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1 Diesel, petrol or electric vehicles: what choices to improve urban air quality in 2 the Ile-de-France region? A simulation platform and case study.

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9 Abstract

10 Air pollution from road traffic and its mitigation is a major concern in most cities. A platform for simulating
11 pollutant emissions and concentrations was developed and applied to the Île-de-France Region (Greater
12 Paris) of France, taking account of anthropogenic and natural sources and 'imported' pollution from
13 elsewhere in France and Europe. Four technological scenarios for 2025 were studied and compared to
14 the 2014 reference situation (1-REF). These scenarios included the current evolution of the park with
15 widespread adoption of diesel particulate filters (DPFs) (2-BAU), decline in the sale of diesel vehicles
16 and a corresponding increase in petrol vehicle sales (3-PET), promotion of electric vehicles in urban
17 areas (4-ELEC), and a combinaison with a decrease in traffic of about 15% in the densely populated
18 area inside the A86 outer ring road (5-AIR). The corresponding vehicle fleets were determined using a
19 fleet simulation model.

20 Traffic pollutant emissions were computed with the COPERT4 European methodology and hourly traffic
21 data over the Île-de-France road network. Particulate matter (PM₁₀, PM_{2.5} and PM_{1.0}), particles number
22 (PN), black carbon (BC), organic matter (OM), nitrogen oxides (NO_x) and nitrogen dioxide (NO₂), non-
23 methane volatile organic compounds (VOC), ammonia (NH₃), carbon monoxide (CO) and carbon dioxide
24 (CO₂) were considered. Emissions for other sectors were taken from a regional inventory. Emissions
25 outside the Île-de-France region (Europe and France) were derived from the European and French
26 emission inventories. Pollutant concentrations (PM_{2.5}, PM₁₀, organic and inorganic PM₁₀, PN, BC, NO₂
27 and O₃) were simulated over nested domains (Europe, France and Île-de-France) using the Polyphemus
28 platform for two scenarios (2-BAU and 3-PET). Methodological aspects and results for Île-de-France are
29 discussed here.

30 All scenarios led to a sharp decrease in traffic emissions in Île-de-France (-30% to -60%) by 2025. The
31 decline in diesel induced a stronger renewal of the fleet. PM and NO_x emissions were more strongly
32 reduced than VOC or NH₃. Traffic reduction reduced all emissions in the densely populated area within
33 the A86 outer ring road (-20% to -45% for exhaust particles and gaseous pollutants).

34 The 2-BAU and 3-PET scenarios lowered annual average concentrations, especially for NO₂ and BC,
35 and more strongly influenced daily-peak than daily-average concentrations. In Île-de-France, PM of
36 diameter <10 µm (PM₁₀), and NO₂ concentrations, decreased in the most densely populated areas. The
37 entire population would benefit from a PM₁₀ annual mean concentration decrease of ≥0.4 µg/m³, and the
38 annual mean NO₂ concentration would decrease by ≥10 µg/m³ for 40-50% of the population. For other

39 pollutants (PM_{2.5}, secondary pollutants, etc.), reductions were more limited, due to the other activity
40 sectors and atmospheric chemistry. Ozone concentrations might even increase in urban locations,
41 suggesting an increase in oxidants and thus an increase in secondary aerosol formation if precursors
42 were not reduced.

43 Differences between 2-BAU and 3-PET scenarios were slight. For PM and NO₂ concentrations, the petrol
44 scenario was slightly more favorable than the “business-as-usual” scenario with diesel vehicles and DPF;
45 differences were strong for primary particles and NO₂ and weak for secondary compounds. This slight
46 advantage was due to lower emissions and accelerated fleet renewal (higher proportion of Euro 5 & 6).

47 **Keywords**

48 Road traffic, pollutant emission, concentration, simulation, vehicle technology, vehicle fleet, scenario,
49 COPERT, Polyphemus

50 **1 Introduction**

51 Air pollution is a major concern in most European cities and road traffic is often considered as one of the
52 main causes even though other sources can contribute significantly. Development and promotion of
53 vehicle technologies and traffic restrictions (e.g., Low Emissions Zones) are levers frequently considered
54 for improving air quality, although their actual effectiveness is rarely established. Among the issues in
55 France, there are several questions regarding diesel cars, progress in design and the actual efficiency of
56 particulate filter and NO_x depolluting systems. Gradual replacement by petrol-driven cars, or even
57 prohibition in city centers, is sometimes envisaged, as is the promotion of electric or alternative-power
58 vehicles.

59 As part of a larger study on the health effects of ambient particulate matter, the ANSES (French Agency
60 for Food, Environmental and Occupational Health & Safety) was asked to investigate the progression in
61 air pollution on various scenarios of road traffic progression, and the impact of vehicle technologies. A
62 working group with several research laboratories and institutions undertook a large state-of-the-art study
63 of the emissions and atmospheric concentrations of pollutants in France, their past and projected
64 progression, the specific contributions of road traffic and other sources, and gaps in the knowledge
65 (André et al., 2019). In this framework, a simulation study over France and the Île-de-France (Greater
66 Paris) area was conducted to analyze the progression in emissions and concentrations under different
67 assumptions regarding vehicle technologies. Methodological aspects and results for the Île-de-France
68 region are discussed here.

69 **2 Case study**

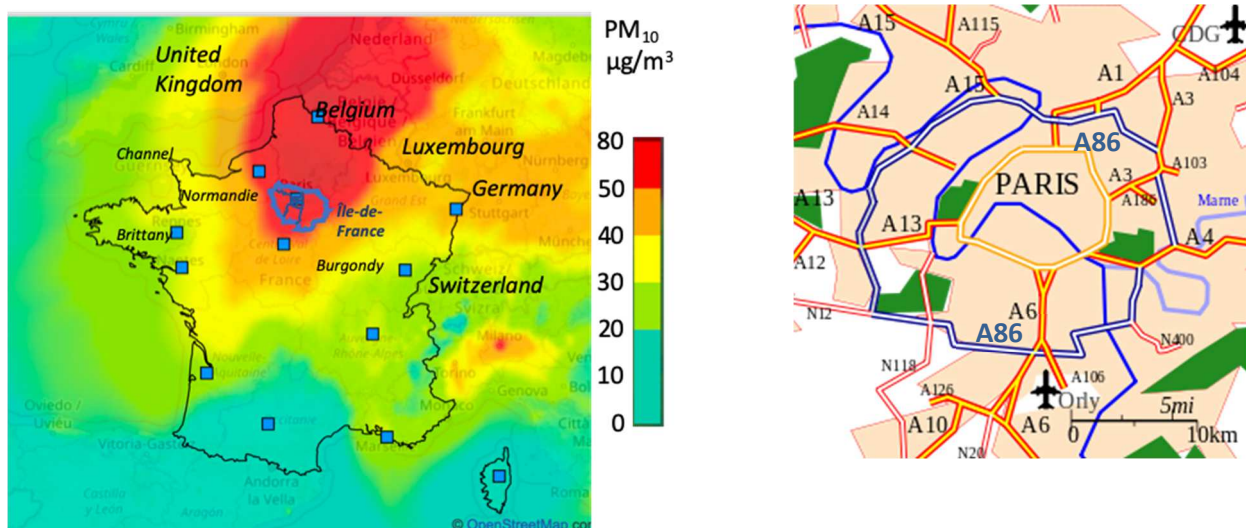
70 The Île-de-France region is the most populated region of France (12 million inhabitants in 2014, 19% of
71 the national population), with a density of 1,000/km². Paris covers a little less than 1% of the area of Île-
72 de-France but more than 20% of its population (2.3 million). The area within the A86 outer ring road (see
73 Figure 1) accounts for approximately 3% of the area (including Paris) and 41% of the Île-de-France
74 population. Thus, the A86 marks the outer boundary of a dense and highly populated urban area.

75 The main sources of anthropogenic pollutant emissions in Île-de-France are road traffic (56% of NO_x,
76 28% of PM₁₀), the residential sector (in particular its contribution to emissions from wood burning), the
77 tertiary or service sector (18% of NO_x, 26% of PM₁₀), and agriculture (91% of NH₃, 18% of PM₁₀). Due to
78 a slight decrease in road traffic in Île-de-France and to a strong reduction in exhaust emissions (around -
79 60% in PM₁₀ and -48% in NO_x over the period 2000-2012), pollutant concentrations have also
80 decreased, by about -25% for PM₁₀ and PM_{2,5} (annual mean concentrations), and by about -45% near
81 main roads. Despite these improvements, exceedances of European regulatory standards and
82 exceedances of air quality guidelines (PM₁₀, NO₂, O₃) remain, as well as peak pollution episodes.

83 The Île-de-France Region was used here as a case study for analyzing the progression in pollutant
84 emissions and atmospheric concentrations under different scenarios with various vehicle technologies.
85 One scenario also included a reduction in traffic volume.

86 3 Method, tools

87 The approach consisted in simulating pollutant emissions and atmospheric concentrations under different
88 scenarios with different compositions of the vehicle fleet. These scenarios corresponded to different
89 options (renewal of diesel vehicles, promotion of petrol or of electric vehicles, traffic reduction).

