

On-road emissions of Euro 6d-TEMP passenger cars on Alpine routes during winter period

Suarez-Bertoa Ricardo,^{*1} Valverde Victor,¹ Pavlovic Jelica,¹ Clairotte Michael,¹ Selleri Tommaso,¹ Franco Vicente,² Kregar Zlatko,² and Astorga Covadonga.^{*1}

¹*European Commission Joint Research Centre.*

²*European Commission Directorate-General for Environment.*

Corresponding authors:

E-mail addresses: ricardo.suarez-bertoa@ec.europa.eu (Suarez-Bertoa R.);

covadonga.astorga-llorens@ec.europa.eu (Astorga C.)

Figure S1. Exhaust mass flow (kg/h) from PHEV during the Alpine1 route under different setup conditions. SOC-min. top panel and SOC 100% bottom panel. In the top panel, the exhaust flow during the Alpine1 SOC-min. HEAT-OFF is represented the measured value (blue line) and as corrected (measured value $\times 3.7$) value (grey line).

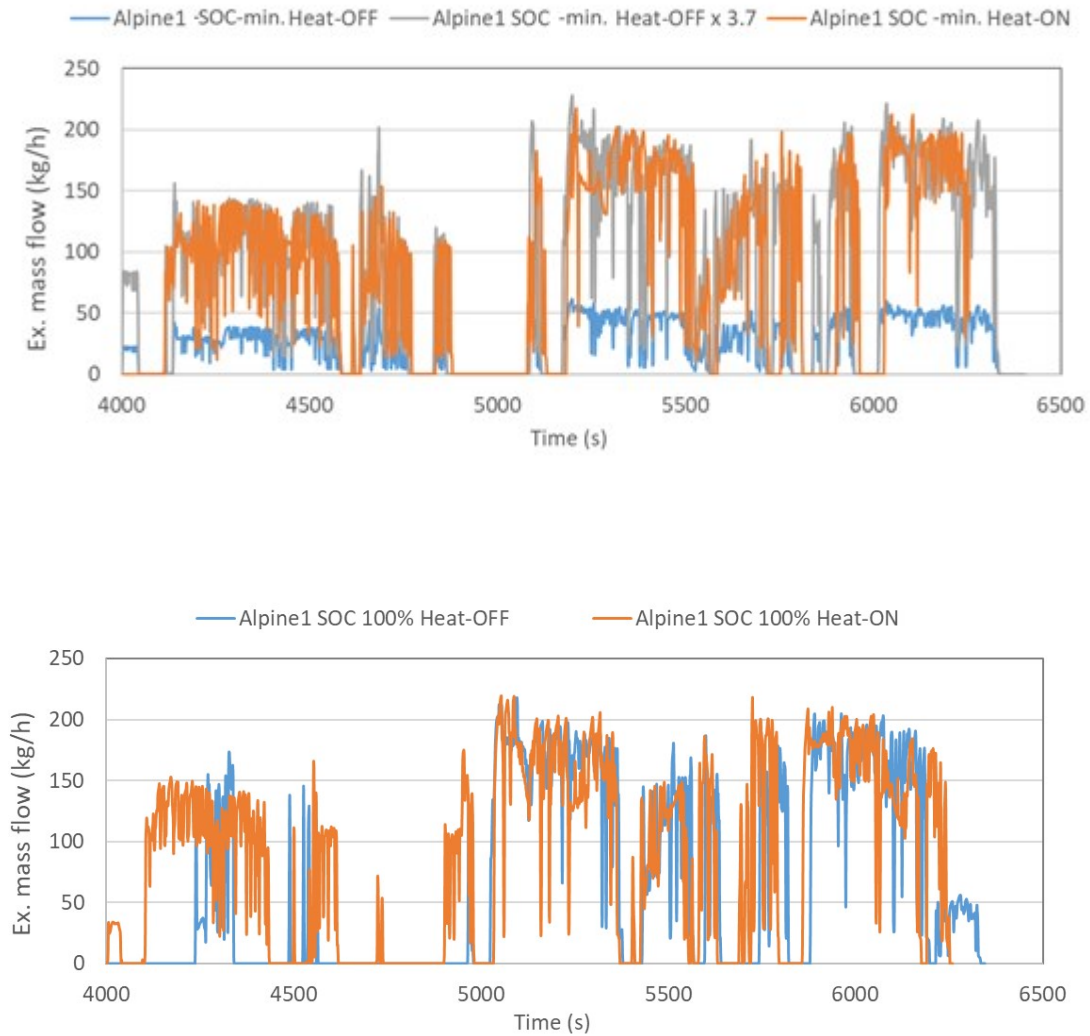


Figure S2. DV's cumulative NOx emissions (green line) and altitude (black line) sensor reading during RDE1(top panel), Alpine1 (center panel) and Alpine2 (extra) (bottom panel).

