SUPPORTING INFORMATION TO THE MANUSCRIPT

Exposure to air pollution inside electric and diesel-powered passenger trains

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Content summary:

The Supporting Information contains 14 pages. It includes 9 tables, 8 figures and one section of method details for metal content analysis from particle matter.

Table S1 – Overview of sampling

Week	Date	Description	Devices and samplers
1	7-8 March 2017	Pilot study (electric and diesel A scenarios)	DM, NT and NanoScan SMPS
2	16-18 May 2017	Electric scenario	BC, NT, NOx/NO_2, Aldehydes
3	6-8 June 2017	Diesel A scenario	BC, NT,NOx/NO_2, Aldehydes
4	27-29 June 2017	Diesel A scenario	BC, NT, NOx/NO_2, Aldehydes
5	1-3 August 2017	Diesel A scenario	BC, DM, NT, NOx/NO_2, Aldehydes
6	8-10 August 2017	Diesel A scenario	BC, DM, NT, NOx/NO_2, Aldehydes
7	15-17 August 2017	Electric scenario	BC, DM, NT, NOx/NO_2, Aldehydes
8	22-24 August 2017	Electric scenario	BC, DM, NT, NOx/NO_2, Aldehydes
9	29-31 August 2017	Diesel A scenario	BC, DM, NT, NOx/NO_2, Aldehydes
10	5-7 September 2017	Diesel A scenario	BC, DM, NT, NOx/NO_2
11	12-14 September 2017	Diesel A scenario	BC, DM, NT, NOx/NO_2
12	19-21 September 2017	Electric scenario	BC, DM, NT, NOx/NO_2, Aldehydes
13	26-28 September 2017	Diesel A scenario	BC, DM, NT, NOx/NO_2, Aldehydes
14	3-5 October 2017	Diesel B scenario	BC, DM, NT, NOx/NO_2, $PM_{2.5}$, PAH
15	10-12 October 2017	Diesel B scenario	BC, DM, NT, NOx/NO_2, $PM_{2.5}$, PAH
16	17-19 October 2017	Electric scenario	BC, DM, NT, NOx/NO_2, $PM_{2.5}$, PAH
17	24-26 October 2017	Electric scenario	BC, DM, NT, NOx/NO_2, $PM_{2.5}$, PAH
18	31 Oct.-2 November 2017	Electric scenario	BC, DM, NT, NOx/NO_2, $PM_{2.5}$, PAH
19	7-9 November 2017	Diesel B scenario	BC, DM, NT, NOx/NO_2, $PM_{2.5}$, PAH
20	14-16 November 2017	Diesel B scenario	BC, DM, NT, NOx/NO_2, $PM_{2.5}$, PAH
21	21-23 November 2017	Diesel B scenario	BC, DM, NT, NOx/NO_2, $PM_{2.5}$, PAH
22	28-30 November 2017	Diesel B scenario	BC, DM, NT, NOx/NO_2, $PM_{2.5}$, PAH
23	5-7 December 2017	Diesel A scenario/Gradient	BC, DM, NT, Electrostatic sampler
24	12-14 December 2017	Diesel A scenario/Gradient	BC, DM, NT, Electrostatic sampler
25	26 January 2018	Underground station with ME	BC, DM
26	2 February 2018	Underground station without ME	BC, DM

DM, DiscMini; NT, NanoTracer; BC, Black carbon; PAH, polycyclic aromatic hydrocarbons; ME, diesel locomotive Litra ME; Gradient, exposure gradient measurements performed on 6, 7 and 13 of December 2017.

Table S2 – Train schedules in the three scenarios

Scenario	Diesel A	Diesel B	Electric
Route	ØS-Kb-CS-Ho-CS	ØS-Ho-CS-Kb-CS	ØS-Els-ØS
Schedule	ØS 8:34 – Kb 10:10 Kb 10:46 – CS 12:12 CS 13:27 – Ho 14:25 Ho 14:35 – CS 15:32	ØS 8:34 – Ho 9:28 Ho 9:35 – CS 10:32 CS 10:45 – Kb 12:10 Kb 12:46 – CS 14:12	ØS 9:39 – Els 10:17 Els 10:38 – ØS 11:16 ØS 11:39 – Els 12:17 Els 12:38 – ØS 13:16 ØS 13:39 – Els 14:17 Els 14:38 – ØS 15:16
Resume	6h 47min (4h 46 min, 36 stops + 2h01min waiting time)	5h 59min (4h 53min, 39 stops + 56min waiting time	5h 37 min (3h 48min, 42 stops + 1h 49min waiting time)
Sampling days	31 days	18 days	22 days

ØS, Østerport station; Kb, Kalundborg station; CS, Copenhagen Central station; Ho, Holbæk station; Els, Elsinore station.

Table S3 – Exposure variables, instruments, resolution, sampling flow, sampling period and sampling sites

Variable	Instrument	Resolution	Sampling flow	Sampling period	Sampling site
UFP number concentration and size distribution	NanoTracer (10-300 nm)	16 sec	0.3-0.4 L/min	23 weeks (70 days)	On-board trains and on platform
	DiSCmini (10-300 nm)	1 sec	1.0 L/min	21 weeks + 2 days (65 days)	On-board trains and on platform
	NanoScan SMPS (10-420 nm)	1 min	0.75 L/min	2 days	On-board trains
Black Carbon	MicroAeth AE51	1 min	150 mL/min	23 weeks (69 days)	On-board trains and on platform
NO_2 and NO_x[1]	Ogawa samplers	Accumulated over 3 days	Passive sampling	21 weeks (63 days)	On-board trains
Aldehydes[2]	Sep-Pak samplers	Accumulated over 3 days	200 mL/min (Gilian low flow sampler)	10 weeks (30 days)	On-board trains
$PM_{2.5}$	Triplex cyclone teflon filters	Accumulated over 3 days	1.5 L/min (Apex2IS, USA, Casella)	9 weeks (27 days)	On-board trains
PAH[3]	Teflon filters and XAD tubes	Accumulated over 3 days	1.5 L/min ((Apex2IS, USA, Casella)	9 weeks (27 days)	On-board trains
Particles	Electrostatic sampler	Accumulated over 6 days	3500 L/min	2 weeks (6 days)	On-board diesel train