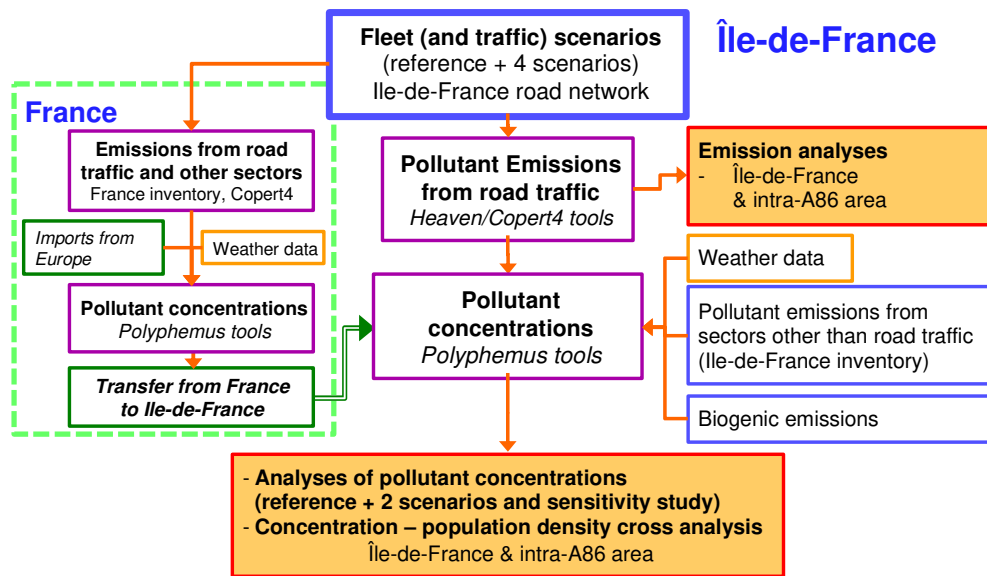


90 Figure 1: The Île-de-France Region during a PM₁₀ pollution episode in February 2018 (source: Prevoir
91 <http://www2.prevoir.org>, left); main roads and A86 motorway (in blue) delimiting the area within the A86
92 outer ring road (right)

93 The overall analysis of air quality required an estimation of the pollutant emissions from all activity
94 sectors, as well as natural emissions and imports of pollution from neighboring areas. It was also
95 necessary to model the transport and physico-chemical transformations of atmospheric pollutants, which
96 depends on contextual conditions such as the chemical regime of the atmosphere.

97 Three nested domains were considered for the simulation: Europe, metropolitan France, and the Île-de-
98 France region (for the outcome of the present case study) (Figure 2). Pollutant emissions from road
99 traffic were computed according to the scenarios for France and Île-de-France, while emissions from the
100 other sectors were derived from the national and regional inventories and were invariant. Weather
101 conditions were also kept constant. Concentrations were simulated successively over 3 nested domains

102 (Europe, France, and Île-de-France) to estimate the boundary conditions and transfers between the
 103 domains.



104
 105 Figure 2: Block diagram of the simulations of pollutant emissions and atmospheric concentrations.

106

107 Selection of the examined pollutants was based on their relevance to the particulate pollution (particulate
 108 fractions, precursor gases), to the traffic-related air pollution, and to air quality issues. The presence in
 109 ambient air of gaseous pollutants and particulate matter has harmful effects on human health and the
 110 environment (WHO Europe, 2013). The issues of particulate matter (PM) and nitrogen dioxide (NO₂) in
 111 ambient air are of particular concern in urban areas, such as the Île-de-France region, that have high
 112 levels of PM and NO₂ concentrations when compared to air quality standards and objectives designed to
 113 protect human health. The impact of exposure to ambient air PM_{2.5} due to human activity has been
 114 estimated at 48,000 premature deaths per year in France. This is exacerbated in urban areas with more
 115 than 100,000 inhabitants, where results show an average loss of 15 months of life expectancy at 30
 116 years of age due to this PM_{2.5} exposure (Pascal et al., 2016). Concentrations of particulate matter in
 117 ambient air have decreased over the years, but still exceed the annual air quality guidelines
 118 recommended by the World Health Organization for PM_{2.5} (WHO Europe, 2006). Among the particulate
 119 components, there is increasing evidence of adverse health effects from exposure to BC (and the
 120 pollutants adsorbed on the carbon core) which is largely emitted by road traffic in urban areas
 121 (Jacquemin et al., 2019). The PM ambient air concentration also comes from emitted gases, especially
 122 NO₂, NH₃, and v VOC, which condense and react to form secondary aerosols (Seigneur, 2019). Besides
 123 the pollutants related to air quality issues, road traffic is one of the main anthropogenic sources of CO₂
 124 (CITEPA, 2016a), a well-known and policy-relevant greenhouse gas. Therefore, the following pollutants
 125 were selected for simulating emissions: particulate matter (PM₁₀, PM_{2.5}, PM_{1.0}), particulate number (PN),
 126 black carbon (BC), organic matter (OM), nitrogen oxide (NO_x) and nitrogen dioxide (NO₂), volatile
 127 organic compounds (VOC), ammonia (NH₃) carbon monoxide (CO) and carbon dioxide (CO₂). For
 128 simulation of atmospheric pollutant concentrations, the following pollutants were specifically analyzed
 129 amongst the outputs of the air-quality model: PM_{2.5}, PM₁₀, organic and inorganic PM₁₀, PN, BC, NO₂ and
 130 O₃.

131 The following sections describe the scenarios and platform used for simulating pollutants emissions and
132 concentrations.

133 3.1 Fleet scenarios and data

134 Vehicle fleet composition scenarios were designed with two main objectives:

- 135 • To observe the evolution of road traffic emissions and the implications for pollutant
136 concentrations over a ten-year horizon,
- 137 • To consider different plausible technological options within this horizon, in relation to current
138 concerns (pollution from diesel engines) and the remediation measures envisaged.

139 The vehicle fleet evolution was estimated using a model which simulates a realistic fleet renewal
140 (introduction of new vehicles and withdrawal of old ones, André et al. 2016), under different assumptions
141 regarding technological choices. The reference fleet compositions (Île-de-France and France) were those
142 observed for the years 2013 to 2014. Scenarios and evolution of fleets were then considered for the
143 2025 horizon. The scenarios were designed as follows:

- 144 - 1-REF: the 2014 reference situation, with the actual vehicle fleet compositions in France (2013) and
145 Île-de-France (2014).
- 146 - 2-BAU: This scenario aimed to characterize the evolution of pollution between 2014 and 2025, in a
147 context of generalization of diesel particulate filters and renewal of the fleet with the evolution of
148 regulations (high share of vehicles complying with recent emission regulations Euro5 and 6). This
149 “business-as-usual” scenario corresponded to the expected evolution up to 2025. The balance
150 between the engine types (petrol, diesel, electric) and between the categories and sizes of vehicles
151 was unchanged.
- 152 - 3-PET: this scenario supposed a marked decline in diesel engines in favor of petrol for light vehicles
153 (to reach an inversion of the diesel/petrol share in the 2025 fleet), by a steady decline in sales of
154 diesel (from 60% to 5% in 2025), with the same regulatory evolution as for the 2-BAU scenario.
- 155 - 4-ELEC: this scenario supposed a marked promotion and increase in electric vehicles (EV) on the
156 urban road network, for all vehicle categories. EV sales reach 40% of passenger cars and 60% of
157 light commercial vehicles in 2025. All Euro 3 and earlier trucks and buses, and all motorized two-
158 wheelers under 250cc, were also replaced with EVs. However, the shift towards electric drives only
159 concerned the vehicle fleet in urban areas, while the vehicle fleet of the 2-BAU scenario was still
160 used in rural areas and on motorways. On a regional scale, the proportion of electric vehicles in
161 traffic reached 11% for light vehicles, 2% for trucks, 15% for buses and coaches and 42% for
162 motorized 2-wheelers.
- 163 - 5-AIR: this voluntary scenario explores the combination of technological change and traffic reduction
164 in dense urban areas to achieve air quality objectives. It combined the fleet composition of the 4-
165 ELEC scenario and an overall reduction in traffic in the densely populated area within the A86 outer
166 ring road by about 15%. The decrease in traffic mainly concerned private cars (-25%) compensated
167 by an increase in motorized two-wheelers (+50%) and urban buses (+75%). Light commercial vehicle

168 and truck traffic decreased by 20% (without compensation). The trend towards electric motorization
169 and traffic reduction applied only to this area. Outside that area, the traffic remained constant and the
170 vehicle fleet of the 2-BAU scenario was used. On the scale of the region, traffic decreased by 4%
171 and the proportion of electric vehicles was 4% for light vehicles, 1% for trucks, 6% for buses and
172 coaches and 18% for motorized two-wheelers.

173 The first three scenarios were simulated for pollutant emissions and concentrations over France and Île-
174 de-France. The last two were simulated only for emissions over Île-de-France.

175 3.2 Anthropogenic pollutant emissions

176 3.2.1 Île-de-France domain

177 For the Île-de-France region, road traffic emissions were computed using the Heaven Platform
178 (Thomassini et al. 2003), and by considering actual hourly traffic data (flow and speed) over the road
179 network (11,000 km of roads and 41,000 segments simulated). These traffic data were derived from real-
180 time observations for the year 2012.

181 The Heaven Platform computed the emissions according to the hourly traffic flows on each road link, the
182 number of vehicles per broad category and detailed technological class, their speed, proportion with cold
183 engine, and ambient temperature. The exhaust and non-exhaust (brake and tyre wear, road abrasion)
184 and evaporative emission factors and functions were those from the EMEP / EEA guidebook and
185 COPERT 4 v11.3 methodology. For the exhaust particulate numbers, emissions from HBEFA 3.2
186 (Handbook of Emission Factors) were used. For evaporative VOC emissions, running and hot-soak
187 losses were spatially distributed while diurnal losses (parked vehicles) were estimated on the regional
188 scale.