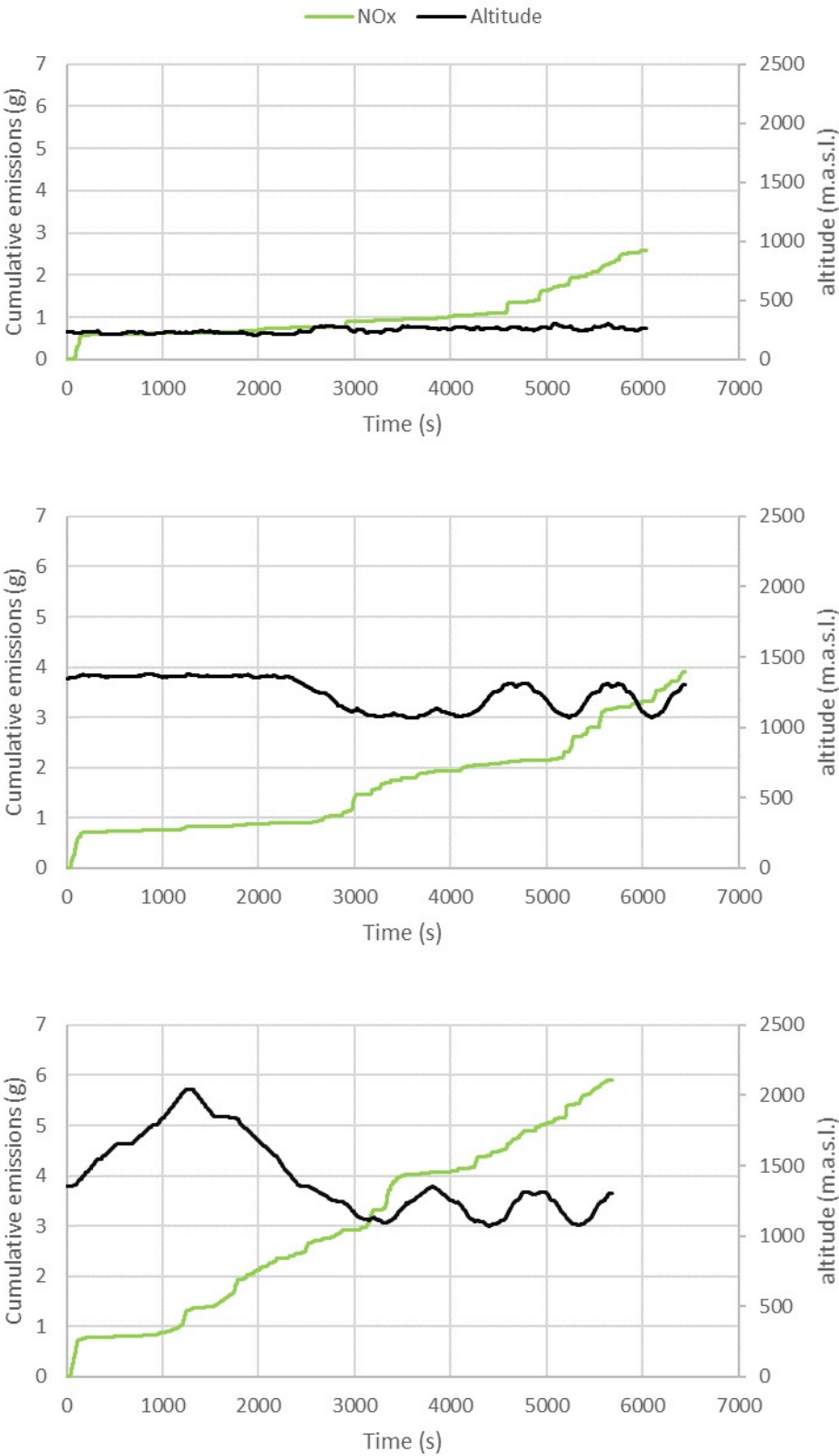


Figure S3. GV's cumulative emissions of CO (grey line) and NOx (green line) during RDE1 (top panel), Alpine1 (center panel) and Alpine2 (extra) (bottom panel).