BC, black carbon; PAH, polycyclic aromatic hydrocarbons; SMPS, scanning mobility particle sizer; UFP, ultrafine particles. [1] Nitrogen oxides analysis was performed at the Division of Occupational and Environmental Medicine, Umeå University, Sweden. [2] Aldehydes were carried out by Occupational and Environmental Medicine at Örebro University Hospital, Sweden. [3] The PAH analysis of collected particles were carried out by the Department of Occupational and Environmental Medicine, Lund University, Sweden; the PAH analysis of collected air samples were carried out by the National Research Centre for the Working Environment, Copenhagen, Denmark.

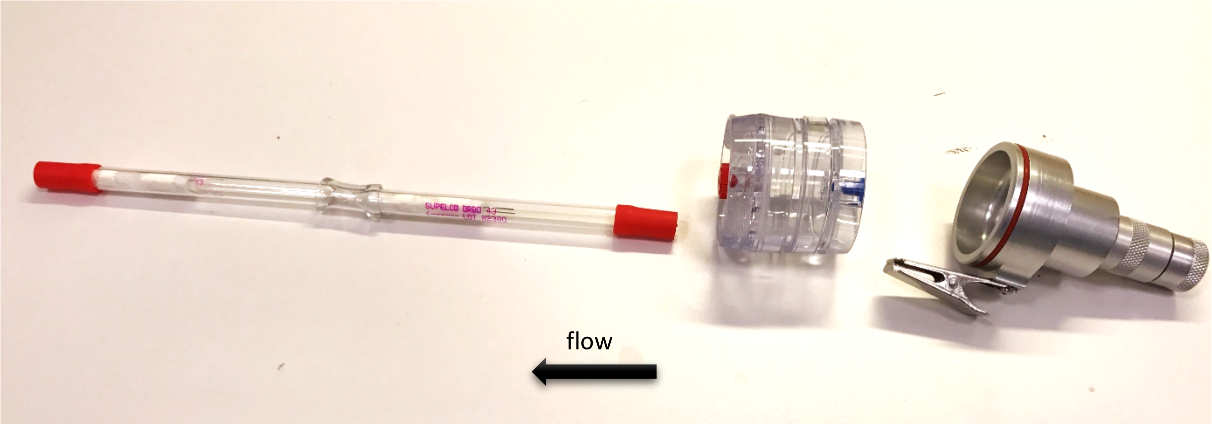

Figure S1. Sequence attached to the pump for the collection of particles on filters for PAH content analysis. Two XAD-2 tubes with caps, cassette holding filter and cyclone

Figure S2. Compartment in front of the first passenger car in the diesel train.