189 The malfunctioning of engines and emission control systems, or their modification or removal (particle
190 filters) are not explicitly considered here, as the emission models do not allow this. According to (T&E
191 2018) the removal of systems is on the increase in recent vehicles, but no real statistics are available (a
192 few thousand cases have been recorded). Moreover, it is likely that these practices will remain limited in
193 the future, in particular due to the restrictive evolution of regulations (periodic inspection of vehicles) and
194 technologies (OBD, on-board diagnostics). Their influence on scenarios is therefore likely to be limited.

195 A detailed vehicle fleet composition in terms of technologies, fuels and emissions standards, derived
196 from local surveys, was used for the reference situation (year 2014). This fleet composition was then
197 adjusted according to the scenario's assumptions. Traffic emissions were then estimated for all pollutants
198 and scenarios and aggregated on a 1x1 km² mesh. For the other sectors, pollutant emissions were
199 derived from the 2012 regional emission inventory (Airparif 2016) on a municipal scale, and spatialized
200 on the 1 km² grid.

201 3.2.2 France domain

202 For metropolitan France, emissions from all activity sectors for 2013 were derived from the 2016 French
203 inventory (CITEPA 2016a, CITEPA 2016b), mainly based on the EMEP/EEA Guidebook approach (EEA,
204 2013). Emissions were then spatially distributed using the 50 x 50 km² grid established for 2013.

205 The vehicle fleet scenarios applied in Île-de-France induced strong evolution of traffic emissions. It was
206 thus critical to consider also emittent evolution of the fleet composition for France, otherwise there would
207 have been important discrepancies in emissions between these two domains, and subsequent bias. The
208 actual French vehicle fleet composition (different from the Île-de-France fleet) was thus used for the
209 reference situation, and a similar process as that for Île-de-France was used for adjustuing it with the
210 scenario assumptions. Road traffic emissions for France were derived from the national inventory for the
211 reference situation, and adjusted for the scenarios by using the aggregated emission factors for the
212 different vehicle fleet compositions.

213 3.2.3 Europe domain

214 For Europe, anthropogenic emissions were computed using the EMEP inventory (50 x 50 km² horizontal
215 resolution, year 2014). Because of the large scale and thus low influence on the regional results, they
216 were kept invariant between scenarios.

217 3.3 Pollutant concentration simulation by the air quality model Polair3D/Polyphemus

218 Polyphemus is a platform for air quality and atmospheric transport simulation, from urban to continental
219 scale, including Gaussian and Eulerian models, data assimilation and inverse modeling tools (Mallet et
220 al. 2007). The Eulerian chemistry-transport model Polair3D provides hourly concentrations, on a discrete
221 meshed domain, of gaseous and particulate compounds, as well as the chemical composition of
222 particulate matter by fractional size. Five classes of size are considered here, from 0.01 to 10
223 micrometers.

224 The dispersion is computed according to wind fields and mixing caused by turbulence. The chemical
225 processes concern the different phases (gaseous, aqueous and particulate). The dynamic evolution of
226 the particle size distribution is simulated, as well as the interactions between the phases, such as the
227 heterogeneous reactions of certain gaseous compounds on the particle surface. Deposition processes
228 remove pollutants from the atmosphere and transfer them to other media.

229 Secondary pollutants such as (O₃ and some particulate precursors are formed in the gas phase by
230 reactions involving NO_x and VOCs, depending on their respective concentrations (chemical regime of
231 the atmosphere). Particulates consist of a complex mixture of dust, BC, inorganic components (sodium,
232 sulphate, ammonium, nitrate, chloride) and organic matter (OM). The inorganic and organic compounds
233 of particulates are largely secondary. OM precursors are volatile organic compounds of biogenic
234 (isoprene, monoterpenese, sesquiterpenes) or anthropogenic (aromatics, intermediate and semi-volatile
235 organic compounds) origin.

236

237 3.4 Set-up and model input data

238 Simulations were performed on three nested domains: Europe ([14.75°E, 34.75°E] x [35.25°N, 69.75°N]
239 with a resolution of 0.5° x 0.5°), France ([5°E, 10°E] x [41°N, 52°N] with a resolution of 0.1° x 0.1°) and
240 Greater Paris ([1.35°E, 3.55°E] x [48.00°N, 49.50°N] with a resolution of 0.02° x 0.02°).

241 Detailed set-up and model input data may be found in Sartelet et al. (2018) and André et al. (2019). An
242 evaluation of the modeled concentrations for 2014 by comparisons to measurements of O₃, NO₂, PM₁₀,
243 PM_{2.5}, BC and OM is presented in Sartelet et al. (2018) and André et al. (2019).

244 Land-use data were obtained from the "Global Land Cover" and Corine databases. Meteorological data
245 were derived from the ECMWF (European Center for Medium-Range Weather Forecasts) reanalyzes for
246 the simulations over Europe and France, and from the WRF (Weather Research and Forecasting) model
247 version 3.6 (Skamarock, 2008) for the simulations over Île-de-France (Kim et al., 2013). Marine salt
248 emissions relied on Jaeglé et al. (2011) parameterization, while biogenic emissions were estimated using
249 the Model of Emissions of Gases and Aerosols from Nature - MEGAN (Guenther et al., 2006).

250 The initial and boundary conditions of the Europe simulations were based on the global model MOZART-
251 4 and the meteorological fields of the NASA GMAO GEOS-5 model. The concentrations simulated for
252 Europe served as initial and limit conditions for the simulations over France, which themselves served as
253 initial and boundary conditions for Île-de-France. The air quality simulations were carried out with 14
254 vertical levels between the ground and 12 km ([0 - 30m], [30- 60m], [60 - 100m], [100 - 150m], [150-
255 200m], [200 - 300m], [300 - 500m], [500 - 750m] [750m - 1km], [1 - 1.5km], [1.5 - 2.4km], [2.4 - 3.5km],
256 [3.5 - 6km], [6 - 12km]).

257 A detailed speciation of pollutant emissions (e.g. NO_x into NO, NO₂ and HONO, VOCs, particulate mass
258 (PM) into elemental carbon (EC), OM and dust) was needed for the simulations. The NO_x, VOCs and
259 particulate speciations were modified for each of the scenarios, in order to take into account the
260 specificities of the vehicle fleet, as these speciations depend on engine type (for example, petrol vehicles
261 tend to emit more aromatic compounds than diesel, while diesel vehicles tend to emit more NO₂). VOC
262 speciations were derived from (Theloke and Friedrich, 2007), NO_x and particulate speciations from
263 EMEP guidelines (Ntziachristos et al., 2013).

264 Secondary organic aerosols (SOA) depend particularly on VOCs and ISVOCs (intermediate and semi-
265 volatile organic compounds), the composition of which varies with the engine (diesel, petrol) and the
266 emission control systems (DPF). ISVOCs are poorly known although they contribute significantly to the
267 formation of organic particles. Gas-phase ISVOCs were estimated by multiplying by 1.5 the emissions of
268 the primary organic compounds (Kim et al., 2016). An alternative approach using a SVOC / NMHC ratio
269 was also tested in a sensitivity study (Sartelet et al., 2018).

270 3.5 Scenario assumptions and simulation conditions

271 The year 2014 was chosen as a reference base, while future scenarios were constructed for 2025.

272 In order to study the impact of technological options, road traffic emissions for France and Île-de-France
273 were changed according to vehicle fleet scenarios, while most assumptions and input data were kept
274 invariant. Notable invariants were weather conditions (2014), land cover, biogenic emissions and
275 emissions from sectors other than traffic, populations and their geographic distribution, total traffic
276 volume (except for one scenario with a traffic reduction) and its spatial and temporal distribution, the
277 traffic shares of different vehicle categories, traffic conditions, and, more generally, mobility behavior and
278 socio-economic context.

279 The geographic distribution of the simulated pollution was also cross-referenced with the spatial
280 distribution of the populations approximated by their place of residence, in order to assess the impact of
281 the scenarios on population exposure.

282

283 **4 Results**

284 *4.1 Fleet compositions*

285 The average fleet composition of Île-de-France for the different scenarios is described in Table 1. It was
286 estimated by weighting the fleets typical of urban and rural areas, the Boulevard Périphérique (the Paris
287 inner ring road), and highways. Light vehicles (passenger cars and light commercial vehicles) accounted
288 for a very high proportion of traffic (86%), followed by motorized two-wheelers (8%). Trucks accounted
289 for only 5% and buses / coaches less than 1%. The 2-BAU scenario doubled the equipment of light
290 diesel vehicles with particulate filters and renewed almost the entire fleet to meet the Euro 5 and 6
291 regulations (from 40% to 80%). The 3-PET scenario reversed the diesel/petrol ratio from 73%-27% to
292 43%-56% (light vehicles). This important change required a greater renewal of the fleet, which broadly
293 amplified the evolution towards Euro 5 and 6 regulations (from 39% to 91%). On the other hand, the fleet
294 of light diesel vehicles was renewed less and hence aged more.

295 The increased EV scenario (4-ELEC) led to a lower renewal of conventional vehicles (diesel and
296 gasoline) and thus to lower rates of vehicles complying with the most recent regulations and of diesel
297 vehicles equipped with DPF. The 5-AIR scenario applied only within the A86 outer ring road and resulted
298 in a lower number of electric vehicles in Île-de-France, but with a higher proportion inside the A86 ring-
299 road, which, combined with an overall reduction in traffic in the city center, makes it "locally" effective.

