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1006 298 5% interval) and percentage of gasoline PCs between Euro 4 and Euro 6 (5 to 25% with 5%
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1009 299 interval). The groups of variables for passenger cars have been made according to the
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1011 300 implementation of new after-treatment or engine technologies. For diesel vehicles, the
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1013 301 diesel particle filter (DPF), which significantly reduces PN and BC emissions, is considered as
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1015 302 variables. Thus, the first category includes the percentage of pre-Euro to Euro 3 diesel
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1018 303 vehicles that are not equipped with DPF; the second category includes the percentage of
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1020 304 Euro 4 diesel vehicles that are partially equipped with DPF; and the last category includes the
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1022 305 percentage of Euro 5 and Euro 6 diesel vehicles that are all equipped with DPF. For gasoline
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1024 306 vehicles, the first category therefore includes the percentage of gasoline vehicles from pre-
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1027 307 Euro to Euro 3 standards, all of which have indirect injection engines; and the second
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1029 308 category includes the percentage of gasoline vehicles from Euro 4 to Euro 6 standards, as the
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1031 309 introduction of direct injection engines has begun on Euro 4 standard vehicles. Moreover,
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1033 310 for ANOVA analysis, the fleet composition has been classed by groups (different gaps of
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1035 311 vehicle number or percentage) to investigate their impact on emissions. Each group has to
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1037 312 contain enough samples to be significant and not too large to have a good sensibility.
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1040 313 Tuesday afternoon PN data have not been taken into account because of its strange
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1042 314 behavior show in section 3.3.

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1045 315 For a result of the ANOVA analysis to be significant, the p-value must be ≤ 0.05 , which is
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1047 316 called a "significant result" in Table 1. However, to increase the power of the ANOVA
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1049 317 analysis, it is possible to consider that a result with a p-value between 0.05 and 0.1 are
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1051 318 significant, which is called "result considered as significant" in Table 1, but with a great
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1053 319 uncertainty. This analysis should be read with a special attention because they might also
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1055 320 indicate that the impacts of the analyzed group on emission could be significant but not
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1057 321 clearly significant.

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322 **Table 1**

323 Results of the ANOVA analysis for the effect of the fleet composition on the emission factors

Fleet composition	Pollutants	Unit	p-value	Groups having a significant impact	
				Negative impact	Positive impact
	PN	#/km	0.6	--	--
	BC	ng/km	0.2	--	--
	Formaldehyde	µg/km	0.2	--	--
	Hexanal	µg/km	0.6	--	--
	Benzene	µg/km	0.6	--	--
Number of HDVs	Toluene	µg/km	0.004*	20-30; 30-40	10-20
	Ethylbenzene	µg/km	0.04*	30-40	0-10; 10-20
	m+p-Xylene	µg/km	0.2	--	--
	o-Xylene	µg/km	0.1	--	--
	Nonane	µg/km	0.5	--	--
	Decane	µg/km	0.4	--	--
	Undecane	µg/km	0.7	--	--
	PN	#/km	0.08**	15-20%	10-15%
	BC	ng/km	0.6	--	--
Percentage of diesel PCs between pre-Euro to Euro 3 standard	Formaldehyde	µg/km	0.3	--	--
	Hexanal	µg/km	0.2	--	--
	Benzene	µg/km	0.6	--	--
	Toluene	µg/km	0.02*	10-15%	15-20%
	Ethylbenzene	µg/km	0.07**	10-15%	15-20%
	m+p-Xylene	µg/km	0.02*	10-15%	15-20%
	o-Xylene	µg/km	0.02*	10-15%	15-20%

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	Nonane	µg/km	0.1	--	--
	Decane	µg/km	0.9	--	--
	Undecane	µg/km	0.7	--	--
	PN	#/km	0.1	--	--
	BC	ng/km	0.001*	10-15%; 15-20%	20-25%; 25-30%
	Formaldehyde	µg/km	0*	20-25%; 25-30%	10-15%; 15-20%
	Hexanal	µg/km	0.7	--	--
Percentage	Benzene	µg/km	0.3	--	--
of diesel PCs	Toluene	µg/km	0.1	--	--
Euro 4	Ethylbenzene	µg/km	0.02*	15-20%	20-25%
standard	m+p-Xylene	µg/km	0.04*	15-20%	20-25%
	o-Xylene	µg/km	0.02*	15-20%	20-25%
	Nonane	µg/km	0.3	--	--
	Decane	µg/km	0.9	--	--
	Undecane	µg/km	0.6	--	--
	PN	#/km	0.006*	30-35%	20-25%
	BC	ng/km	0.2	--	--
Percentage	Formaldehyde	µg/km	0.06**	15-20%	30-35%
of diesel PCs	Hexanal	µg/km	0.3	--	--
between	Benzene	µg/km	0.07**	15-20%	30-35%
Euro 5 to	Toluene	µg/km	0.2	--	--
Euro 6	Ethylbenzene	µg/km	0.2	--	--
standard	m+p-Xylene	µg/km	0.1	--	--
	o-Xylene	µg/km	0.06**	15-20%	30-35%
	Nonane	µg/km	0.2	--	--

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	Decane	µg/km	0.6	--	--
	Undecane	µg/km	0.007*	15-20%	30-35%
	PN	#/km	0.5	--	--
	BC	ng/km	0.7	--	--
Percentage	Formaldehyde	µg/km	0.9	--	--
of gasoline	Hexanal	µg/km	0.07	--	--
PCs	Benzene	µg/km	0.4	--	--
between	Toluene	µg/km	0.07**	5-10%	10-15%
pre-Euro to	Ethylbenzene	µg/km	0.004*	5-10%	10-15%
Euro 3	m+p-Xylene	µg/km	0.007*	5-10%	10-15%
standard	o-Xylene	µg/km	0.02*	5-10%	10-15%
	Nonane	µg/km	0.2	--	--
	Decane	µg/km	0.9	--	--
	Undecane	µg/km	0.7	--	--
	PN	#/km	0.004*	5-10%	20-25%
	BC	ng/km	0*	5-10%; 10-15%	20-25%
Percentage	Formaldehyde	µg/km	0.5	--	--
of gasoline	Hexanal	µg/km	0.6	--	--
PCs	Benzene	µg/km	0.4	--	--
between	Toluene	µg/km	0.3	--	--
Euro 4 to	Ethylbenzene	µg/km	0.1	--	--
Euro 6	m+p-Xylene	µg/km	0.1	--	--
standard	o-Xylene	µg/km	0.1	--	--
	Nonane	µg/km	0.3	--	--
	Decane	µg/km	0.5	--	--