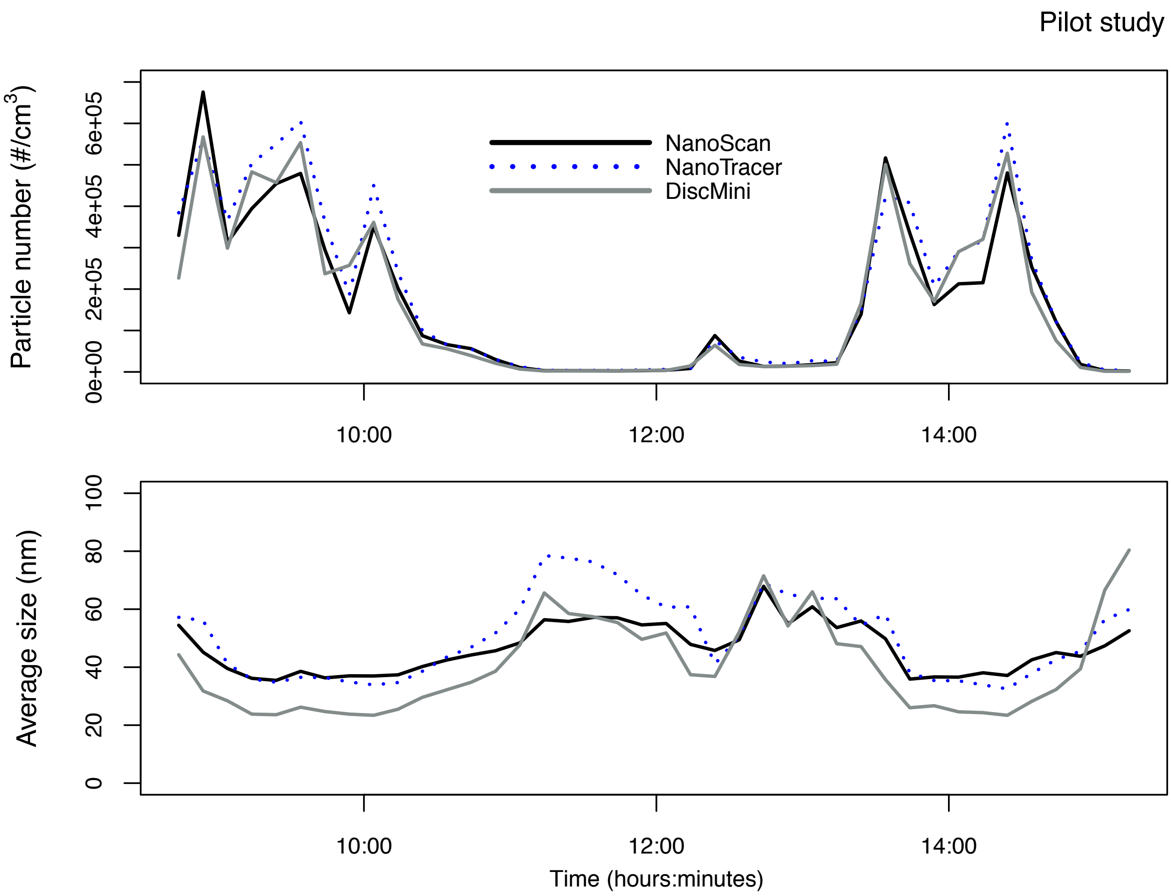

Figure S3 – Time-series data from pilot study for Diesel A scenario recorded with NanoScan SMPS, NanoTracer and DiscMini on 08-March-2017

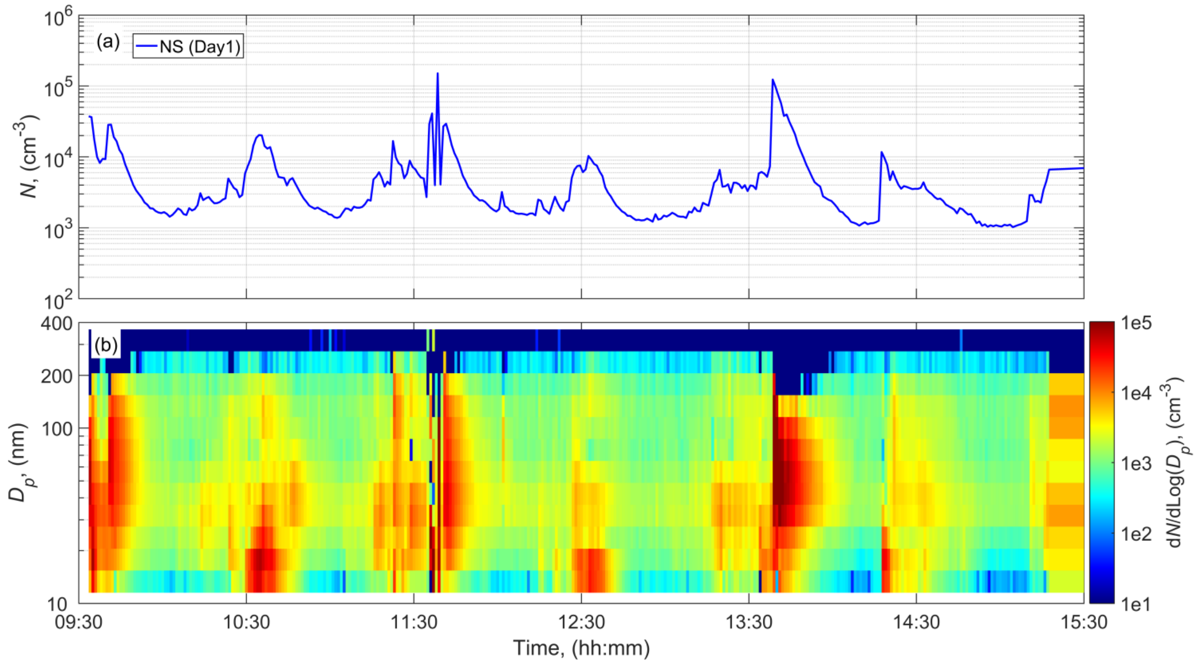

Figure S4. Time series from Electric scenario with (a) total particle number concentration, and (b) particle number size distributions measured by NanoScan SMPS (pilot study on 07-March-2017)