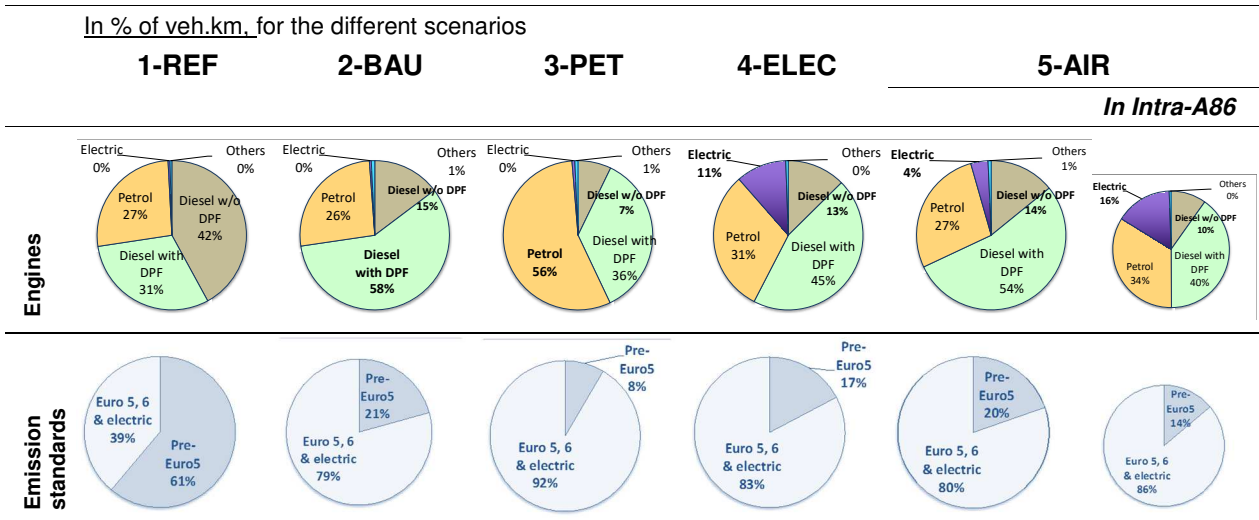
300 Figure 3 gives the average light-vehicle composition for Ile-de-France. The share of Euro 5 and 6
301 regulations (including EVs) increased from 39% in the reference scenario to 80%-90% in the projected
302 scenarios. Light diesel vehicles decreased from 73% to 43% in the petrol scenario (3-PET), 58% in the 4-
303 ELEC, 68% in the 5-AIR scenario (50% within the A86 outer ring road). About 80% of light diesel
304 vehicles were equipped with DPF in the different projected scenarios, against 42% in the reference.
305 Electric vehicles represented 11% in the 4-Elec scenario in Île-de-France, and reached 16% within the
306 area bounded by the A86 in the 5-AIR scenario.

307

308 Table 1: Average fleet composition for the scenarios in Île-de-France (main evolution in **bold**)

In % of veh.km, for the different scenarios		1-REF	2-BAU	3-PET	4-ELEC	5-AIR (with traffic reduction)
Vehicles	Categories					
Light duty vehicles (passenger cars and vans)	Diesel (<i>incl. hybrids</i>)	73	73	43	58	68
	<i>% with DPF</i>	42	80	83	78	79
	Petrol (<i>incl. hybrids</i>)	27	26	56	31	28
	Electric	0.4	0.4	0.6	10.9	3.7
	<i>% Euro 5 and 6</i>	39	79	91	81	80
	<i>% of total traffic of which Pass. Cars</i>	86	86	86	86	84
		71	71	71	71	69
Trucks	Diesel	99	99	99	97	98
	Electric	0.1	0.1	0.1	2.3	0.9
	<i>% Euro 5 and 6</i>	43	83	83	85	84
	<i>% of total traffic</i>	5.3	5.3	5.3	5.3	5.3
Urban buses and coaches	Diesel	99	99	99	99	99
	Electric	-	-	-	15	6
	<i>% Euro 5 and 6</i>	49	90	90	97	92
	<i>% of total traffic</i>	0.7	0.7	0.7	0.7	0.8
Motorized two-wheelers	Petrol	100	100	100	59	80
	Electric	0.0	0.0	0.0	42	18
	<i>% Euro 5 and 6</i>	0.0	54	54	54	54
	<i>% of total traffic</i>	7.8	7.8	7.8	7.8	9.4

309
310



311 Figure 3: Light vehicle fleet composition in the Île-de-France region and within the A86 outer ring road
312 of Paris, in terms of engine and emission standards

313 4.2 Pollutant emissions

314 Pollutant emissions in Île-de-France and road traffic contribution are given in Table 2 for the reference
315 situation (1-REF). Their distribution according to vehicle categories is provided in Table 3. Overall, road
316 traffic contributed significantly to emissions of nitrogen oxide (58% and 78% of total NO_x and NO₂ in Île-
317 de-France), BC (54%), and intermediate and semi-volatile compounds (ISVOC) (37%), but less to PM₁₀
318 and PM_{2.5} (20%-25%), and VOCs (11%).

319 Passenger cars represented 71% of the traffic and accounted for 58% of CO₂ emissions, 44% of VOCs,
 320 46% of NO_x, and 42% to 46% of particulates. Light commercial vehicles (vans less than 3.5 tons)
 321 accounted for 16% of traffic and emitted 19% of CO₂, 17% of NO_x. They contributed more strongly to
 322 particulate emissions (36%-40%). Motorized two-wheelers accounted for only around 8% of traffic, but
 323 contributed very significantly to VOC (45% of the total). Their contribution to other pollutants was rather
 324 limited. Heavy vehicles (trucks, buses and coaches) accounted for only 6% of traffic, but contributed
 325 significantly to emissions of CO₂ (20%), NO_x (36%), NO₂ (18%) and particulates (12%-16%).

326 Table 2: Pollutant emissions from all sectors and from road traffic (in tons per year) in Île-de-France for
 327 the reference situation (scenario 1-REF)

Total emissions (in t.yr ⁻¹)	NO _x	NO ₂	NH ₃	VOC	PM ₁₀	PM _{2.5}	BC
All sectors	78,490	13,682	5,713	82,253	19,038	12,200	2,037
Road traffic	45,216	10,622	508	8,631	3,769	2,993	1,096
<i>Road traffic (in % of total emissions)</i>	<i>57.6</i>	<i>77.6</i>	<i>8.9</i>	<i>10.5</i>	<i>19.8</i>	<i>24.5</i>	<i>53.8</i>

328

329 Table 3: Distribution of road traffic (in % of veh.km) and pollutant emissions (in % of t.yr⁻¹) in terms of
 330 vehicles categories in Île-de-France for the reference situation (scenario 1-REF)

Vehicles	Traffic	Exhaust & evaporation (VOC) emission			Exhaust and non-exhaust emission		
		CO ₂	VOC	NO _x	PM ₁₀	PM _{2.5}	BC
Passenger cars	70.8 %	57.6 %	43.8 %	45.9 %	42.8 %	45.3 %	46.3 %
Light duty vehicles	15.5 %	18.6 %	5.5 %	17.1 %	40.0 %	35.9 %	35.7 %
Two-wheelers	7.8 %	3.6 %	45.2 %	1.3 %	3.3 %	3.3 %	1.5 %
Trucks	5.3 %	15.0 %	3.5 %	24.2 %	10.7 %	12.3 %	11.7 %
Buses / coaches	0.7 %	5.2 %	1.9 %	11.6 %	3.2 %	3.1 %	4.7 %
Total	5.46 x 10 ⁴ veh.km	1.13 x 10 ⁷ tons	8.64 x 10 ³	4.39 x 10 ⁴	2.93 x 10 ³	3.62 x 10 ³	1.09 x 10 ³

331 In the reference, 69% of traffic was diesel vehicles (light and heavy), which emitted 75% of CO₂, 92% of
 332 NO_x, and 96% to 98% of particulates. Gasoline traffic (25% of CO₂) emitted mainly VOCs and NH₃ (86%
 333 and 87%) and contributed marginally to particulates (2% to 4%) and NO_x (8%).

334 With regard to emission regulations, 68% of the reference traffic was carried by vehicles complying with
 335 Euro 4 (Euro IV) or earlier regulations, which produced 69% to 96% of emissions of the different
 336 pollutants. Euro 5 and 6 technologies (V and VI for heavy vehicles) represented 31% of total traffic and
 337 contributed much less to emissions (8% of VOCs, 16% of NH₃ and 4% to 6% of particulate pollutants),
 338 except for NO_x (29%).

339 Among diesel passenger cars and light commercial vehicles, those equipped with particulate filters
 340 accounted for 28% of the distances traveled, but only contributed 1% to 2% of particulate emissions and
 341 5% of NH₃ emissions. However, they were responsible for 30% of NO_x emissions.

342 4.3 *Evolution of the traffic emissions with the technology scenarios*

343 Pollutant emissions and traffic in the 2025 scenarios are compared to the 2014 reference situation in
344 Table 4. The 2-BAU scenario, which was almost a business-as-usual progression from diesel with
345 particulate filters, resulted in very sharp reductions in exhaust particulate emissions (-60% to -70% for
346 BC, a compound of fine particles), while reductions were less significant for coarse particles (-30 to -40%
347 for PM₁₀) due to the wear and abrasion contribution. With the regulatory evolution and renewal of
348 vehicles, the emissions of gaseous pollutants also decreased: by 10% for CO₂, 30% for VOCs, 50% for
349 nitrogen oxides, and 36% for NH₃.