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	Undecane	µg/km	0.07**	5-10%; 10-15%	20-25%
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- 324 * Significant results
- 325 ** Results considered as significant
- 326 -- No results

327 For BC, the groups of “20-25%” and “25-30%” Euro 4 diesel PCs and “20-25%” gasoline
328 PCs between Euro 4 to Euro 6 have a significant positive impact on the emissions. This
329 observation indicates that higher percentage of these two categories present in the fleet
330 induces more BC emission. For the gasoline PCs between Euro 4 to Euro 6, the group “20-
331 25%” has also a significant positive impact on the PN emissions. The positive impact of
332 gasoline PCs between Euro 4 and Euro 6 on the PN and BC emissions can be explained by the
333 introduction of direct injection technology on certain gasoline vehicles, which induces more
334 PN and BC emissions than multipoint injection gasoline vehicles. These emissions could
335 reach the level of some diesel vehicles without a particulate filter (Liang et al., 2013,
336 Martinet et al., 2017).

337 The percentage of diesel and gasoline PCs between pre-Euro and Euro 3 has a significant
338 positive impact on toluene, ethylbenzene and m+p- and o-xylene emission factors, more
339 particular the groups “15-20%” and “10-15%” respectively. Comparing to the average
340 emission factors (1.4×10^6 µg/km for toluene, 3.4×10^5 µg/km for ethylbenzene, 9×10^5 µg/km
341 for m+p-xylene and 4.2×10^5 µg/km for o-xylene), the group “15-20%” of Pre-Euro to Euro 3
342 diesel induces 1.5, 1.4, 1.6 and 1.6 times higher emission respectively for toluene,
343 ethylbenzene, m+p-xylene and o-xylene. The group “10-15%” of Pre-Euro to Euro 3 gasoline
344 induces 1.2, 1.4, 1.3 and 1.3 times higher emission respectively for toluene, ethylbenzene,
345 m+p-xylene and o-xylene. Moreover, the group “20-25%” of diesel Euro 4 PCs has also a
346 positive impact on ethylbenzene and m+p- and o-xylene emission factors, 1.4, 1.4 and 1.5

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1301 347 times higher respectively comparing to the average emission factors. For the analyses on the
1302
1303 348 number of HDVs, emission factors estimated in the weekend have not been taken into
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1306 349 account because of the HDV driving ban. The Table 1 showed that the impact of the number
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1308 350 of HDVs on pollutant emission does not show a significant positive impact. This observation
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1310 351 might be explained on one side by the small percentage of HDVs in the fleet (0 to 43 HDVs
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1313 352 per hour); and on the other side by the low HDVs emission since 80% of these HDVs are
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1315 353 recent vehicles (\geq Euro 4).
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1318 354 3.5 Emission Factors Per Vehicle and Comparison with Other Studies 1319 1320

1321 355 In this section, the average emission factors calculated by equation (1) were used (# or
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1323 356 mass/veh/km) in order to compare with other studies. Fig. 7 shows the box-and-whisker plot
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1326 357 for these average emission factors per vehicle for carbonyl compounds, BTEX, alkanes, PN,
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1328 358 and BC. In these plots, the boxes contain 50% of the emission factors around the median
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1330 359 (black line in the box). The upper and lower halves of the boxes represent respectively the
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1332 360 75th and 25th percentiles and the whiskers represent the 90th and 10th percentiles. The
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1334 361 emission factors that are above or below the whiskers are considered to be atypical values.
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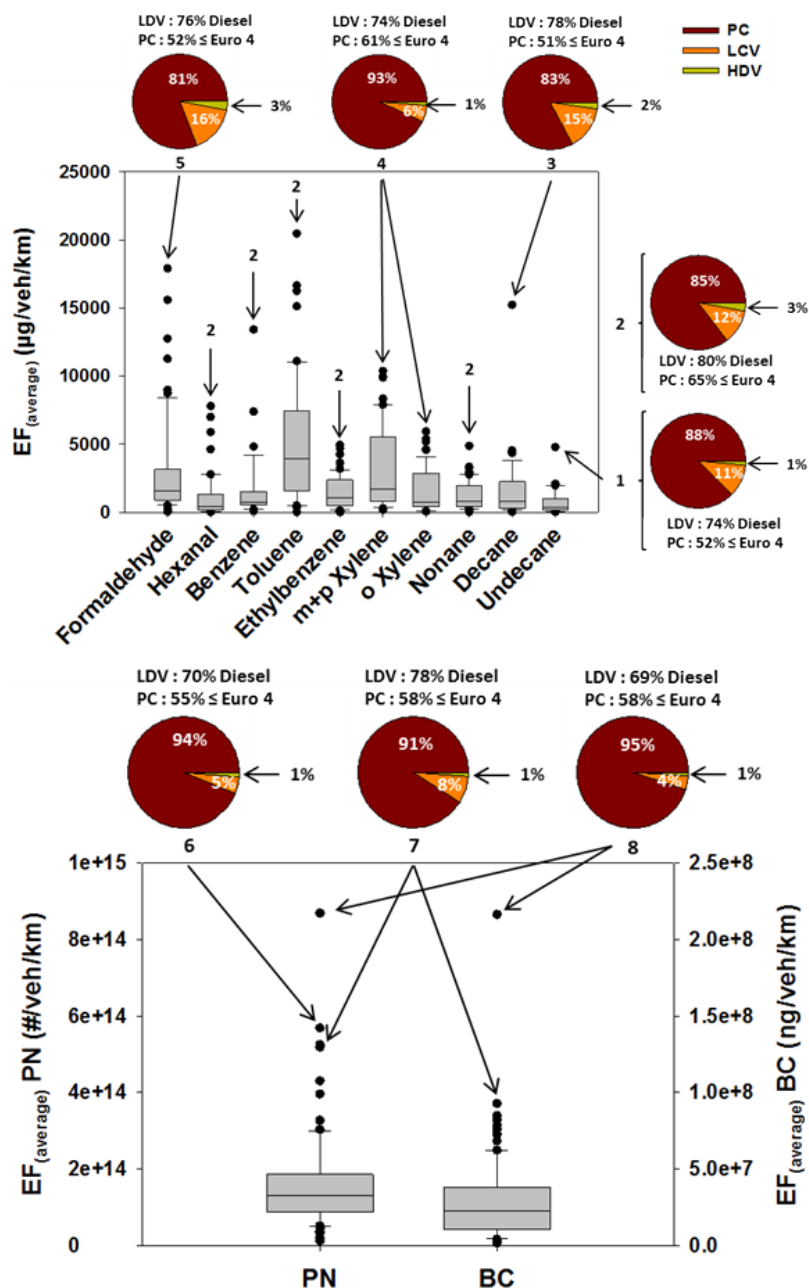
1337 362 Fig. 7 shows the average emission factors per vehicle for PN and BC, which are between
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1339 363 1.2×10^{13} and 8.7×10^{14} #/km/veh and between 1.7×10^6 and 2.16×10^8 ng/km/veh,
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1341 364 respectively. For both emission factors, the median is in the middle of the box, which
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1343 365 indicates a symmetric distribution. Half the emission factors are between 9.1×10^{13} and
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1345 366 1.87×10^{14} #/km/veh for PN and between 1.1×10^7 and 3.8×10^7 ng/km/veh for BC. In addition,
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1347 367 the boxes are comparatively short, suggesting that the PN emission factors have a high level
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1349 368 of agreement between them, and the BC emission factors have also a high level of
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1351 369 agreement between them. Fig. 7 shows also the average emission factors per vehicle for the
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370 measured VOCs and SVOCs. For all these compounds, the median is in the lower half of the
371 box, which assumes an asymmetric distribution toward the low values. Their emission
372 factors varied between 14 and 2.1×10^4 $\mu\text{g}/\text{veh}/\text{km}$.