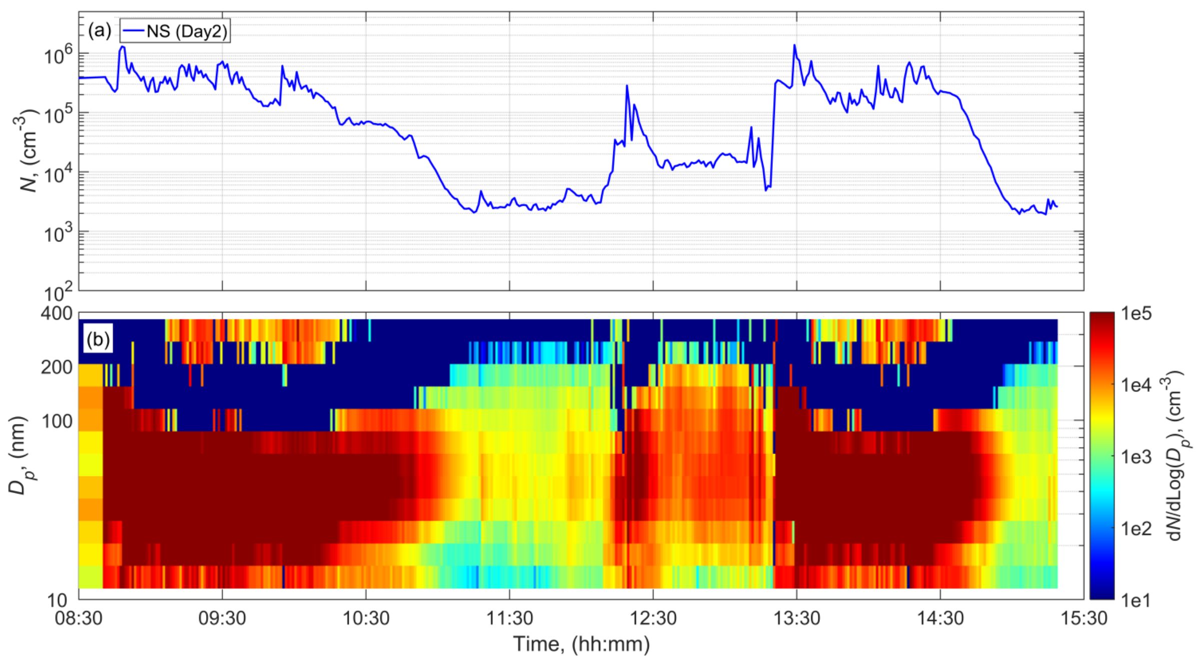

Figure S5. Time series from Diesel A scenario with (a) total particle number concentration, and (b) particle number size distributions measured by NanoScan SMPS (pilot study on 08-March-2017)

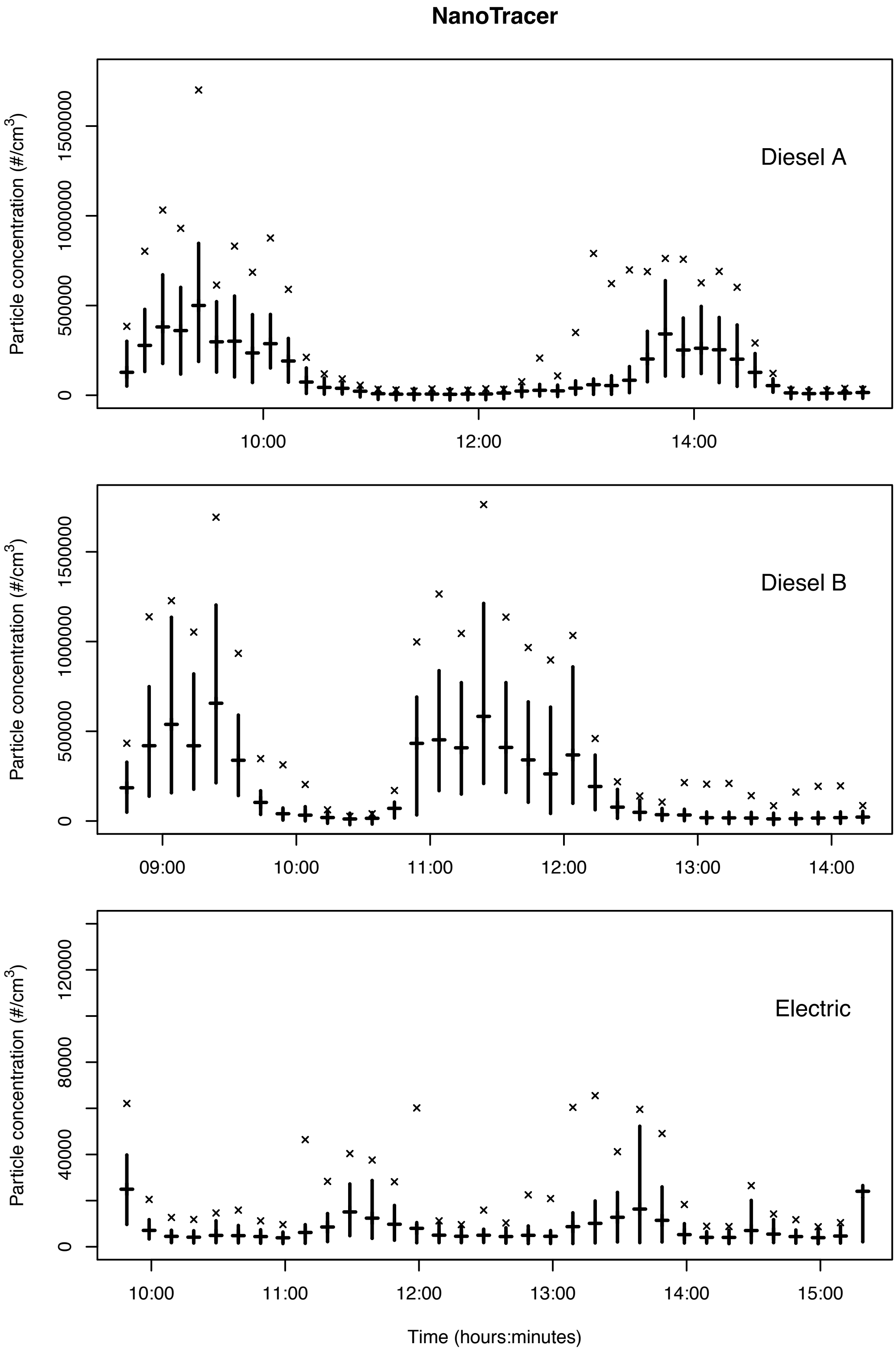

Figure S6. Daily temporal variation of 10 minutes averages UFP number concentration (from NanoTracer) in the defined route scenarios (Diesel A, Diesel B and Electric). The symbols represent the arithmetic mean (horizontal lines), the 10^{th} to 90^{th} percentile distributions (vertical lines) and the maximum values (point crosses) for 10 minutes averaged data. Data results from time series from 29, 18 and 20 measurement days, respectively, for Diesel A, Diesel B and Electric