350 The petrol scenario (3-PET) accentuated reductions in NO_x (-60%) and exhaust particulate emissions (-
351 74%), but led to a lower reduction in VOCs (-12%) and NH₃ (17%). The 4-ELEC scenario (promotion and
352 increase in electric vehicles in urban areas) had a clear CO₂ advantage (-19% vs -10%). NO_x and NH₃
353 reductions were also very high (-60% and -37%). Particulate emission reductions were slightly higher
354 than those of the 2-BAU scenario, but lower than those of the petrol scenario.

355 At the Île-de-France scale, the 5-AIR scenario (combining promotion and increase in electric vehicles
356 and reduction in traffic inside the A86) did not offer a significant advantage over the scenarios favouring
357 petrol or electric vehicles. However, emission reductions were markedly increased within the A86 outer
358 ring road of Paris (-71% for NO_x instead of -58% in Île-de-France, -75% for BC, -57% for PM_{2.5}). This
359 scenario, which included restrictions within a given perimeter, therefore had a definite advantage for the
360 atmosphere over the heavily urbanized and densely populated area inside the A86.

361 Technological scenarios are compared in Table 5. The petrol scenario led to an increase of 15% in VOC
362 emissions and 30% in NH₃, while it brought further reduction of PM from -10% to -30%. These
363 differences were quite similar inside the A86 and throughout the Île-de-France. The reduction in
364 particulate emissions was more limited with the 4-ELEC scenario (but more marked within the A86). This
365 scenario led to a net reduction in VOC (-25%) and CO₂. Finally, the 5-AIR scenario yielded the strongest
366 benefits to the areas inside the A86: -34% of BC, -38% of nitrogen oxide and about -20% of VOCs,
367 highlighting the benefit of reduced traffic in densely populated areas.

368 Table 4: Road traffic volume and pollutant emissions in Île-de-France with the 2025 scenarios,
 369 compared to the 2014 reference situation

Variations in % relative to the scenario 1-REF (year 2014)	Traffic	Exhaust & evaporation (VOC) emission			Exhaust and non-exhaust emission		
		CO ₂	VOC	NO _x	PM ₁₀	PM _{2.5}	BC
Entire Île-de-France region (year 2025)							
2-BAU, diesel, high share of DPF	0.0	-10	-30	-53	-33	-43	-62
3-PET, decline of diesel for petrol	0.0	-9	-12	-62	-40	-52	-74
4-ELEC, increase in EVs	0.0	-19	-42	-62	-36	-47	-66
5- AIR, increase in EVs and traffic reduction	-3.9	-17	-39	-58	-37	-47	-65
Highly populated intra-A86 area (year 2025)							
5- Air, increase in EVs and traffic reduction	-14.5	-34	-47	-71	-47	-57	-75

370

371 Table 5: Road traffic volume and pollutant emissions in Île-de-France with the 2025 scenarios,
 372 compared to the “business-as-usual” scenario inducing a generalization of diesel particulate filters (2-
 373 BAU)

Variations in % relative to the scenario 2-BAU (year 2025)	Traffic	Exhaust & evaporation (VOC) emission			Exhaust and non-exhaust emission		
		CO ₂	VOC	NO _x	PM ₁₀	PM _{2.5}	BC
Entire Île-de-France Region (year 2025)							
3-PET, decline of diesel for petrol	0.0	1	15	-19	-11	-16	-31
4-ELEC, increase in EVs	0.0	-10	-25	-18	-5	-7	-11
5- AIR, increase in EVs and traffic reduction	-3.9	-7	-6	-10	-6	-7	-8
Highly populated intra-A86 area (year 2025)							
5- AIR, increase in EVs and traffic reduction	-14.5	-26	-19	-38	-24	-27	-34

374 *4.4 Vehicle fleet renewal effect*

375 From the reference to 2025 scenarios, fleet compositions differed not only in terms of technologies
 376 (diesel, petrol, etc.) and their traffic proportions, but also in renewal induced by evolution. So, the 3-PET
 377 scenario led to a higher fleet turnover and a higher proportion of Euro 5 and Euro 6 vehicles. The
 378 differences in emissions thus included a renewal effect, which can be separated from the technology
 379 effect by adjusting the emissions estimation according to similar Euro distributions (Table 6).

380 For NO_x, the benefit was mainly due to the change from diesel to petrol engines, while the renewal effect
 381 was opposite between diesel (NO_x increase) and petrol (NO_x decrease) vehicles. The reduction in
 382 exhaust VOCs between 2-BAU and 3-PET scenarios was driven by accelerated renewal of the petrol
 383 vehicles, which induced, on the other hand, an increase in evaporative (and total) VOC emissions. For
 384 particulates, the benefit of petrol engines was around 55% and 70% of the total effect, the remaining
 385 benefit being due to the accelerated renewal.

386 Table 6: Pollutant emission variations between the 2-BAU and 3-PET scenarios: respective
 387 contributions due to diesel to petrol change and to accelerated fleet renewal

Difference (%) in emission (exhaust or total) between scenarios 3-PET (decline of diesel for petrol) and 2-BAU (diesel, high share of DPF)							
(All vehicles - Île-de-France)	NOx	VOCs Exhaust	VOCs Total	PM _{2.5} Exhaust	PM _{2.5} Total	BC Exhaust	BC Total
Total difference	-19.8	-12.4	+15.2	-32.7	-15.8	-40.4	-31.3
Contribution from Euro regulatory change and vehicle renewal							
- Light vehicles - diesel	+11.4	-0.9	-0.7	-9.1	-3.1	-18.2	-13.3
- Light vehicles - petrol	-4.5	-17.2	-10.1	-0.1	+0.1	-0.1	-0.0
Vehicle renewal total effect	+6.9	-18.1	-10.8	-9.1	-3.0	-18.3	-13.3
Net effect due to the diesel-petrol change	-25.7	+5.8	+26.0	-23.5	-12.8	-22.1	-18.0

388 4.5 Evolution of the total emissions with the technology scenarios

389 The reductions in total emissions (all sectors) through the scenarios were more limited than the reduction
 390 in road traffic emissions. The most significant reductions concerned NOx (-35% to -40%) and NO₂ (-47%
 391 to -54%), and BC (-36% to -42%) compared to the reference situation. Reductions in particulate
 392 emissions were lower (-15 % for PM_{2.5}, -20% to -23% for OM, and less than 5% for PM₁₀).

393 4.6 Evolution of pollutant concentrations

394 4.6.1 Spatial distribution and evolution of concentrations

395 Figure 5 shows the annual average concentrations of ozone, PM_{2.5}, BC, and of secondary inorganic and
 396 organic aerosols over Île-de-France in the reference simulation, as well as the relative differences
 397 between the 2-BAU scenario and the reference.

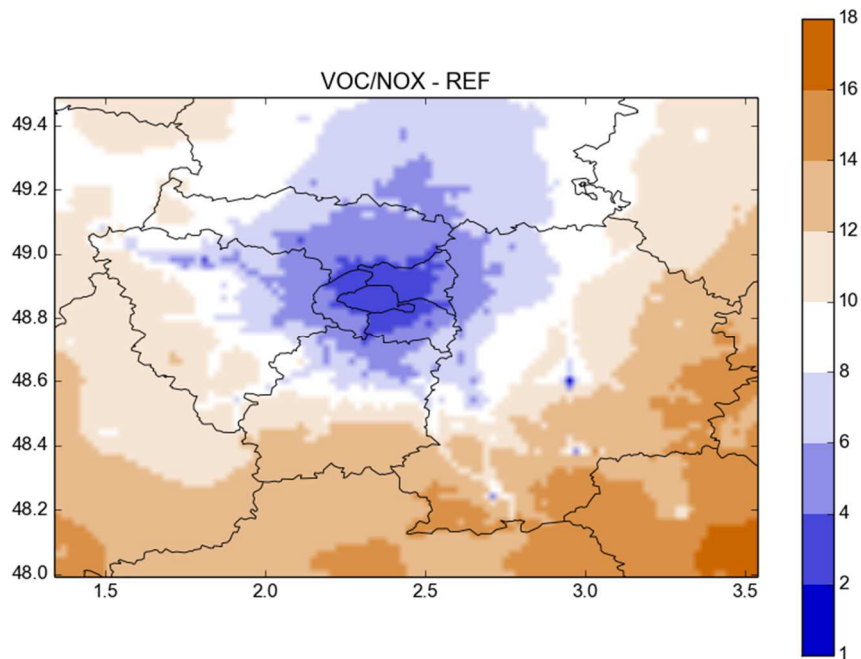
398 In the reference, O₃ concentrations were lower in Paris and along main roads than over the rest of the
 399 Île-de-France. Indeed, O₃ was titrated by the high concentrations of NO in Paris and along the main
 400 roads. On the other hand, the average PM_{2.5} concentrations (and other primary particulate compounds)
 401 were higher in Paris than in the rest of Île-de-France. BC is an inert compound and emitted mainly by
 402 road traffic. The highest BC concentrations were therefore observed in Paris and along the main roads,
 403 with concentrations between 0 and 2 µg.m⁻³, while concentrations were less than 0.4 µg.m⁻³ over most of
 404 Île-de-France. However, these were concentrations averaged annually and on grid cells, and thus much
 405 lower than those measured at roadside. Average concentrations of primary pollutants, such as BC and
 406 secondary pollutants such as O₃ and PM_{2.5}, were higher in the northern part of the domain, because of
 407 the prevailing meteorology.