373 For each compound, the atypical values are presented by black dots. Here, only the
374 atypical values above the upper whisker limit are further analyzed with the corresponding
375 fleet composition. The emission factors above the upper whisker for PN and BC are,
376 respectively, 2.3 to 6.6 times higher and 2.7 to 9.6 times higher compared to the median.
377 The highest emission factor for both corresponds to the same fleet composition with 69% of
378 LDVs diesel and 58% of PCs \leq Euro 4 (composition 8 in the Fig. 7) for the Wednesday
379 between 8:00 p.m. and 9:00 p.m. The second highest emission factor for BC and the third
380 highest for PN (composition 7 in the Fig. 7) correspond to the Sunday between 8:00 a.m. and
381 9:00 a.m.

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382
 383 **Fig. 7.** Box-and-whisker plot of the average vehicle emission factors for PN, BC, carbonyl compounds, BTEX and alkanes.
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 385 Fleet composition of 1: Monday 2:00 - 3:00 p.m.; 2: Sunday 6:00 - 7:00 a.m.; 3: Wednesday 11:00 - 12:00 a.m.; 4: Sunday
 386 11:00 - 12:00 a.m.; 5: Monday 11:00 - 12:00 a.m.; 6: Monday 8:00 - 9:00 p.m.; 7: Sunday 8:00 - 9:00 a.m.; 8: Wednesday
 387 8:00 - 9:00 p.m.

387 The emission factors for carbonyl compounds above the upper whisker are 5 to 11 times
 388 higher and 6 to 17 times higher than the median for formaldehyde and hexanal, respectively.
 389 For the three alkanes, the emission factors above the upper whisker are 3 to 18 times higher