Table S4 – Time series data and data loss

	Scenario	Black carbon	Ultrafine particles (DiscMini)	Ultrafine particles (Nanotracer)
Diesel A	Week 1 (1 day) [a]	Missing data	Loss of 5%	
	Week 3 (3 days)		Missing data (for 2 days)	
	Week 4 (3 days)		Missing data (for 3 days)	Loss of 10% in 1 day
	Week 5 (3 days)		Missing data (for 1 day)	
	Week 6 (3 days)		Missing data (for 1 day) and loss of 21% in other day	
	Week 9 (3 days)		Missing data (for 1 day) and loss of 5% in 1 day	
	Week 10 (3 days)		Loss of 12% in 1 day	
	Week 11 (2 days) [b]			
	Week 13 (2 days) [b]		Loss of 12% and 10%	Loss of 2% in both days
	Week 14 (1 day) [c]		Loss of 17%	
	Week 23 (3 days)		[d]	Loss of 3% in 2 days
	Week 24 (2 days) [b]		[d]	Loss of 10% in 1 day
	Total (29 days)	**28 days**	**21 days**	**29 days**
Diesel B	Week 14 (2 days) [c]			
	Week 15 (3 days)			
	Week 19 (3 days)		Loss of 18%, 50% and 30%	
	Week 20 (3 days)			
	Week 21 (3 days)			
	Week 22 (3 days)		Loss of 3% in 1 day	
	Total (17 days)	**17 days**	**17 days**	**17 days**
Electric	Week 1 (1 day) [a]	Missing data	Missing data	Missing data
	Week 2 (3 days)		Missing data (for 3 days)	Loss of 3% in 1 day
	Week 7 (3 days)			
	Week 8 (3 days)	Missing data (for 2 days)	Loss of 6% and 12% in 2 days	Loss of 12% in 1 day
	Week 12 (3 days)			
	Week 16 (3 days)		Los of 6% and 3% in 2 days	Loss of 6% in 1 day
	Week 17 (3 days)		Loss of 6%, 12% and 9%	Loss of 12% in 1 day
	Week 18 (2 days) [b]		Loss of 9% and 12%	Loss of 12% in both days
	Total (21 days)	**18 days**	**17 days**	**20 days**

Missing data was due to no availability of devices, failure in flow, no recording mode or lack of battery for more than 50% day monitoring time, and the eventual data fragments were not considered for that day. When data loss (by device failure) was less than 50%, data were included in the analysis.

[a] Week 1 was the pilot study, with only one day of monitoring in each of the electric and Diesel A scenarios; [b] Different schedules of trains (cancelation or delay of trips that did not allowed the synchronization and therefore data not considered; [c] Week 14 was a transition between Diesel A and B scenarios, with 1 day in one and 2 days in the other scenario; [d] Weeks where we also performed gradient measurements. The devices at other positions than position 1 were briefly disconnected when the train was stopped at stations.

Table S5 – Results from particle-bound and gas phase PAHs analysis, presented in air concentrations (ng/m^3)

Week	14	15	16	17	18	19	20	21	22
Scenario	**Diesel**	**Diesel**	**Electric**	**Electric**	**Electric**	**Diesel**	**Diesel**	**Diesel**	**Diesel**
PARTICLE-BOUND PAHs									
Acenaphthylene	0.036[a]	<0.017[b]	<0.017	<0.017	<0.017	<0.017	<0.017[b]	0.025[a]	<0.017
Acenaphthene	0.030[a]	<0.057[b]	<0.057	<0.057	0.14[a]	<0.057	<0.017[b]	<0.057	<0.057
Fluorene	0.31[a]	<0.021[b]	<0.021	<0.021	0.094[a]	0.040[a]	<0.021[b]	<0.021	<0.021
Phenanthrene	0.51	0.16[b]	<0.14	<0.14	0.26[a]	0.20	0.14[b]	0.16[a]	<0.14
Fluoranthene	0.20	0.13[b]	<0.051	<0.051	<0.051	0.20	0.10[b]	0.12	0.086
Pyrene	0.21	0.13[b]	0.02	0.03	0.016	0.20	0.10[b]	0.13	0.10
Benz(a)anthracene	0.085	0.088[b]	0.005	0.004	0.002	0.15	0.088[b]	0.15	0.10
Chrysene	0.063	<0.057[b]	<0.057	<0.057	<0.057	0.17	0.059[b]	0.12	0.077
Benzo(b)fluoranthene	0.18	0.17[b]	0.058	0.079	0.05	0.48	0.21[b]	0.49	0.27
Benzo(k)fluoranthene	0.033	0.047[b]	0.014	0.019	0.012	0.15	0.05[b]	0.14	0.083
Benzo(a)pyrene	0.081	0.10[b]	0.035	0.030	0.028	0.27	0.12[b]	0.30	0.18
Indeno(1,2,3-cd)pyrene	0.079	0.090[b]	0.035	0.044	0.044	0.29	0.12[b]	0.33	0.18
Dibenz(a,h)anthracene	<0.021	<0.021[b]	<0.021	<0.021	<0.021	0.046	<0.021[b]	0.059	0.030
Benzo(g,h,i)perylene	0.15	0.12[b]	0.045	0.047	0.052	0.32	0.15[b]	0.37	0.21
∑PAH filter	**1.90**	**1.04**	**0.21**	**0.25**	**0.45**	**2.47**	**1.14**	**2.28**	**1.29**
GAS PHASE PAHs									
Naphthalene	143.5	133.1	66.91	170.32	86.65	163.09	98.80	154.91	108.54
Acenapthene			16.94	12.47[a]	13.97[a]		10.47[a]	7.01[a]	
Fluorene	11.20[a]		9.35	8.89[a]					
Phenanthrene	23.06	19.73[a]	16.03	15.95	16.95	24.02[a]	8.66[a]		
Antracene	9.36	5.63	20.98[a]	4.01	5.73	5.45	3.74[a]	7.52[a]	
Fluoranthene	57.87	6.15							
Pyrene	21.61	6.89				8.54[a]		2.50[a]	2.16
∑PAH XAD-2	**261.12**	**161.58**	**119.72**	**200.96**	**116.31**	**184.82**	**110.24**	**163.42**	**110.71**