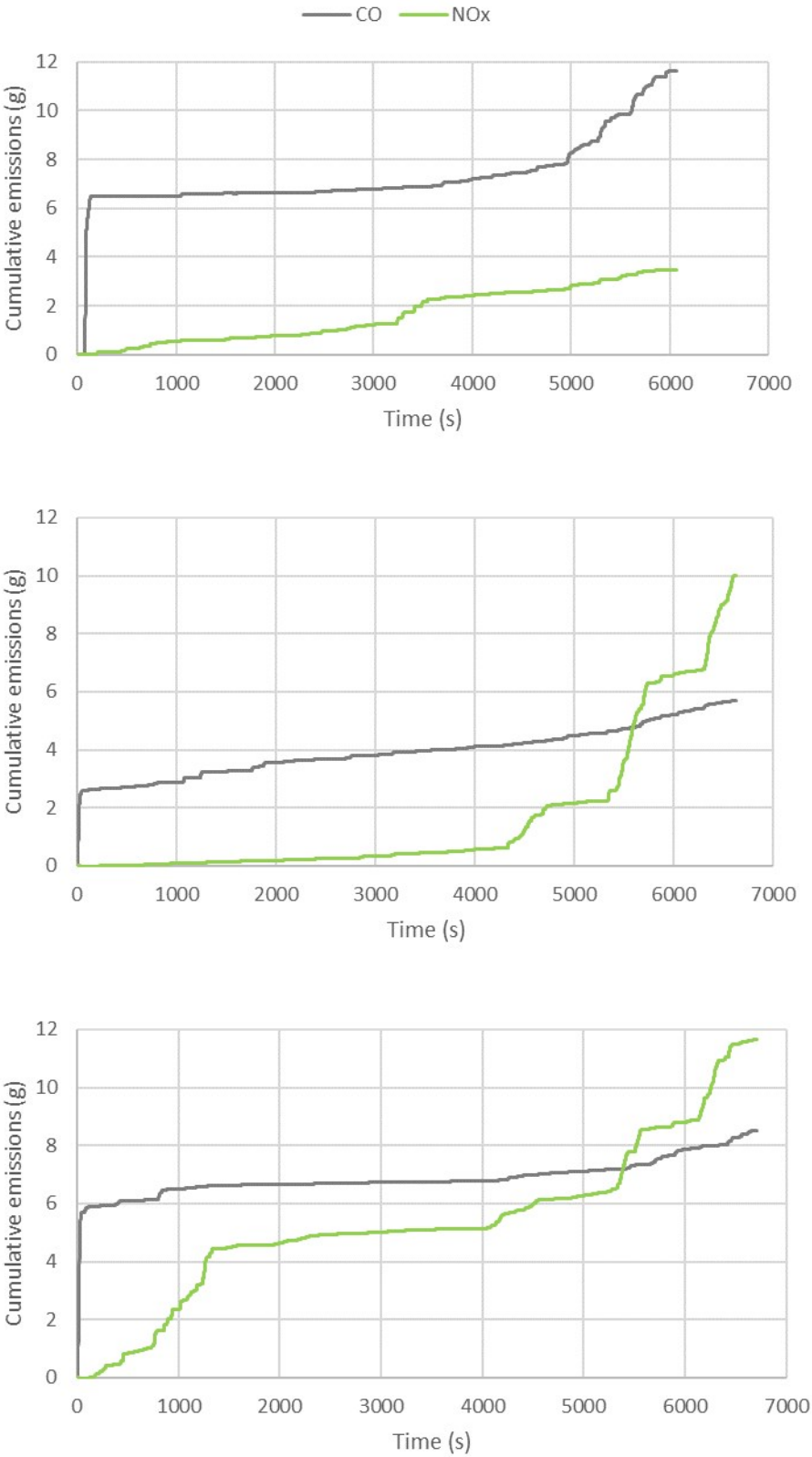


Figure S4. GV's lambda sensor reading during (top panel) RDE1, (center panel) Alpine1 and (bottom panel) Alpine2 (extra). Values of 1.0 indicate stoichiometric combustion condition. Numbers above 1.0 indicate a lean condition while numbers below 1.0 indicate fuel-rich mixture.