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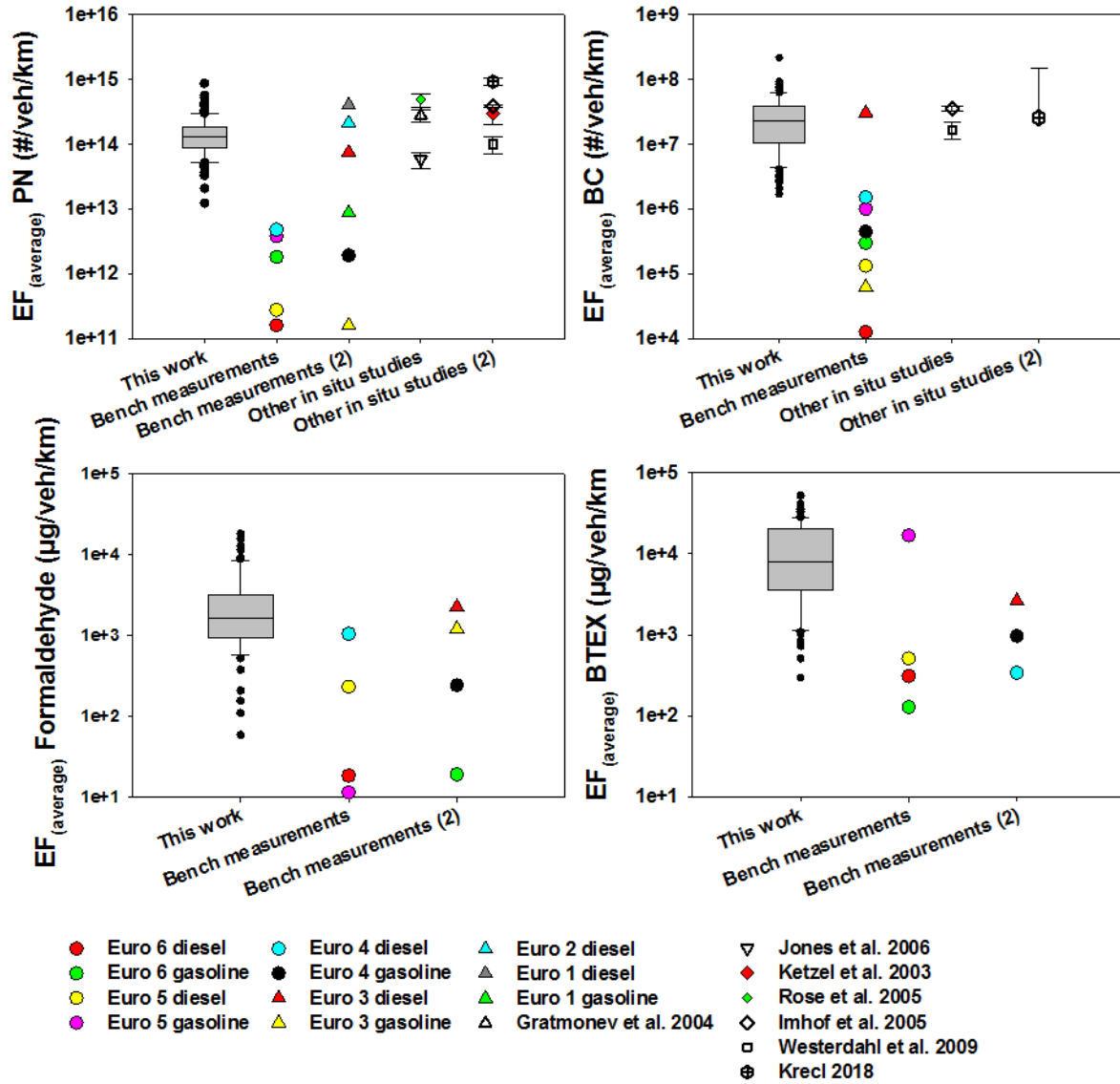
390 compared to their median. The BTEX emission factors above the upper whisker are 1.4 to 8
391 times higher compared to their median. The highest emission factor for hexanal, benzene,
392 toluene, ethylbenzene and nonane correspond to the same fleet composition (composition 2
393 in the Fig. 7) for the Sunday between 6:00 a.m. and 7:00 a.m. We remark that, in this time
394 interval, the fleet composition composed relatively high percentage of LDVs diesel (80%),
395 PCs \leq Euro 4 (65%) and HDVs (3%), which have been showed by the ANOVA analysis to have
396 significant impacts on emission of these compounds (Table 3). For m+p and o xylene
397 compounds, the highest emission factor corresponds to the fleet composition of the Sunday
398 between 11:00 a.m. and 12:00 a.m. (composition 4 in the Fig. 7), with relatively high
399 percentage of PCs \leq Euro 4. For formaldehyde, the highest emission factor corresponds to
400 the Monday between 11:00 a.m. and 12:00 a.m. (composition 5) with 3% of HDVs.

401 Fig. 8 shows the comparison of PN, BC, formaldehyde and BTEX emission factors
402 estimated in this study and with those estimated during lab bench measurements with
403 Artemis urban driving cycles that is not exactly the same driving condition but might
404 represent the most similar driving condition (average speed from 8.7 to 31.8 km/h from
405 congestion to fluid situations) comparing to our traffic site (hourly average speed between
406 16 and 34 km/h). The detail of bench measurement of Euro 1 to Euro 6 gasoline and diesel
407 PCs were presented in our previous works (Rehn 2013; Louis et al., 2016; Martinet et al.,
408 2017). Moreover, the PN and BC emission factors estimated in this study were also
409 compared with other in-situ studies with similar site characteristics (Ketzler et al., 2003;
410 Gratmonev et al., 2004; Rose et al., 2005; Imhof et al., 2005; Jones et al. 2006; Westerdahl et
411 al., 2009; Krecl et al., 2018).

412 The emission factors estimated by other in-situ studies are between 5.8×10^{13} and
413 9.3×10^{14} #/veh/km for PN; and between 1.7×10^7 and 3.5×10^7 ng/veh/km for BC, which are in

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414 the same range as those estimated in this paper (Fig. 8), even fleet compositions are
415 different in different countries and different years.



416
417 **Fig. 8.** Comparison of PN, BC, formaldehyde and BTEX emission factors per vehicle in this work with emission factors
418 estimated by bench measurements (Rehn 2013; Louis et al., 2016; Martinet et al., 2017) or by other in-situ studies (Ketznel
419 et al., 2003; Gratmonev et al., 2004; Rose et al., 2005; Imhof et al., 2005; Jones et al., 2006; Westerdahl et al., 2009; Krecl et
420 al., 2018).

421 The PCs emission factors in this work are also compared to the bench measurement
422 (previous work). The bench emission factors of PN and BC obtained from diesel vehicles

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1595
1596 423 without particle filter and gasoline vehicles with direct injection system are in the same
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1598 424 range as the box plot. The impact of gasoline with direct injection system and Euro 4 diesel
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1601 425 vehicles on PN and BC emission has been observed with ANOVA analysis. However, for the
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1603 426 pre-Euro to Euro 3 old diesel vehicles, even they induce a high BC and PN emission with
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1605 427 individual vehicle measurement, their impact on BC and PN emission could be considered
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1608 428 either as significant but with a great uncertainty or not significant because they are
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1610 429 omnipresent in each one-hour period with very closed percentage in the fleet (10 to 20%).
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1612 430 These in-situ emission factors are also comparable with old HDVs without particle filter (PN
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1614 431 emission factors between 5×10^{13} and 2×10^{14} #/veh/km) (Giechaskiel et al., 2012), contrary to
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1616 432 recent HDVs equipped with DPF that induce lower PN emissions (between 5×10^{10} and 2×10^{12}
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1619 433 #/veh/km) (Giechaskiel et al., 2018). For formaldehyde, the emission factors of Euro 3 and
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1621 434 Euro 4 diesel and gasoline vehicles are in the same range as the emission factors estimated
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1623 435 in this work. More recent Euro 5 and Euro 6 PCs seem to contribute less emission. For BTEX,
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1625 436 the Euro 5 gasoline DI vehicle is located above the box that might indicate its high impact on
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1628 437 BTEX emission. However, we want to attract special attention here, because only one Euro 5
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1630 438 gasoline DI vehicle data from bench has been provided (Louis et al., 2016). More vehicles for
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1632 439 each category should be tested on the chassis bench under similar experimental conditions
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1634 440 to confirm this observation.
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1639 441 **4. Conclusion**

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1642 442 This paper aimed to estimate the emission factors of PN, BC, and several aliphatic,
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1644 443 aromatic and carbonyl compounds with a real fleet present on the measurement site. The
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1646 444 fleet composition characterized during the measurement campaign was comparable with
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445 the 2017 French fleet. A total of 140,076 vehicles were counted for seven days with about
446 21,000 to 23,000 vehicles in the weekdays and 10,000 to 18,000 in the weekend.