PAH, polycyclic aromatic hydrocarbon; ∑PAH, sum of PAHs. Values only for the PAHs that were detected in at least one sample and presented as averages of duplicate samples, unless specified differently.
[a] value from one of the samples, the other was below limit of detection
[b] value from one sample, the other was eliminated from analysis

Table S6 – Results from elemental analysis of acid extracts from particulate matter collected with the electrostatic sampler and SRM 2975 (more details of the method are described below)

Element	**Estimated LOD for the collected particles content** (µg/g particle)	**Collected particles inside diesel train** (µg/g particle)	**SRM2975** [a] (µg/g particle)
Magnesium (Mg)	173.9	1 664	272.5
Vanadium (V)	13	ND	ND
Chromium (Cr)	6.9	105	5.5
Manganese (Mn)	4.7	439	4.5
Iron (Fe)	603.4	44 556	589.5
Cobalt (Co)	0.3	5	0
Nickel (Ni)	6.9	48	4
Copper (Cu)	2.3	1 520	18
Zinc (Zn)	43.7	3 388	385
Gallium (Ga)	13	ND	ND
Arsenic (As)	0.3	9	ND
Selenium (Se)	0.9	2	1
Rubidium (Rb)	0.5	4	ND
Strontium (Sr)	4.3	119	ND
Silver (Ag)	< 0.1	147	0
Cadmium (Cd)	< 0.1	1	ND
Indium (In)	< 0.1	0	0
Caesium (Cs)	0.4	ND	ND
Barium (Ba)	4.6	63	26
Mercury (Hg)	0.1	1	ND
Thallium (Tl)	0.1	ND	ND
Lead (Pb)	1.9	23	12.5
Bismuth (Bi)	0.1	5	0
Uranium (U)	0.1	ND	ND

LOD, limit of detection; ND, not detectable ; [a] values are means of two duplicate analysis.

SRM2975 (Standard Reference Material 2975) was purchased from the National Institute of Standards and Technology (Gaithersburg, MD, USA). SRM2975 consists of diesel exhaust particles collected from an industrial forklift as described in detail elsewhere (https://www-s.nist.gov/srmors/certificates/2975.pdf).

Method details for results in Table S6:

A volume of 1 mL of 25% (v/v) nitric acid (PlasmaPure 67-69 % HNO_3, SCP Science, USA) was added to the flask containing 2.35 mg of the particles. Additionally, SRM2975 (diesel particulate matter reference material from the National Institute of Standards) was included in the analysis (N=2). For the preparation of SRM2975, approximately 1 mg of material was weighed into 13 mL polypropylene tubes (Sarstedt, Germany) and 1 mL of 25% (v/v) nitric acid added. The flasks and tubes were transferred to a shaker (Stuart Scientific SF1, UK) and agitated at 600 oscillations per minute overnight. After incubation for approximately 7 hours at room temperature without agitation, the samples were placed in the shaker for another 72 hours and finally transferred with 6 mL of ultrapure water into polypropylene tubes. An empty flask (same type as used to collect the particles) and a polypropylene tube (as used for SRM2975) were treated in the same way as the samples to obtain suitable blank solutions. Before analysis, the samples were centrifuged for 5 minutes at 4500 x g using a centrifuge (Heraeus Multifuge X3 FR, Thermo Scientific, Germany). A volume of 5 mL of the supernatant was transferred to a new polypropylene tube and the samples further diluted 5- or 100-times with 5% HNO_3.

An inductive coupled plasma mass spectrometer (ICP-MS) (Agilent 8900 ICP-QQQ-MS, Agilent, USA) equipped with a MicroMist borosilicate glass concentric nebulizer and a Scott type double-pass water-cooled spray chamber was run in no gas (Cd, Hg, Pb, Bi, U) or helium (remaining elements) mode with 0.1 - 3 s integration time per mass. The following plasma parameters were used: 1550 W RF power, 15 L/min plasma gas, 0.9 L/min auxiliary gas and 0.99 L/min nebulizer gas. The cell gas flow in helium mode was 5 mL/min. The auto sampler (SPS4, Agilent Technologies) introduced the samples into the ICP-MS with a sample uptake time of 30 s (0.5 rps) and a stabilization time of 30 s (0.1 rps). Quantification was performed based on external calibration (multi-element standards of 5, 10, 25, 50 and 100 µg/L; for mercury 0.5, 1.0, 2.5, 5.0 and 10 µg/L). As quality control, a mixture of 1 µg/L Li, Ba, Bi, V and As was analyzed. Limits of detection for the samples were estimated based on three times the standard deviation of the blanks and taking into account the sample dilution factors.

Table S7 – Gradient levels summary of black carbon mass concentration (μg/m^3) measured with MicroAeth inside the train in scenario "diesel A" (all day)

	Day 1 (ME 1509)		**Day 2** (ME 1511)		**Day 3** (ME 1505)	
	Position 1	**Position 2 (%)**	**Position 1**	**Position 3 (%)**	**Position 1**	**Position 4 (%)**
Min	0.3	0.4 (133)	0.2	0.4 (200)	0.3	0.3 (100)
1st quartile	1.1	1.3 (118)	2.3	2.8 (122)	1.6	1.5 (94)
Median	3.4	4.0 (118)	5.8	5.9 (102)	4.9	5.2 (106)
Mean	7.2	8.1 (113)	8.6	7.3 (85)	13.1	7.8 (60)
3rd quartile	8.9	11.2 (126)	12.6	9.1 (72)	15.7	9.7 (62)
Max	66.3	59.5 (90)	47.8	65.1 (136)	129.6	81.8 (63)

Position 1, inside the first passenger compartment closest to the engine in the first car; position 2, just outside the glass that partially separate the first passenger compartment, in the first car; position 3, in the end of the first car; position 4, in the beginning of the second car. A percentage in relation to position 1 is presented for each component of the distribution in the relative positions in the train. The reference code for the ME locomotive engine is presented in parenthesis for each day.