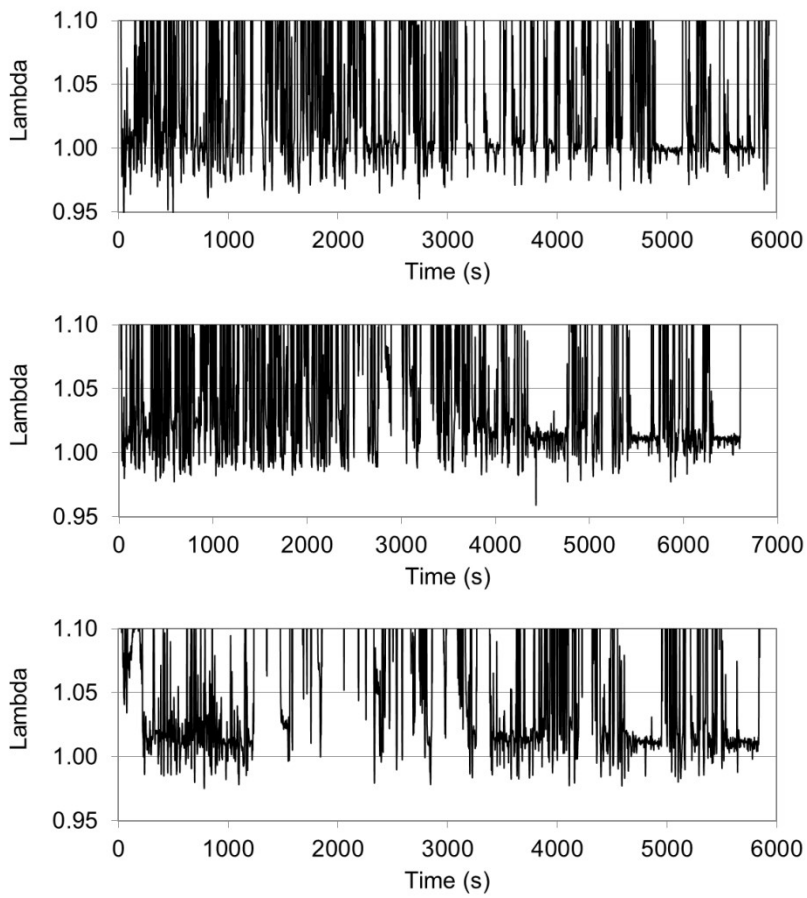


Figure S5. Vehicle PHEV emission rates of CO, NOx and PN during the Alpine routes (left panel Alpine1; right panel Alpine2 (extra)).