447 The highest emissions were measured during the morning between 7:00 a.m. - 10:00
448 a.m. and during the end of afternoon between 5:00 p.m. - 8:00 p.m. for the weekdays, and
449 between 10:00 a.m. - 1:00 p.m. and between 5:00 p.m. - 8:00 p.m. for the Saturday. These
450 periods correspond to traffic peaks. The higher emission measured in the morning can be
451 explained by vehicle cold start, which emits large amounts of pollutants such as BC, PN,
452 BTEX, and carbonyl compounds. PN and BC emission factors show a good correlation, except
453 the Tuesday afternoon between 2:00 p.m. - 8:00 p.m. The emission factor values for BC
454 decreased while those for PN increased sharply. This could imply that the particle number
455 emissions, especially the PN size between [0-50] nm, measured during this afternoon were
456 not due to road traffic.

457 The impacts of the fleet composition on the pollutant emissions were studied by ANOVA
458 analyses. These analyses show the positive impact of the higher percentage of gasoline PCs
459 between Euro 4 and Euro 6 and Euro 4 diesel PCs on the BC emissions and the higher
460 percentage of diesel and gasoline PCs between pre-Euro and Euro 3 on toluene,
461 ethylbenzene, m+p-xylene and o-xylene emissions. The higher percentage of Euro 4 diesel
462 PCs induces higher emission of ethylbenzene, m+p-xylene and o-xylene. And the number of
463 HDVs present in the weekdays does not induce a significant impact on measured pollutant
464 emissions since 80% of HDVs in the fleet is recent HDVs (\geq Euro 4).

465 The emission factors per vehicle were studied with boxplots and compared to other
466 emission factors calculated in previous in-situ studies and with bench measurement. PN and
467 BC emission factors assume a symmetric distribution contrary to the BTEX, alkanes and
468 carbonyl compounds emission factors. For PN and BC, the highest emission factors

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469 correspond to the same fleet composition with high percentage of diesel PCs. The highest
470 emission factors for hexanal, benzene, toluene, ethylbenzene and nonane correspond to a
471 fleet composition with high percentage of diesel PCs (85%) and old PCs (65%), and for m+p
472 and o Xylene, they correspond to high percentage of old PCs (61%). These results have also
473 been observed by the ANOVA analyses for toluene, ethylbenzene, m+p-xylene and o-xylene.
474 The PN and BC emission factors estimated by other in-situ studies are in the same range as
475 the emission factors estimated in this work. For the chassis bench comparison, the PN and
476 BC emission factors estimated in this work are in the same range as those measured for
477 diesels PCs without particle filter, gasoline PCs with direct injection system and old HDVs. For
478 BTEX, bench emission factors are in the same range as in-situ emission factors estimated in
479 this work.

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496 **Appendices**

497 **Table A.1**

498 Analytical methods for BTEX, carbonyl compounds, and PAH samples in the gas and particulate phases with quantification
499 limit and uncertainty

Compound family	Cartridge type	Analytical technique	Standardized method	Quantification limit	Analytical uncertainty
BTEX					
Benzene	Tenax	ATD-GC/MS*	ISO 16000-6	10 ng/cartridge	20%
Toluene				1 ng/cartridge	
Ethylbenzene					
m-p,Xylene					
o-Xylene					
Alkanes					
Nonane	Tenax	ATD-GC/MS*	ISO 16000-6	1 ng/cartridge	20%
Decane					
Undecane					
Cyclopropane, Ethyl					
Cyclohexane, Ethyl					
Carbonyl					
Formaldehyde	DNPH	HPLC/UV#	ISO 16000-3	30 ng/cartridge	20%
Acetaldehyde					
Acetone					
Acrolein					
Propionaldehyde					
Crotonaldehyde					
Methacrolein					
Butanal					

Benzaldehyde					
Pentanal					
Hexanal					

* ATD-GC-MS: Automated Thermal Desorption – Gas Chromatograph – Mass Spectrometer

HPCL/UV: High Performance Liquid Chromatography/Ultra Violet Detector

Table A.2

Vehicle emission factors per hour for PN, BC, carbonyl compounds, BTEX and alkanes.

Pollutants		Emission factors (Min-Max)	Mean	Standard deviation
PN (#/veh/km)	Weekdays	$1.2 \times 10^{13} - 8.7 \times 10^{14}$	2×10^{14}	1.9×10^{14}
	Weekend	$6.1 \times 10^{13} - 5.3 \times 10^{14}$	1.7×10^{14}	1×10^{14}
BC (ng/veh/km)	Weekdays	$1.7 \times 10^6 - 2.2 \times 10^8$	2.4×10^7	2.8×10^7
	Weekend	$9 \times 10^6 - 9.3 \times 10^7$	4.7×10^7	2.1×10^7
Formaldehyde (mg/veh/km)	Weekdays	$1.6 \times 10^{-1} - 18$	3	3.9
	Weekend	$6 \times 10^{-2} - 13$	3.2	3.1
Hexanal (mg/veh/km)	Weekdays	$1.4 \times 10^{-2} - 2.8$	7.1×10^{-1}	8.8×10^{-1}
	Weekend	$2.1 \times 10^{-1} - 7.8$	1.8	1.8
Benzene (mg/veh/km)	Weekdays	$9.1 \times 10^{-2} - 7.4$	1.2	1.5
	Weekend	$2.3 \times 10^{-1} - 13.4$	2.4	3.5
Toluene (mg/veh/km)	Weekdays	$3.4 \times 10^{-2} - 11$	3	2.6
	Weekend	3.3 - 20.5	9.6	4.7
Ethylbenzene (mg/veh/km)	Weekdays	$1.3 \times 10^{-2} - 2.6$	8.5×10^{-1}	7×10^{-1}
	Weekend	$7 \times 10^{-1} - 5$	2.6	1.2