Table S8 – Gradient levels summary of ultrafine particle number concentration (particles/cm^3) measured with DiscMini inside the train in scenario "diesel A" (all day)

	Day 1 (ME 1509)		**Day 2** (ME 1511)		**Day 3** (ME 1505)	
	Position 1	**Position 2 (%)**	**Position 1**	**Position 3 (%)**	**Position 1**	**Position 4 (%)**
Min	2 081	2 295 (110)	1 955	1 603 (82)	1 782	1 338 (75)
1st quartile	7 739	9 917 (128)	39 748	56 391 (142)	34 515	20 761 (60)
Median	80 473	84 960 (106)	159 914	159 955 (100)	142 032	88 647 (62)
Mean	171 295	176 057 (103)	343 925	270 082 (79)	445 183	131 732 (30)
3rd quartile	267 992	296 412 (111)	499 046	463 666 (93)	525 035	206 014 (39)
Max	1 360 644	966 000 (71)	2 003 503	1 099 951 (55)	3 339 889	611 748 (18)

Position 1, inside the first passenger compartment closest to the engine in the first car; position 2, just outside the glass that partially separate the first passenger compartment, in the first car; position 3, in the end of the first car; position 4, in the beginning of the second car. A percentage in relation to position 1 is presented for each component of the distribution in the relative positions in the train. The reference code for the ME locomotive engine is presented in parenthesis for each day.

Table S9 – Underground train platform measurements of black carbon mass concentration (BC) and particle number concentration (UFP) on two different days (with and without ME trains in circulation)

	Day 1 (26/01/2018)		Day 2 (02/02/2018)	
	111 trains (37 ME; 14 other diesel; 60 electric)		89 trains (20 other diesel; 69 electric)	
	BC (µg/m³)	**UFP (#/cm³)**	**BC (µg/m³)**	**UFP (#/cm³)**
Min	1.9	24,000	1.5	8,900
1st quartile	10.1	111,000	4.4	19,300
Median	18.1	170,000	7.8	30,800
Average	24.8	196,400	11.4	43,200
3rd quartile	32.9	244,000	13.6	50,700
Max	114.9	983,600	72.1	267,800