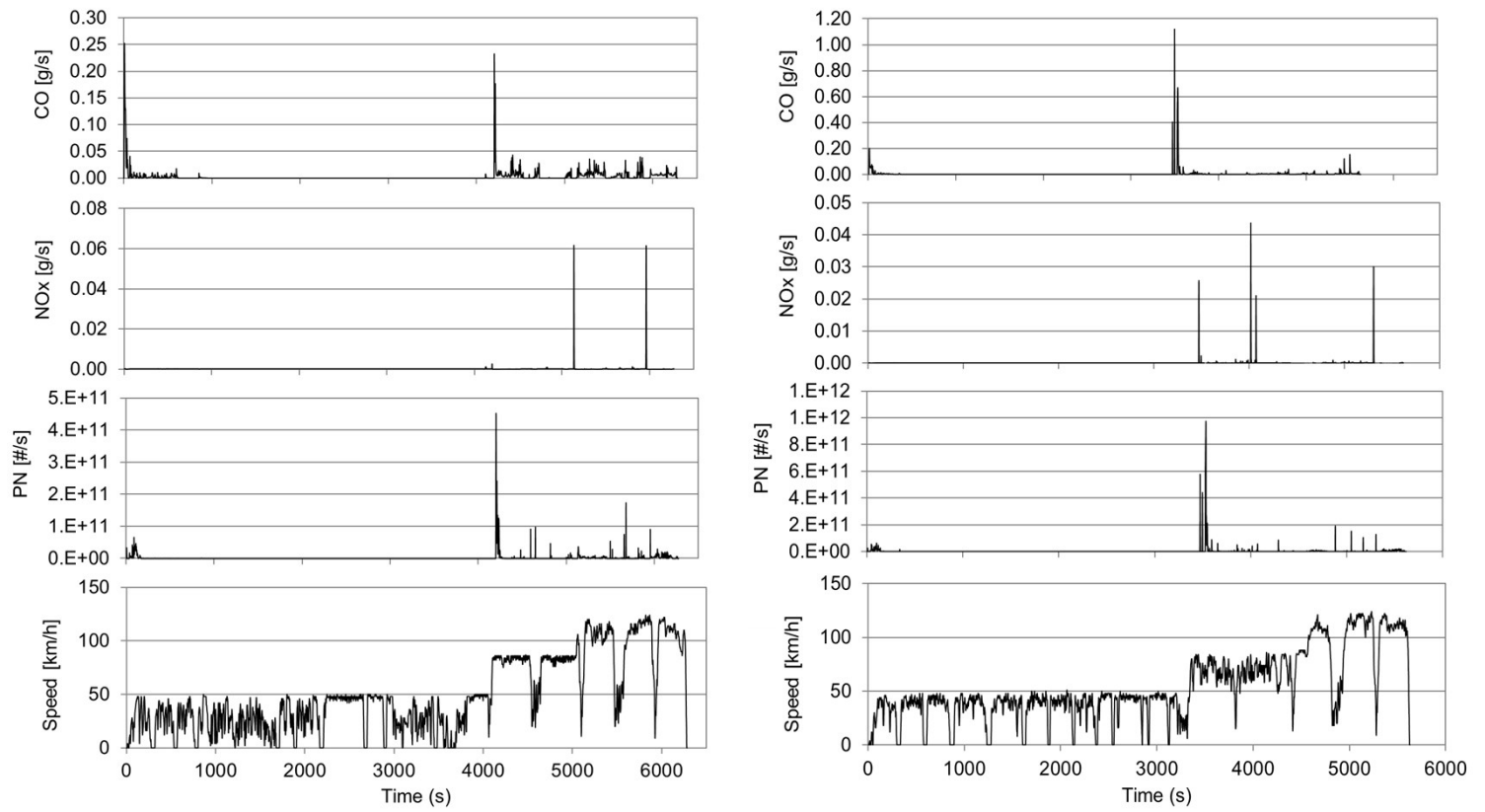


Table S1. Number of tests repeats by route, cycle and vehicle. Tests with GV and DV were always performed with air conditioning/heating system turned ON.

	GV DV		PHEV			
			SOC 100%	SOC 100%	SOC-min.	SOC-min.
			Heat-ON	Heat-OFF	Heat-ON	Heat-OFF
RDE1	1	1	1	1	1	-
RDE2	1	1	-	-	-	-
Alpine1	2	2	1	1	1	1
Alpine2 (extra)	2	2	1	1	1	1
WLTP	2	2	-	1	-	1
WLTP low-T	2	2	-	1	-	1

Table S2. Emission factors of NO_x (mg/km), CO (mg/km), PN (#/km), CO₂ (g/km), distance (km) and temperature (°C) for the complete test, the urban section and the cold start during: the RDE (average emission factors of RDE1 and RDE2 routes), the Alpine routes: Alpine1 and Alpine2 (extra), and the WLTP at 23°C (WLTP) and -7°C (WLTP low-T) for the DV, the GV and the PHEV. The PHEV's emission factors correspond to tests with 100% battery SOC. PHEV cold start emissions during WLTP tests took place during the extra-high phase. Error refers to standard deviation of the two tests performed.

DV Complete test						DV Urban section					DV Cold start				
	WLTP	WLTP low-T	RDE	Alpine1	Alpine2 (extra)	WLTP	WLTP low-T	RDE	Alpine1	Alpine2 (extra)	WLTP	WLTP low-T	RDE	Alpine1	Alpine2 (extra)
NO _x	65±2	233±19	51±29	72±1	113±4	271±20	1157±111	67±45	99±18	169±14	364±47	1226±94	323±15	509±187	306±14
PN×10 ¹¹	0.7±0.2	1.0±0.4	1.3±0.9	2.0±0	1.3±0.1	0.8±0.4	1.0±0.1	1.3±0.9	1.9±0	1.2±0.5	0.9±0.5	1.3±0.1	1.3±0.3	2.4±0.8	3±2
CO	43±7	318±61	41±41	83±38	149±39	259±85	1428±630	74±74	136±91	255±39	381±122	1420±338	497±304	789±334	373±55
CO ₂	125±5	150±8	134±0	134±1	143±2	143±7	205±27	136±11	129±3	138±4	148±4	199±23	225±38	243±4	371±4
Dist.	23.3	23.3	87±11	87	86	3.1	3.1	36±0	36	36	2.0	2.0	1.9±0.5	1.8±0.1	2.4±0.3
T (°C)	23	-7	24	-5	-7	23	-7	23	-5	-7	23	-7	23	-5	-7