408 Inorganic aerosols are secondary pollutants formed mainly by condensation of nitric acid and ammonia
 409 (NH₃) in Île-de-France (in other regions, sulfates may be predominant). Their concentration was relatively
 410 uniform over Île-de-France, with concentrations higher than 6 µg.m⁻³. Organic aerosols are also largely
 411 secondary pollutants. Their concentrations were higher than 2 µg.m⁻³ throughout Île-de-France. Higher
 412 concentrations were observed in Paris due to anthropogenic emissions of VOCs and ISVOC, as well as
 413 near the Fontainebleau Forest (South-West), the Chevreuse High Valley Nature Park (South-East) and
 414 the Regional Park of Oise (North of Île-de-France). In the vicinity of these forests, organic matter is

415 formed by oxidation of biogenic VOCs emitted by forests. Oxidized compounds partition on the particles
416 and are therefore partly in gaseous and partly in particulate phase.

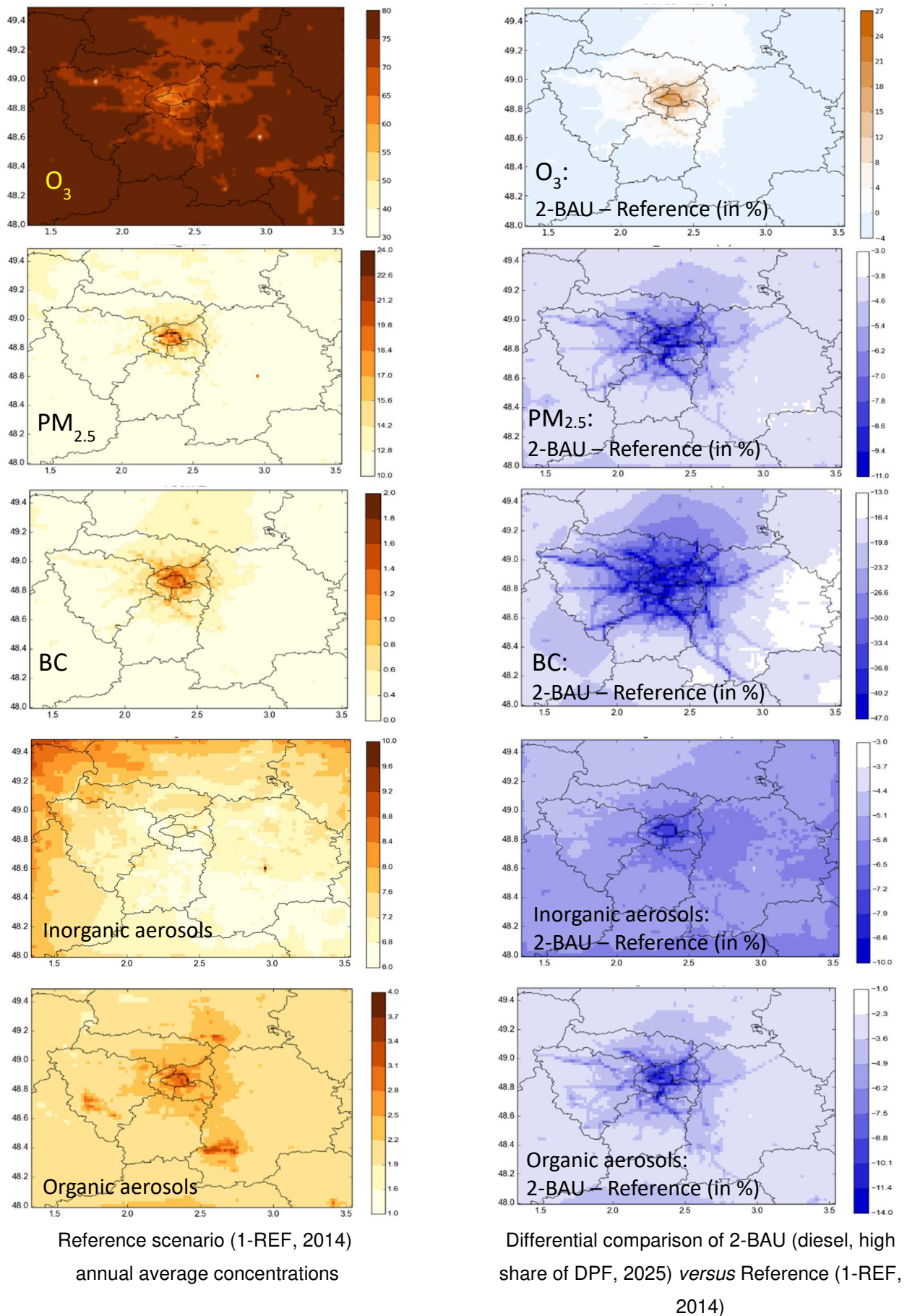
417 Compared to the reference year 2014, all scenarios for 2025 led to quite similar evolution due to the
418 large reduction in emissions. We therefore discuss here only the difference between the 2-BAU scenario
419 and the 1-REF. We will compare 2-BAU and 3-PET later.

420 The 2-BAU scenario mainly induced a decrease in NO_x emissions. The impact on O₃ concentration
421 depends on the chemical regime, which can be inferred from Figure 4. The regime is limited in NO_x (low
422 NO_x) where the VOC/NO_x ratio is higher by a factor of about 8, and the regime is limited in VOC (high
423 NO_x), where the VOC/NO_x ratio is lower than 8 (Seinfeld and Pandis, 1998). The decrease in NO_x
424 emissions by this 2025 scenario led to a slight decrease in O₃ over part of Île-de-France, where the
425 chemical regime was limited in NO_x (low NO_x). However, where the regime was limited in VOC (high
426 NO_x), the NO_x reduction induced by the scenario reduced the O₃ titration with NO, leading to an
427 increase of O₃. O₃ increased significantly (up to 27% of annual average) in Paris and along main roads.
428 This increase in O₃ was not a real problem because it occurred in areas of low average concentrations.
429 Nevertheless, it indicates that the 2-BAU scenario (which maintains a high proportion of diesel vehicles)
430 also leads to an increase in oxidants in Paris and along roads, which would lead to increased production
431 of secondary aerosols if precursors (NO₂ and VOC that form SOA) are not reduced.



432
433 Figure 4 : Determination of chemical regime: VOC/NO_x ratio for the reference simulation (1-REF).

434



435 Figure 5: Annual average concentrations of pollutants for the 2014 reference situation (left) and
 436 impact of the 2-BAU (diesel, with a high share of DPF) scenario in 2025 (right)

437 For PM_{2.5}, the highest differences between the 2-BAU scenario and the baseline simulation were
438 observed along major highways as well as in Paris. Across the Île-de-France, PM_{2.5} concentrations
439 decreased from 3% to 12%. A strong reduction in BC concentrations (up to -47%) was also observed.

440 The 2-BAU diesel scenario induced a reduction in inorganic aerosol concentrations of between 3% and
441 10%. This was due to the decrease in NO_x emissions, and thus in concentrations of nitric acid, which is
442 the limiting factor for the formation of ammonium nitrate in Île-de-France. The sharpest decline was in
443 Paris. However, the reduction in inorganic aerosol concentrations was limited (at most 7% on average in
444 Paris), because the increase in oxidants counterbalanced the decrease in NO₂, limiting the decrease in
445 nitric acid induced by the NO_x reduction. The reduction in Paris and along main roads was less visible
446 than for PM_{2.5}, because PM_{2.5} consists of both secondary compounds, such as ammonium nitrate, and
447 primary compounds, such as BC, which were strongly reduced.

448 The 2-BAU scenario also led to a reduction in organic aerosol concentrations in Paris along main roads,
449 and near forests and nature parks. The decrease was due to the diminution in ISVOC emissions along
450 main roads, and to the decrease in oxidants (due to reduced NO_x emissions) in the vicinity of the forests.

451 Compared to the 2-BAU scenario (see Figure 6), the 3-PET scenario, with a decline of diesel for petrol
452 engines, induced a slightly larger increase in annual mean O₃ concentrations in Paris (+ 3%) due to a
453 further reduction in NO_x emission, whilst VOC concentrations were limited. On the other hand, the 3-PET
454 scenario led to greater reduction in particulate compounds than the 2-BAU scenario.

455 Thus, the petrol scenario led to a further reduction in PM_{2.5} concentrations, by -1% to -2% in Île-de-
456 France, and a more marked decrease along the main roads around Paris. Additional reductions in BC
457 concentrations were also observed, reaching as much as -17% along main roads.