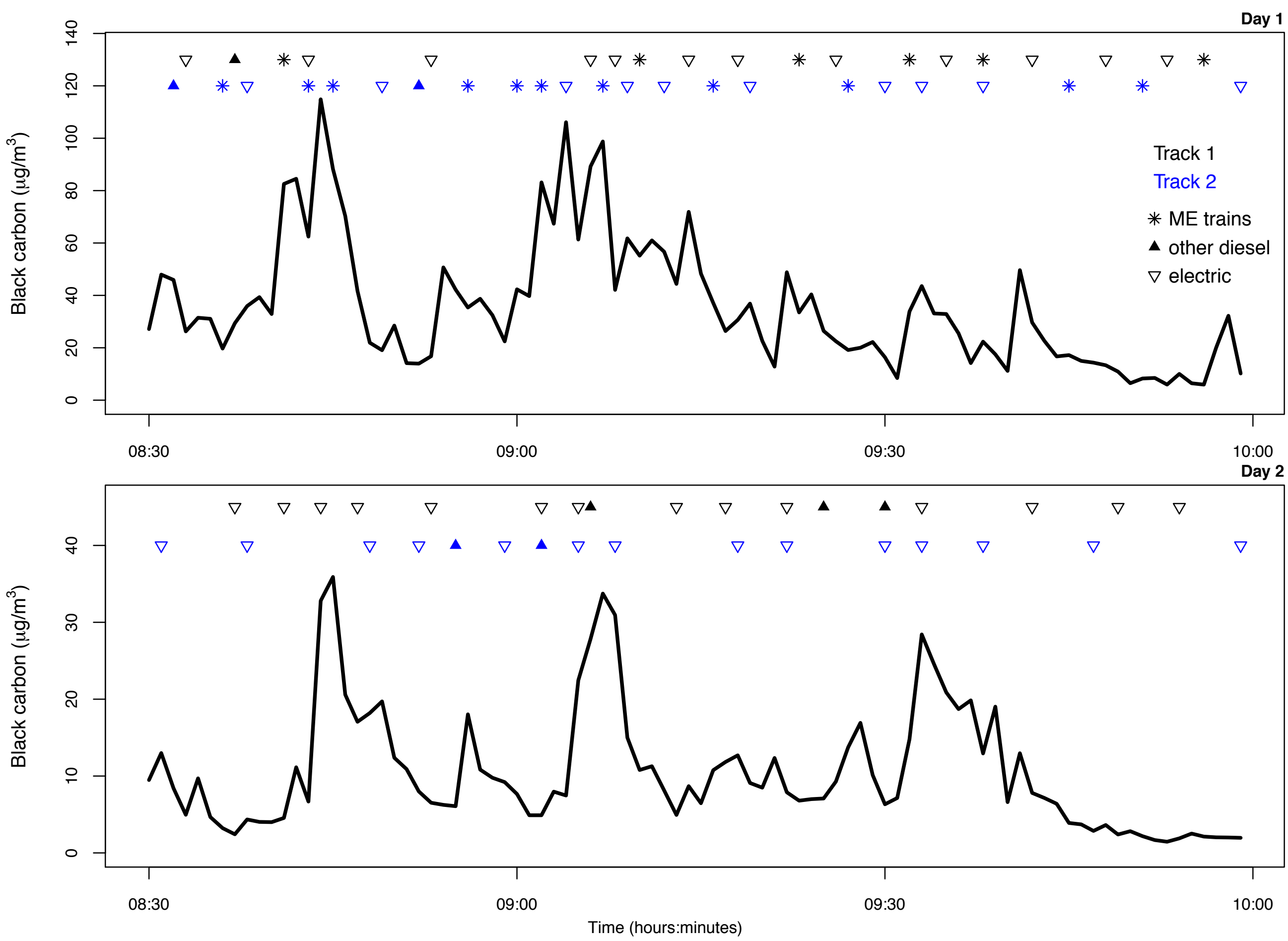

Figure S7. Time-series from 08h30 to 09h59 data from black carbon mass concentration measured on underground train platform on two different Fridays, with and without ME trains in circulation. Day 1, with ME trains in circulation and Day 2 without ME trains in circulation. The train passages were recorded as ME trains, other diesel train types and electric trains and distinguished for passages on track 1 (in black) or on track 2 (in blue). Time-series data with 1-minute resolution.

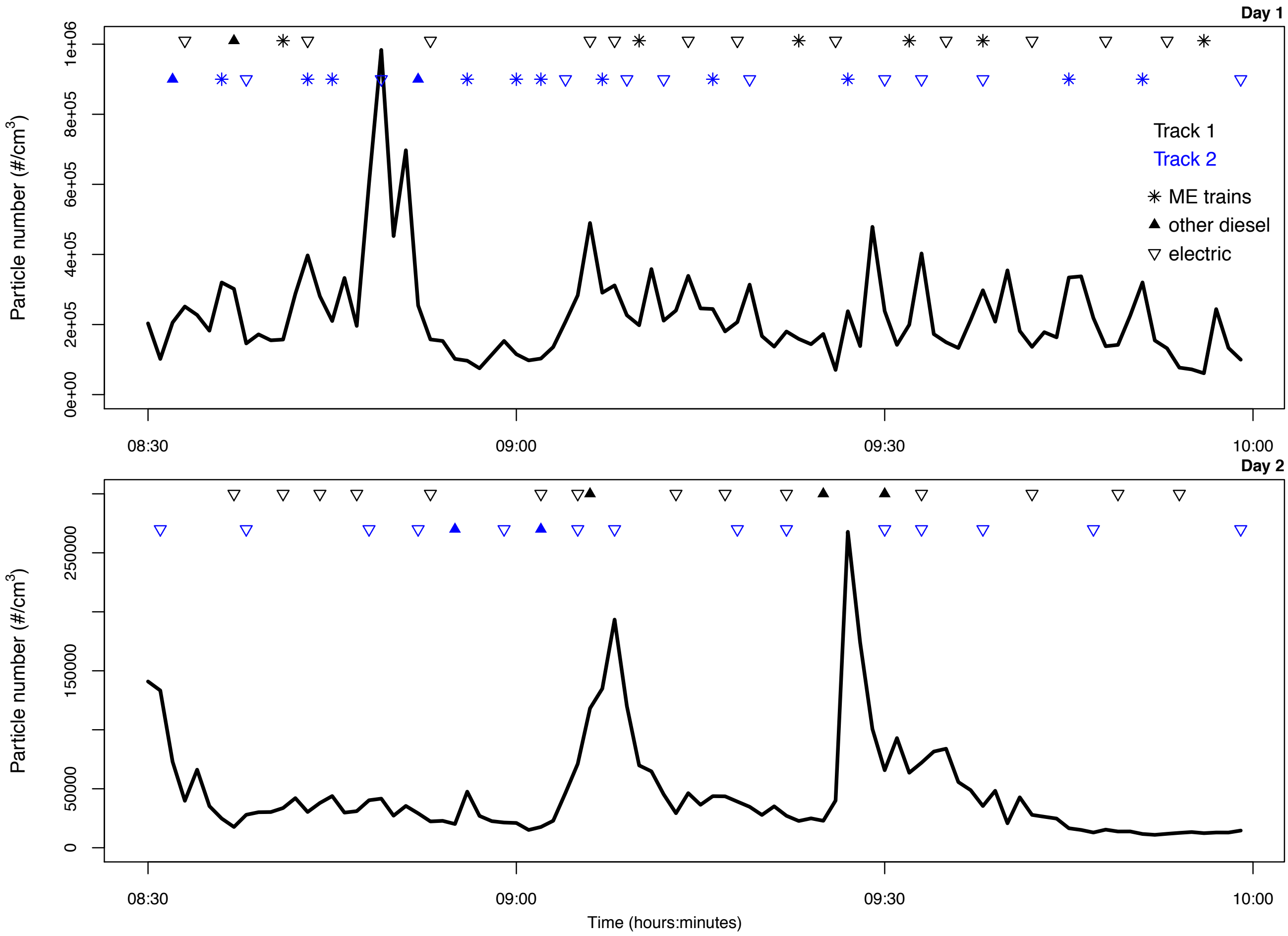

Figure S8. Time-series from 08h30 to 09h59 data from ultrafine particles number concentration measured on underground train platform on two different Fridays, with and without ME trains in circulation. Day 1, with ME trains in circulation and Day 2 without ME trains in circulation. The train passages were recorded as ME trains, other diesel train types and electric trains and distinguished for passages on track 1 (in black) or on track 2 (in blue). Time-series data with 1-minute resolution.