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m+p Xylene	Weekdays	$1.8 \times 10^{-1} - 6.8$	1.6	1.5
(mg/veh/km)	Weekend	1.4 - 10.4	6.4	2.8
o Xylene	Weekdays	$7 \times 10^{-2} - 2.9$	7.1×10^{-1}	6.4×10^{-1}
(mg/veh/km)	Weekend	$6.1 \times 10^{-1} - 5.9$	3.2	1.6
Nonane	Weekdays	$3.5 \times 10^{-2} - 3.3$	8×10^{-1}	7.5×10^{-1}
(mg/veh/km)	Weekend	$3.3 \times 10^{-1} - 4.9$	2	1.1
Decane	Weekdays	$1.5 \times 10^{-1} - 15.2$	1.5	3.1
(mg/veh/km)	Weekend	$4.1 \times 10^{-2} - 4.5$	1.7	1.3
Undecane	Weekdays	$5.5 \times 10^{-2} - 4.8$	5.3×10^{-1}	$8..9 \times 10^{-1}$
(mg/veh/km)	Weekend	$3.5 \times 10^{-2} - 2.1$	1.1	7×10^{-1}

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508 **Table A.3**

509 Example of COPERT input data for calculating NO_x emission factors

Category	Fuel	Segment	Euro Standard	Stock [n]	Mean Activity [km/year]	Urban Speed [km/h]
Passenger Cars	Gasoline	Small	PRE ECE	0	0	25
Passenger Cars	Gasoline	Small	Euro 1	1	4077	25
Passenger Cars	Gasoline	Small	Euro 2	2	5055	25
Passenger Cars	Gasoline	Small	Euro 3	1	6820	25
Passenger Cars	Gasoline	Small	Euro 4	2	8508	25
Passenger Cars	Gasoline	Small	Euro 5	1	11007	25
Passenger Cars	Gasoline	Small	Euro 6	5	13309	25
Passenger Cars	Gasoline	Medium	PRE ECE	0	0	25
Passenger Cars	Gasoline	Medium	Euro 1	2	5398	25
Passenger Cars	Gasoline	Medium	Euro 2	4	6672	25
Passenger Cars	Gasoline	Medium	Euro 3	5	8995	25
Passenger Cars	Gasoline	Medium	Euro 4	0	11319	25