458

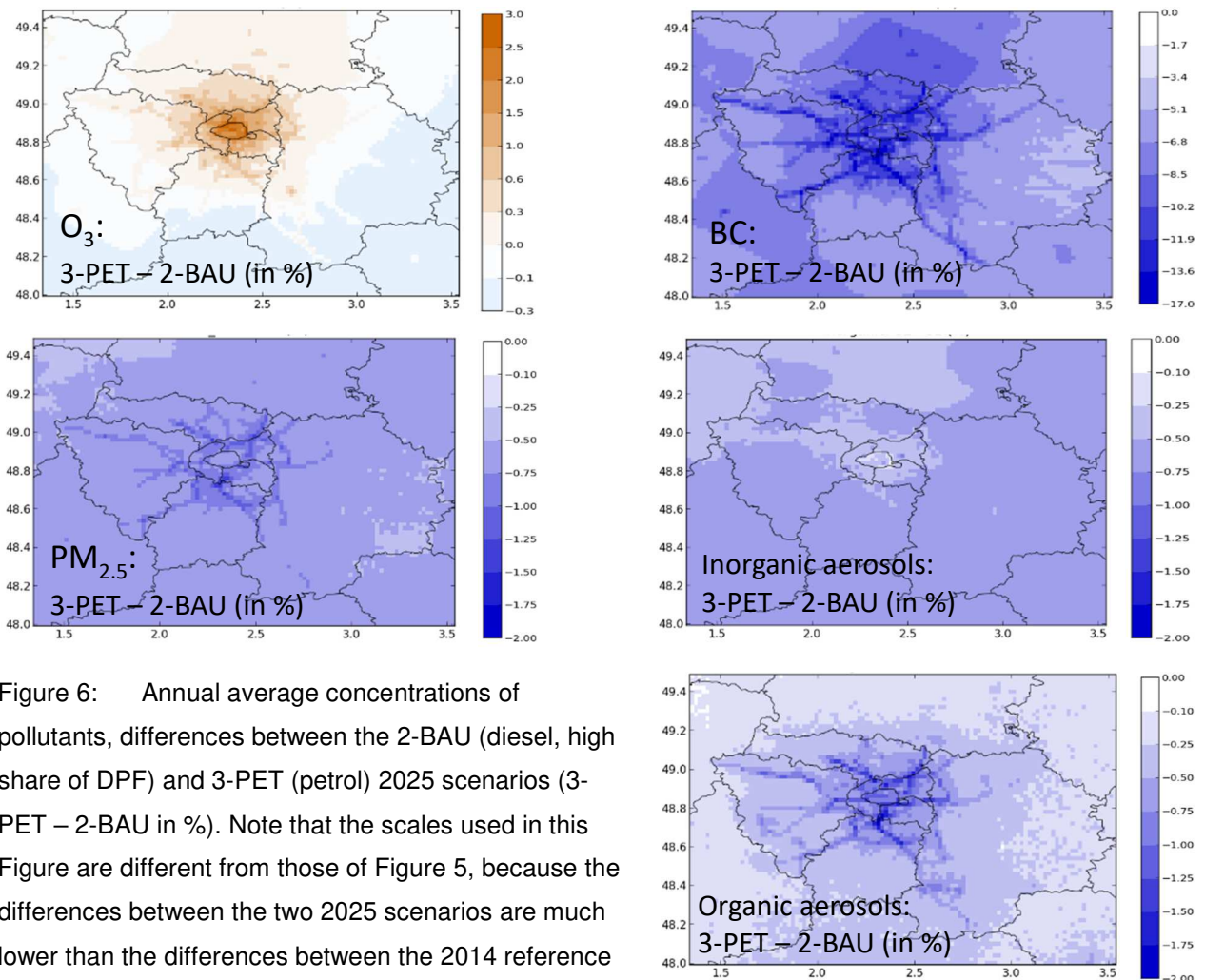


Figure 6: Annual average concentrations of pollutants, differences between the 2-BAU (diesel, high share of DPF) and 3-PET (petrol) 2025 scenarios (3-PET – 2-BAU in %). Note that the scales used in this Figure are different from those of Figure 5, because the differences between the two 2025 scenarios are much lower than the differences between the 2014 reference simulation and each of the 2025 scenarios.

459 A drop of a few percentage points more for inorganic concentrations was due to the greater decrease in
 460 NO₂ emissions in this petrol scenario (3-PET), compared to the 2-BAU scenario. This decrease was
 461 slightly lower in Paris and along the Boulevard Périphérique (inner ring road), because oxidant levels
 462 were higher in the petrol scenario.

463 The petrol scenario caused a further decrease in organic concentrations (up to -1.5%, especially along to
 464 main roads), due to a larger decline in emissions from ISVOC organic aerosol precursors. However, this
 465 decline was more limited in Paris where the scenario induced an increase in oxidant levels.

466 4.6.2 Concentration statistics

467 For the reference simulation over Île-de-France, Table 7 shows the average annual concentrations (in
 468 µg.m⁻³) for each pollutant as well as their standard deviation (spatial variation of the annual
 469 concentrations). The standard deviation is large for NO₂ and BC because they are local pollutants mainly
 470 emitted by traffic. It is smaller for O₃ and inorganic particles because they are secondary pollutants
 471 formed by the interactions of pollutants from different emission sources.

472 We also defined a threshold or limit (P98, i.e., the 98th percentile of the time series of daily
 473 concentrations in each grid cell) to count the number of temporal events for which daily concentration
 474 values are higher than this limit, and to assess the evolution of this number of exceedances through the

475 scenarios. This P98 threshold is thus a theoretical short-term concentration limit. It does not correspond
 476 to the recommended or authorized limits for health, but enables assessment of events corresponding to
 477 high pollution levels, for each pollutant.

478 Table 7: Statistics of the pollutant concentrations (average concentrations and number of values
 479 exceeding the P98 threshold) for the different scenarios compared to the reference

	PM _{2.5}	PM ₁₀	PM ₁₀ inorganic	PM ₁₀ organic	BC	NO ₂	O ₃
1-REF, reference (year 2014)							
Average concentration (µg.m ⁻³)	12.3	13.1	7.0	2.2	0.4	6.7	75.5
Standard deviation (spatial variations)	1.1	1.4	0.3	0.2	0.2	5.3	2.9
P98 threshold in µg.m ⁻³ (i.e. 2% of values exceeding)	27.9	29.9	16.5	6.0	1.3	35.5	126.3
2-BAU scenario (generalization of diesel DPF, year 2025) – compared to 1-REF (year 2014)							
Variation in average concentration (%)	-5.0	-4.8	-5.7	-4.1	-26.8	-40.5	0.6
Variation in the number of values exceeding the P98 threshold (%)	-10.5	-11.2	-16.9	-12.2	-73.0	-84.6	-7.4
3-PET scenario (strong decline in diesel for light vehicles, year 2025) – compared to 1-REF (year 2014)							
Variation in average concentration (%)	-5.6	-5.3	-6.2	-4.5	-32.6	-40.8	0.6
Variation in the number of values exceeding the P98 threshold (%)	-11.8	-11.6	-21.2	-14.2	-77.9	-85.0	-12.4

480
 481 Except for O₃ (for which an increase of 0.6% was recorded), the average concentrations decreased for
 482 each of the scenarios compared to the reference situation. The greatest differences were observed for
 483 NO₂ (-41%), BC (-27% for 2-BAU, -33% for 3-PET). For particulate matter (PM_{2.5}, PM₁₀) and secondary
 484 particulate matter (inorganic, organic), the decrease in mean annual concentrations was lower (between
 485 -4% and -6% in the 2-BAU scenario; -4.5% to -6.2% in the 3-PET scenario).

486 Although the average concentration in O₃ increased, high concentrations - i.e., occurrences exceeding
 487 the P98 threshold - decreased by 7% for the 2-BAU, and 12% in the 3-PET scenario.

488 For NO₂ and BC, the decrease in occurrence of high concentrations was much stronger. It reached -85%
 489 for NO₂ and -73% for BC in the 2-BAU scenario. The reduction was slightly higher in the 3-PET scenario
 490 (-95% for NO₂ and 78% for BC). Finally, for particulate matter, the reduction in exceedance events was
 491 more limited. This was similar to what was observed for the average value. Still, the reduction was
 492 significant: from -11% to -17% in the 2-BAU scenario, and -12% to -21% in the petrol scenario.

493 Overall, future scenarios more strongly reduced occurrence of exceedance of short-term thresholds
 494 (estimated here through P98), than the annual average concentrations, and that is true for all pollutants.

495 Comparing the scenarios 3-PET (promoting petrol vehicles) and 2-BAU (maintaining a high proportion of
 496 diesel),, the statistics were quite close. However, we observed a slight advantage for the petrol scenario,
 497 the differences with the baseline being always greater than those observed in the 2-BAU scenario.

498 The increase in annual O₃ was slightly higher in the petrol scenario, but high concentrations were more
 499 strongly reduced. Indeed, the O₃ increase was mainly a feature of Paris and its periphery (where the

500 chemical environment was limited in VOC) due to higher VOC emissions in the petrol scenario. Higher
501 O₃ concentrations mainly occurred outside Paris (low-NO_x chemical environment), where the petrol
502 scenario was more favorable due to lower NO_x emissions.

503 Concentrations in BC (inert pollutant) were also more reduced by the petrol scenario due to stronger
504 reduction in BC emissions.

505 For organic and inorganic secondary aerosols, the 3-PET scenario led to slightly larger decreases in
506 concentration. For organics, the high concentrations along main roads and in Paris decreased more than
507 with the 2-BAU scenario, although the concentrations in O₃ and oxidants were higher. The decrease was
508 due to lower emissions of ISVOC, intermediate semi-volatile compounds. These were supposed to be
509 proportional to emissions of organic particles (OM) which were lower with the petrol scenario. The same
510 conclusions held when simulations were performed by estimating ISVOC emissions from VOC emissions
511 instead of from OM emissions (Sartelet et al. 2018).

512 For inorganics, the advantage of the 3-PET scenario was due to lower NO_x emissions and
513 concentrations, inducing a decrease in nitric acid (HNO₃) concentrations. Inorganics in Ile-de-France are
514 mainly composed of ammonium nitrate, the formation of which is limited by HNO₃ concentrations
515 (Sartelet et al., 2007). Hence the decrease in NO_x and thus in HNO₃ concentrations induces a reduction
516 in inorganic concentrations.

517 **5 Conclusions**

518 Simulations of pollutant emissions and concentrations over the Île-de-France region under different
519 technological scenarios demonstrated a strong decrease in road traffic emissions by 2025 compared with
520 2014 (-30% to -60% according to the different pollutants). This was due to generalization of particulate
521 filters on diesel vehicles and large renewal of the vehicles fleet to comply with the most recent
522 regulations (Euro5 and 6) (2-BAU scenario). A scenario favoring petrol engines (3-PET) would induce a
523 stronger renewal of the fleet and reduce more particulate and NO_x emissions, but less VOC and NH₃
524 compared to the business-as-usual scenario.