GV Complete test						GV Urban section					GV Cold start				
	WLTP	WLTP low-T	RDE	Alpine1	Alpine2 (extra)	WLTP	WLTP low-T	RDE	Alpine1	Alpine2 (extra)	WLTP	WLTP low-T	RDE	Alpine1	Alpine2 (extra)
NO _x	36±1	69±22	37±10	176±9	178±56	97±16	65±1	52±8	44±10	170±82	145±24	74±6	61±9	13±3	140±24
PN×10 ¹¹	8.5±0.2	32±1	7.1±0.2	7±4	14±12	40±3	166±9	14.3±0.2	11±4	23±16	57±3	239±15	96±12	65±8	110±36
CO	149±15	659±96	136±15	135±44	155±6	800±128	3395±267	176±86	261±93	265±40	1194±174	5083±388	1909±1399	2119±1054	1687±605
CO ₂	126±0	141±1	149±0	149±1	152±5	145±4	195±4	163±10	166±3	158±9	146±4	196±5	200±5	244±2	322±12
Dist.	23.3	23.3	87±11	88	85	3.1	3.1	33±0	35	36	2.0	2.0	2.3±0.1	2±0	2.7±0.1
T (°C)	23	-7	8	-5	-8	23	-7	7	-5	-6	23	-7	13	-5	-6

PHEV Complete test						PHEV Urban section					PHEV Cold start				
	WLTP	WLTP low-T	RDE	Alpine1	Alpine2 (extra)	WLTP	WLTP low-T	RDE	Alpine1	Alpine2 (extra)	WLTP	WLTP low-T	RDE	Alpine1	Alpine2 (extra)
NO _x	3	3	7	6	4	-	-	1	0	0	10	12	4	0	0
PN×10 ¹¹	13	64	13.0	2.3	3.6	-	-	3.1	1.0	1.2	70.0	362.3	48.1	10.6	9.5
CO	56	1484	253	337	433	-	-	26	238	168	1040	5872	1077	2716	1856
CO ₂	56	75	119	139	130	-	-	15	47	46	66	145	191	365	471
Dist.	23.3	23.3	80	87	87	-	-	32	36	42	7.3	7.4	3.5	1.9	2.3
T (°C)	23	-7	8	-4	-1	-	-	8	-4	-1	23	-7	17	-4	-1

Table S3. Emission factors of NO_x (mg/km), CO (mg/km), PN (#/km), CO₂ (g/km), for the complete on-road tests and their sections (urban, rural and motorway (MW)) for DV, GV and PHEV. The emission factors of PHEV correspond to tests with 100% battery SOC. Error refers to hemi-dispersion of the two performed tests. In brackets the highest emission factor if standard deviation was higher than the average.

	DV RDE				DV Alpine1				DV Alpine2 (extra)			
	Comp.	Urban	Rural	MW	Comp.	Urban	Rural	MW	Comp.	Urban	Rural	MW.
NO_x	51±29	67±45	28±3	50±30	72±1	99±18	30±0	71±0	113±4	169±14	65±11	78±21
PN ×10¹¹	1.3±0.9	1.3±0.9	2±1	1.2±0.9	2.0±0	1.9±0	2.3±0	1.9±0	1.3±0.1	1.2±0.5	1.6±0.7	1.3±0
CO	41±41	74±74	21±21	15±15	83±438	136±91	52±0	39±0	149±39	255±39	72±30	68±43
CO₂	134±0	136±11	115±3	145±13	134±1	129±3	117±0	157±0	143±2	138±4	124±10	168±1
	GV RDE				GV Alpine1				GV Alpine2 (extra)			
	Comp.	Urban	Rural	MW	Comp.	Urban	Rural	MW	Comp.	Urban	Rural	MW
NO_x	37±10	52±8	37±8	17±12	176±9	44±10	138±22	367±69	178±56	170±82	91±21	290±71
PN ×10¹¹	7.1±0.2	14.3±0.2	2.6±0.8	2.3±0.7	6.6±4	11±4	3 [6]	4 [6]	14±12	23±16	6 [12]	9 [17]
CO	136±15	176±86	58±17	159±42	135±44	261±93	40±2	57±12	155±6	265±40	64±10	73±46
CO₂	149±0	163±10	115±0	165±9	150±2	166±3	110±5	163±6	152±5	158±9	131±8	167±2
	PHEV RDE				PHEV Alpine1				PHEV Alpine2 (extra)			
	Comp.	Urban	Rural	MW	Comp.	Urban	Rural	MW	Comp.	Urban	Rural	MW
NO_x	7	1	7	15	6	0	11	9	4	0	18	0
PN ×10¹¹	13.0	3.1	7.3	32.4	2.3	1.0	4.5	2.3	3.6	1.2	9.7	1.8
CO	253	26	231	585	337	238	392	416	433	168	989	343
CO₂	119	15	118	263	139	47	140	249	130	46	134	246