2007							
2008							
2009	Passenger Cars	Gasoline	Medium	Euro 5	2	14555	25
2010	Passenger Cars	Gasoline	Medium	Euro 6	3	17592	25
2011	Passenger Cars	Gasoline	Large-SUV-Executive	PRE ECE	0	0	25
2012	Passenger Cars	Gasoline	Large-SUV-Executive	Euro 1	0	5610	25
2013	Passenger Cars	Gasoline	Large-SUV-Executive	Euro 2	0	7069	25
2014	Passenger Cars	Gasoline	Large-SUV-Executive	Euro 3	0	9523	25
2015	Passenger Cars	Gasoline	Large-SUV-Executive	Euro 4	1	12000	25
2016	Passenger Cars	Gasoline	Large-SUV-Executive	Euro 5	0	15454	25
2017	Passenger Cars	Gasoline	Large-SUV-Executive	Euro 6	3	18619	25
2018	Passenger Cars	Diesel	Mini	Euro 4	10	15608	25
2019	Passenger Cars	Diesel	Mini	Euro 5	5	17572	25
2020	Passenger Cars	Diesel	Mini	Euro 6	5	19	25
2021	Passenger Cars	Diesel	Small	Euro 1	1	10957	25
2022	Passenger Cars	Diesel	Small	Euro 2	3	12152	25
2023	Passenger Cars	Diesel	Small	Euro 3	7	13560	25
2024	Passenger Cars	Diesel	Small	Euro 4	16	15236	25
2025	Passenger Cars	Diesel	Small	Euro 5	12	17146	25
2026	Passenger Cars	Diesel	Small	Euro 6	17	18122	25
2027	Passenger Cars	Diesel	Large-SUV-Executive	Euro 1	0	11376	25
2028	Passenger Cars	Diesel	Large-SUV-Executive	Euro 2	1	12489	25
2029	Passenger Cars	Diesel	Large-SUV-Executive	Euro 3	2	14286	25
2030	Passenger Cars	Diesel	Large-SUV-Executive	Euro 4	2	15807	25
2031	Passenger Cars	Diesel	Large-SUV-Executive	Euro 5	2	17770	25
2032	Passenger Cars	Diesel	Large-SUV-Executive	Euro 6	2	18788	25
2033	Light Commercial Vehicles	Diesel	N1-II	Conventional	0	2313	25
2034	Light Commercial Vehicles	Diesel	N1-II	Euro 1	0	5012	25
2035	Light Commercial Vehicles	Diesel	N1-II	Euro 2	0	7490	25
2036	Light Commercial Vehicles	Diesel	N1-II	Euro 3	2	10979	25
2037	Light Commercial Vehicles	Diesel	N1-II	Euro 4	9	15840	25
2038	Light Commercial Vehicles	Diesel	N1-II	Euro 5	13	21249	25
2039	Light Commercial Vehicles	Diesel	N1-II	Euro 6	23	25636	25
2040	Heavy Duty Trucks	Diesel	Rigid <=7,5 t	Euro I	0	846	25
2041	Heavy Duty Trucks	Diesel	Rigid <=7,5 t	Euro II	0	4475	25
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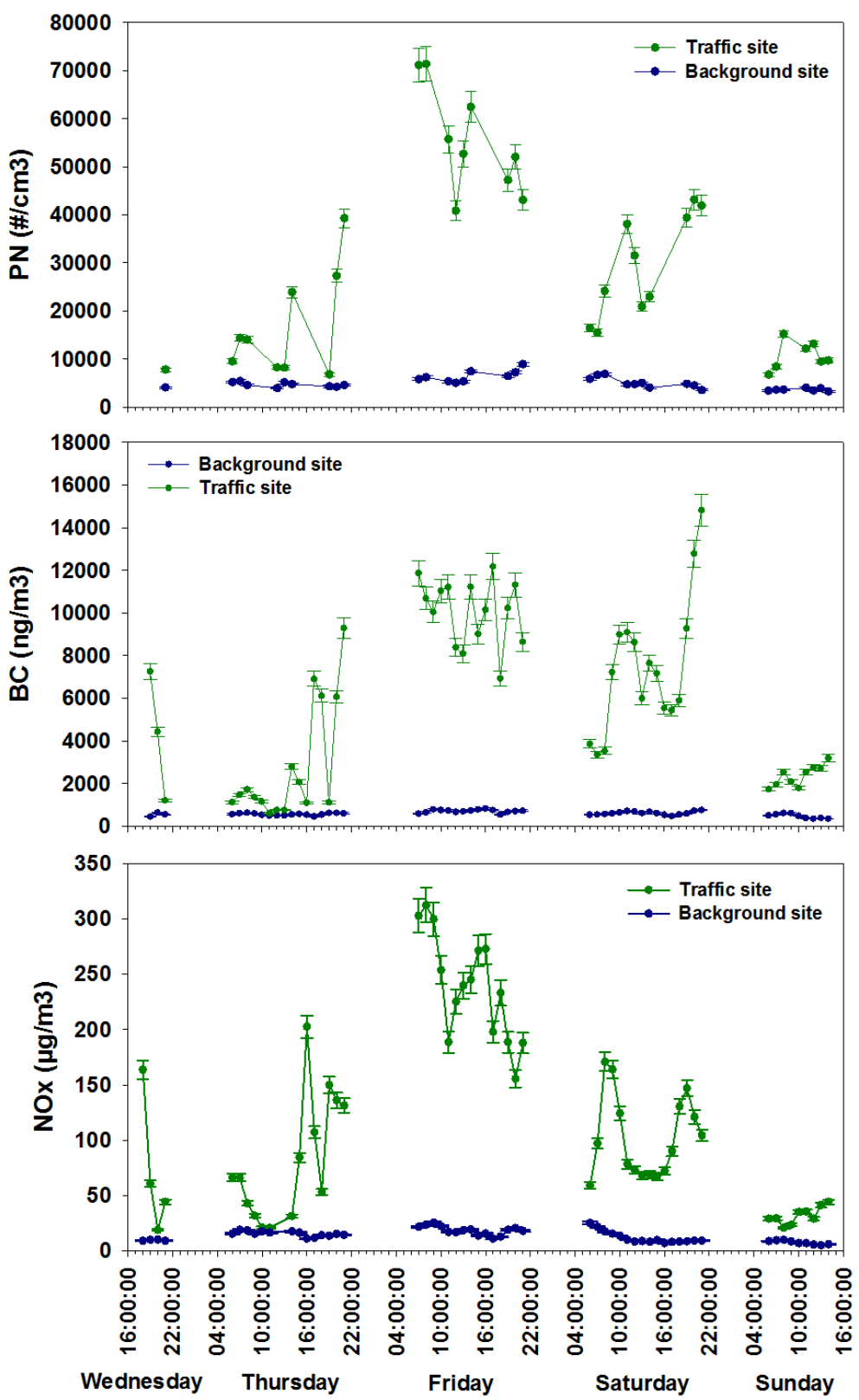
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2069	Heavy Duty Trucks	Diesel	Rigid <=7,5 t	Euro III	0	11207	25
2070	Heavy Duty Trucks	Diesel	Rigid <=7,5 t	Euro IV	0	19789	25
2071							
2072	Heavy Duty Trucks	Diesel	Rigid <=7,5 t	Euro V	0	32935	25
2073	Heavy Duty Trucks	Diesel	Rigid <=7,5 t	Euro VI	0	50409	25
2074							
2075	Heavy Duty Trucks	Diesel	Rigid 7,5 - 12 t	Euro I	0	903	25
2076	Heavy Duty Trucks	Diesel	Rigid 7,5 - 12 t	Euro II	0	4404	25
2077							
2078	Heavy Duty Trucks	Diesel	Rigid 7,5 - 12 t	Euro III	0	11191	25
2079	Heavy Duty Trucks	Diesel	Rigid 7,5 - 12 t	Euro IV	1	19733	25
2080							
2081	Heavy Duty Trucks	Diesel	Rigid 7,5 - 12 t	Euro V	1	33797	25
2082	Heavy Duty Trucks	Diesel	Rigid 7,5 - 12 t	Euro VI	0	53438	25
2083							
2084	Heavy Duty Trucks	Diesel	Rigid 14 - 20 t	Euro I	0	952	25
2085	Heavy Duty Trucks	Diesel	Rigid 14 - 20 t	Euro II	0	4598	25
2086							
2087	Heavy Duty Trucks	Diesel	Rigid 14 - 20 t	Euro III	0	11195	25
2088	Heavy Duty Trucks	Diesel	Rigid 14 - 20 t	Euro IV	0	19669	25
2089							
2090	Heavy Duty Trucks	Diesel	Rigid 14 - 20 t	Euro V	0	33306	25
2091	Heavy Duty Trucks	Diesel	Rigid 14 - 20 t	Euro VI	1	50609	25
2092							
2093	Heavy Duty Trucks	Diesel	Rigid 20 - 26 t	Euro I	0	983	25
2094	Heavy Duty Trucks	Diesel	Rigid 20 - 26 t	Euro II	0	4800	25
2095							
2096	Heavy Duty Trucks	Diesel	Rigid 20 - 26 t	Euro III	0	11470	25
2097	Heavy Duty Trucks	Diesel	Rigid 20 - 26 t	Euro IV	0	19795	25
2098							
2099	Heavy Duty Trucks	Diesel	Rigid 20 - 26 t	Euro V	0	33762	25
2100	Heavy Duty Trucks	Diesel	Rigid 20 - 26 t	Euro VI	0	50832	25
2101							
2102	Heavy Duty Trucks	Diesel	Rigid 26 - 28 t	Conventional	0	0	25
2103							
2104	Heavy Duty Trucks	Diesel	Rigid 26 - 28 t	Euro I	0	995	25
2105	Heavy Duty Trucks	Diesel	Rigid 26 - 28 t	Euro II	0	4999	25
2106							
2107	Heavy Duty Trucks	Diesel	Rigid 26 - 28 t	Euro III	0	11940	25
2108	Heavy Duty Trucks	Diesel	Rigid 26 - 28 t	Euro IV	0	19884	25
2109							
2110	Heavy Duty Trucks	Diesel	Rigid 26 - 28 t	Euro V	2	34084	25
2111	Heavy Duty Trucks	Diesel	Rigid 26 - 28 t	Euro VI	0	50947	25
2112							
2113	Buses	Diesel	Urban Buses Midi <=15 t	Euro IV	0	27800	25
2114							
2115	Buses	Diesel	Urban Buses Midi <=15 t	Euro V	0	38074	25
2116							
2117	Buses	Diesel	Urban Buses Midi <=15 t	Euro VI	0	45582	25
2118							
2119	Buses	Diesel	Urban Buses Articulated >18 t	Conventional	0	2000	25
2120							
2121	Buses	Diesel	Urban Buses Articulated >18 t	Euro I	0	5823	25
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2127			Urban Buses				
2128	Buses	Diesel	Articulated >18 t	Euro II	0	11357	25
2129			Urban Buses				
2130	Buses	Diesel	Articulated >18 t	Euro III	0	19120	25
2131			Urban Buses				
2132	Buses	Diesel	Articulated >18 t	Euro IV	1	27763	25
2133			Urban Buses				
2134	Buses	Diesel	Articulated >18 t	Euro V	1	37992	25
2135			Urban Buses				
2136	Buses	Diesel	Articulated >18 t	Euro VI	0	45633	25