525 Both 2-BAU and 3-PET 2025 scenarios led to lower annual average concentrations compared to the
526 2014 reference baseline, especially for NO₂ (-54% to -60%) and BC (-47% to -56%), and more strongly
527 reduced the number of high concentration events. For other compounds (PM_{2.5}, secondary pollutants),
528 reductions were more limited due to the influence of other activity sectors and atmospheric chemistry.
529 Ozone concentrations might even increase in some urban locations and periods, but remained low in
530 these cases.

531 The differences between the 2025 scenarios themselves were smaller. For PM emissions and
532 concentrations, the petrol scenario (3-PET) was slightly more favorable than the 2-BAU one, across all
533 pollutants. Differences were marked for primary particles from traffic (BC) and less for secondary
534 compounds (PM_{2.5}, organic and inorganic fractions). The difference was also marked for NO₂. The petrol
535 scenario advantage was mainly due to lower emissions (-80% of PM_{2.5}, -60% of BC), partially linked to
536 the accelerated fleet renewal with this scenario (higher share of Euro 5 & 6).

537 A more ambitious scenario (5-AIR) combining the promotion of electric vehicles and a traffic reduction in
538 the densely populated urban area inside the A86 outer ring road of Paris would bring supplementary
539 benefits for all emissions in this zone (-34% for BC, -20% to -44% for gaseous pollutants). Although
540 concentrations were not simulated for that scenario, a definite advantage could be expected, due to the
541 combination of vehicle technologies and traffic reduction for the most urbanized and densely populated
542 area.

543 Beyond these results, this study demonstrated the value of exhaustive simulation for the evaluation of
544 traffic evolution scenarios and technological options. Pollutant emissions and concentrations were
545 estimated as well as their geographical distribution (in relation to population exposure), taking into
546 account other sectors of activity and emission sources that had a considerable influence on
547 concentrations.

548 A critical and systematic analysis of the approach (André et al., 2019) clarified the methodological
549 choices and identified limitations: fragility of certain hypotheses, invariance of emissions from other
550 sectors, insufficient knowledge of the real emission factors of recent engines and pollution control
551 technologies, emissions of unregulated pollutants, precursors of secondary pollutants and semi-volatile
552 organic compounds, insufficient spatial scale to simulate proximity concentrations.

553 Different ways were identified for exploring these boundaries:

- 554 - Simulation of more radical scenarios (e.g., 100% petrol) and sensitivity analysis to different
555 assumptions;
- 556 - Studies at finer resolutions and the broadening of the assessment to include exposure and health
557 impacts;
- 558 - The development of more comprehensive prospective scenarios integrating the evolution of all
559 sectors of activity, demographic and mobility trends.

560 This study also highlighted the need for coordination of public policies in favor of air quality (and climate)
561 due to the contributions of the different sectors of activity. As regards road traffic, reducing traffic in
562 densely populated areas appeared to be an important lever for reducing impacts, alongside technological
563 and regulatory developments.

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570 The analyses, interpretations and conclusions in the present study are those of the authors and do not
571 necessarily reflect those of the mentioned institutions.

572 **References**

- 573 Airparif (2016). Inventaire régional des émissions en Île-de-France. Année de référence 2012. Eléments
574 synthétiques. http://www.airparif.fr/_pdf/publications/inventaire-emissions-idf-2012-150121.pdf
- 575 André M., Carteret M., Pasquier A. (2016). Traffic and vehicle fleet statistics for the calculation of air
576 pollutant emissions from road transports in France; *In: André M. (Ed.) Res. for Innov. Transp. Sets, Vol.*
577 *1: Energy and Environment*. ISTE Wiley. 417-433.
- 578 André M., Redaelli M., André J.M., Charron A., Gagnepain L., Honoré C., Moukthar S., Sartelet K.,
579 Brasseur A., Léger C. (2019). Impact sur la pollution atmosphérique des technologies et de la
580 composition du parc de véhicules automobiles circulant en France. Part B (*in French*). Saisine n°2014-
581 SA-0156. ANSES report, Maisons-Alfort (France). 280p.
- 582 CITEPA (2016a). Inventaire des émissions de polluants atmosphériques en France métropolitaine,
583 format CEE-NU (March 2016 edition)
- 584 CITEPA (2016b). Rapport OMINEA – 13^{ème} Ed (methodology of the French inventory of pollutant
585 emissions).
- 586 EEA (2013). EMEP/EEA – Air Pollutant Emission Inventory Guidebook – Technical report N° 12/2013 -
587 1.A.3.b Road transport <https://www.eea.europa.eu/publications/>
- 588 Guenther, A., Karl, T., Harley, P., Wiedinmyer, C., Palmer, P., Geron, C. (2006). Estimates of global
589 terrestrial isoprene emissions using MEGAN (Model of Emissions of Gases and Aerosols from Nature).
590 *Atmos. Chem. Phys.*, 6:3181–3210.
- 591 Jacquemin B., Baeza A., Blanchard M., Fuertes E., Garçon G., Mullot J.U., Sanchez M., Brasseur A.,
592 Léger C., Redaelli M. (2019). Effets sanitaires des particules de l'air ambiant extérieur selon les
593 composés, les sources et la granulométrie. Part A (*in French*). Saisine n°2014-SA-0156. ANSES report,
594 Maisons-Alfort (France). 487p.
- 595 Jaeglé, L., Quinn, P.K., Bates, T.S., Alexander, B., and Lin, J. (2011). Global distribution of sea salt
596 aerosols: new constraints from in situ and 5 remote sensing observations, *Atmos. Chem. Phys.*, 11,
597 3137–3157.
- 598 Kim Y, K. Sartelet, J.-C. Raut and P. Chazette (2013). Evaluation of the WRF/urban model over Greater
599 Paris. *Boundary-Layer Meteorology*, 2013, 149, 105–132.
- 600 Kim Y., Sartelet K., Seigneur C., Charron A., Besombes J.-L., Jaffrezo J.-L., Marchand N., Polo L.
601 (2016), Effect of measurement protocol on organic aerosol measurements of exhaust emissions from
602 gasoline and diesel vehicles. *Atmos. Env.*, 140, 176-187.
- 603 Mallet, V., Quélo, D., Sportisse, B., Ahmed de Biasi, M., Debry, É., Korsakissok, I., Wu, L., Roustan, Y.,
604 Sartelet, K., Tombette, M., Foudhil, H. (2007). Technical Note: The air quality modeling system
605 Polyphemus. *Atmos. Chem. Phys.*, 7(20):5479–5487.
- 606 Ntziachristos L., Samaras, Z., Kouridis C., Hassel D., Mellios G., McCrae I., Hickman J., Zierock K.-H.,
607 Keller M., Rexeis M., Andre M., Winther M., Pastramas N., Gorissen N., Boulter P., Katsis P.,
608 Joumard, R., Rijkeboer R., Geivanidis S., Hausberger S. (2013). Exhaust emissions from road transport,
609 EMEP Guidebook 2014.

610 Pascal M., de Crouy Chanel P., Wagner V., Corso M., Tillier C., Bentayeb M., Blanchard M., Cochet A.,
611 Pascal L., Host S., Gorla S., Le Tertre A., Chatignoux E., Ung A., Beaudeau P., Medina S. (2016) The
612 mortality impacts of fine particles in France. *Sci Total Environ* 571:416-25.

613 Sartelet, K., Debry, É., Fahey, K., Roustan, Y., Tombette, M., Sportisse, B. (2007). Simulation of
614 aerosols and gas-phase species over Europe with the Polyphemus system: Part I Model-to-data
615 comparison for 2001. *Atmos. Env.*, 41:6116–6131.

616 Sartelet K., S. Zhu, S. Moukhtar, M. André, J.M. André, V. Gros, O. Favez, A. Brasseur, M. Redaelli
617 (2018). Emission of intermediate, semi and low volatile organic compounds from traffic and their impact
618 on secondary organic aerosol concentrations over Greater Paris. *Atmos. Env.*, 180: 126-137

619 Seinfeld, J., Pandis, S. (1998). Atmospheric Chemistry and Physics. Wiley-interscience.

620 Seigneur, C. (2019). Air Pollution: Concepts, Theory, and Applications, Cambridge University Press,
621 370p.

622 Skamarock W., J. Klemp, J. Dudhia, D. Gill, D. Barker, M. Duda, X. Huang, W. Wang and J. Powers
623 (2008). A description of the advanced research WRF version 3, NCAR Techn. Note, NCAR/TN-
624 475+STR, 8, p. 123.

625 T&E (2018). Cars with engines: can they ever be clean?. Transport & Environment Report. Brussels,
626 Belgium. 40p. <https://www.transportenvironment.org/publications/cars-engines-can-they-ever-be-clean>

627 Theloke J., Friedrich R. (2007), Compilation of database on the composition of anthropogenic VOC
628 emissions for atmospheric modeling in Europe. *Atmos. Env.*, 41, 19, 4148-4160.

629 Tomassini M. (coord.) (2003) Healthier Environment through Abatement of Vehicle Emission and Noise,
630 EC project IST-1999-112444, Final Report. 61p.

631 WHO Europe (2013). Review of evidence on health aspects of air pollution – REVIHAAP Project. Report
632 of the WHO Europe. 302p.

633 WHO Europe (2006). Air Quality Guidelines Global Update 2005 - Particulate matter, ozone, nitrogen
634 dioxide and sulfur dioxide. Report of the WHO Europe. 484p.

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