Table S4. Emission factors of PHEV for NO_x (mg/km), CO (mg/km), PN (#/km), CO₂ (g/km), corresponding to the complete on-road tests and their sections (urban, rural and motorway (MW)) during the Alpine1 and Alpine2 (extra) tests. All tests were performed with the PHEV at depleted battery (SOC-min.) and 100% battery SOC and with the air conditioning heating system enabled (Heat-ON) and disabled (Heat-OFF). Coolant temperature ranged between 4°C and 8°C.

Alpine1 –Heat-ON –SOC-min.					*Alpine1 – Heat -OFF –SOC-min.			
	Comp.	Urban	Rural	MW	Comp.	Urban	Rural	MW
CO	267	122	302	418	318	285	433	275
CO ₂	191	163	162	247	162	123	143	224
NO _x	3	5	11	0	21	30	5	22
PN ×10 ¹¹	13	7.5	2.1	28	9.4	14.5	2.1	8.7

Alpine1 – Heat-ON –SOC 100%					Alpine1 – Heat-OFF –SOC 100%			
	Comp.	Urban	Rural	MW	Comp.	Urban	Rural	MW
CO	337	238	392	416	423	47	868	560
CO ₂	139	47	140	249	97	7	35	252
NO _x	6	0	11	9	0	0	0	0
PN ×10 ¹¹	2.3	1.0	4.5	2.3	13	1.0	27	17

Alpine2 (extra) – Heat-ON –SOC-min.					Alpine2 (extra) – Heat-OFF –SOC-min.			
	Comp.	Urban	Rural	MW	Comp.	Urban	Rural	MW
CO	713	445	447	1350	766	509	264	1573
CO ₂	201	188	171	247	193	182	139	258
NO _x	5	2	10	5	0	0	0	0
PN ×10 ¹¹	1.3	1.3	1.6	1.0	2.9	4.1	1.9	2.1

Alpine2 (extra) – Heat-ON –SOC 100%					Alpine2 (extra) – Heat-OFF –SOC 100%			
	Comp.	Urban	Rural	MW	Comp.	Urban	Rural	MW
CO	433	168	989	343	1343	653	3101	742
CO ₂	130	46	134	246	102	21	64	244
NO _x	4	0	18	0	0	0	0	0
PN ×10 ¹¹	3.6	1.2	9.7	1.8	7.1	5.9	15	2.1

* Emissions factors for the test Alpine1 – Heat -OFF –SOC 0% were calculated by correcting a shift on the exhaust flow rate multiplying it by a 3.7 factor. Therefore, the values should be taken as indicative and not absolute.

Table S5. Emissions factors of NO_x (mg/km), CO (mg/km), PN (#/km), CO₂ (g/km) from the vehicle PHEV, for the complete on-road tests and their sections (urban, rural and motorway (MW)) during the RDE compliant tests performed with the PHEV 100% battery SOC at depleted battery (SOC-min.) on the RDE1 route.

RDE –Heat-ON –SOC 100%					RDE – Heat -OFF –SOC 100%			
	Comp.	Urban	Rural	MW	Comp.	Urban	Rural	MW
CO	253	26	231	585	293	57	253	661
CO ₂	119	15	118	263	94	8	40	273
NO _x	7	1	7	15	5	0	1	14
PN ×10 ¹¹	13.0	3.1	7.3	32.4	9.8	0.9	12.4	19.3

RDE – Heat-ON –SOC-min.				
	Comp.	Urban	Rural	MW
CO	188	75	92	441
CO ₂	185	169	157	238
NO _x	4	5	3	5
PN ×10 ¹¹	9.3	5.5	3.4	20.7