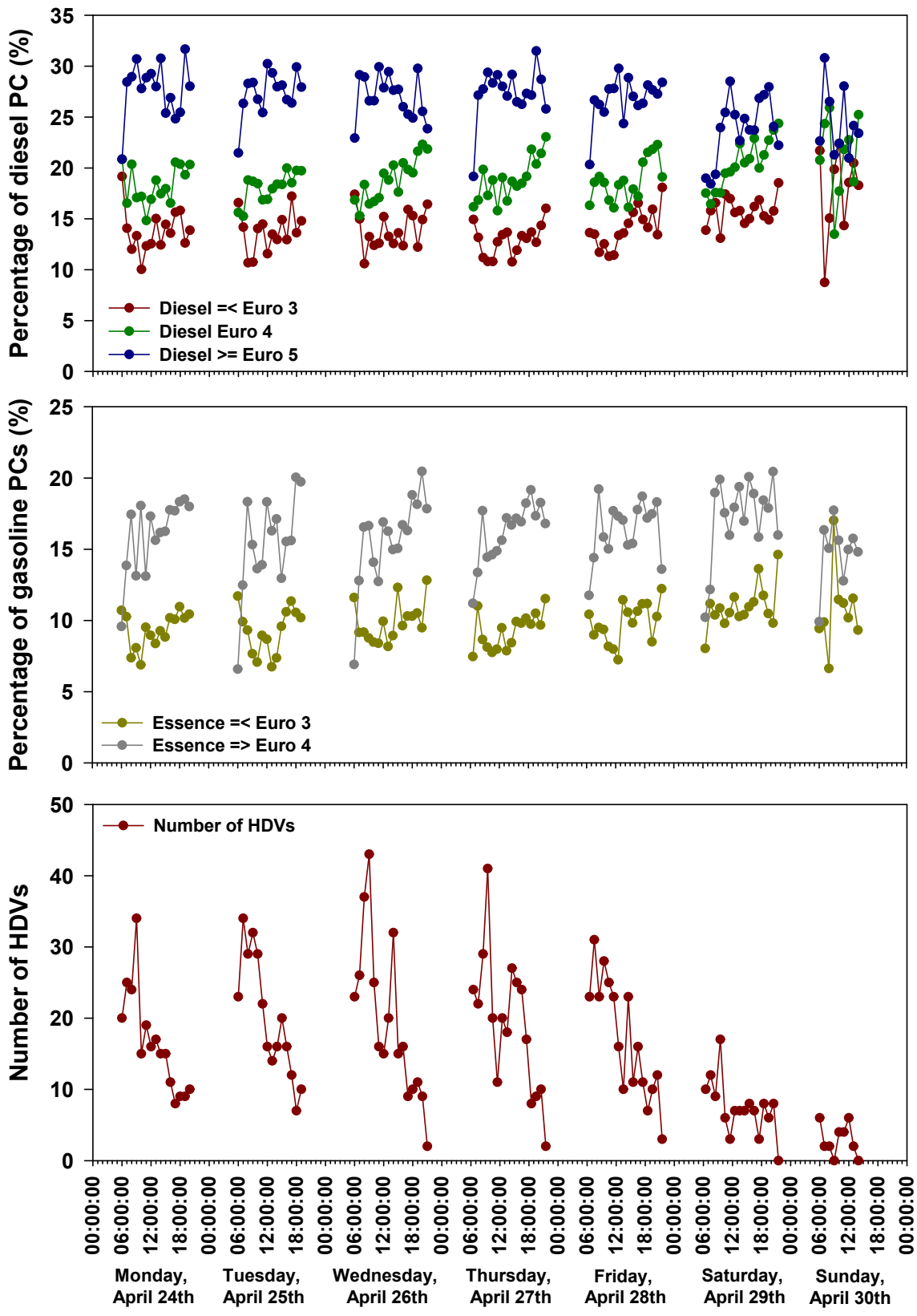
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512 **Fig. A.1.** Time profiles of PN, BC and NO_x concentrations on the traffic site and the background site From Wednesday to
513 Sunday.



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Fig. A.2. Time profiles of the percentages of the diesel PCs, the percentages of gasoline PCs and the numbers of HDVs on

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the measurement week.

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