

Supplementary Material: The Role of Belgian Airborne Sniffer Measurements in the MARPOL Annex VI Enforcement Chain

Ward Van Roy ^{1,*}, Jean-Baptiste Merveille ¹, Kobe Scheldeman ¹, Annelore Van Nieuwenhove ¹, Benjamin Van Roozendaal ¹, Ronny Schallier ¹ and Frank Maes ²

¹ Royal Belgian Institute of Natural Sciences, 1000 Brussels, Belgium

² Faculty of Law & Criminology, University Ghent, 9000 Ghent, Belgium

* Correspondence: wvanroy@naturalsciences.be

1. Additional figures

2. Additional tables

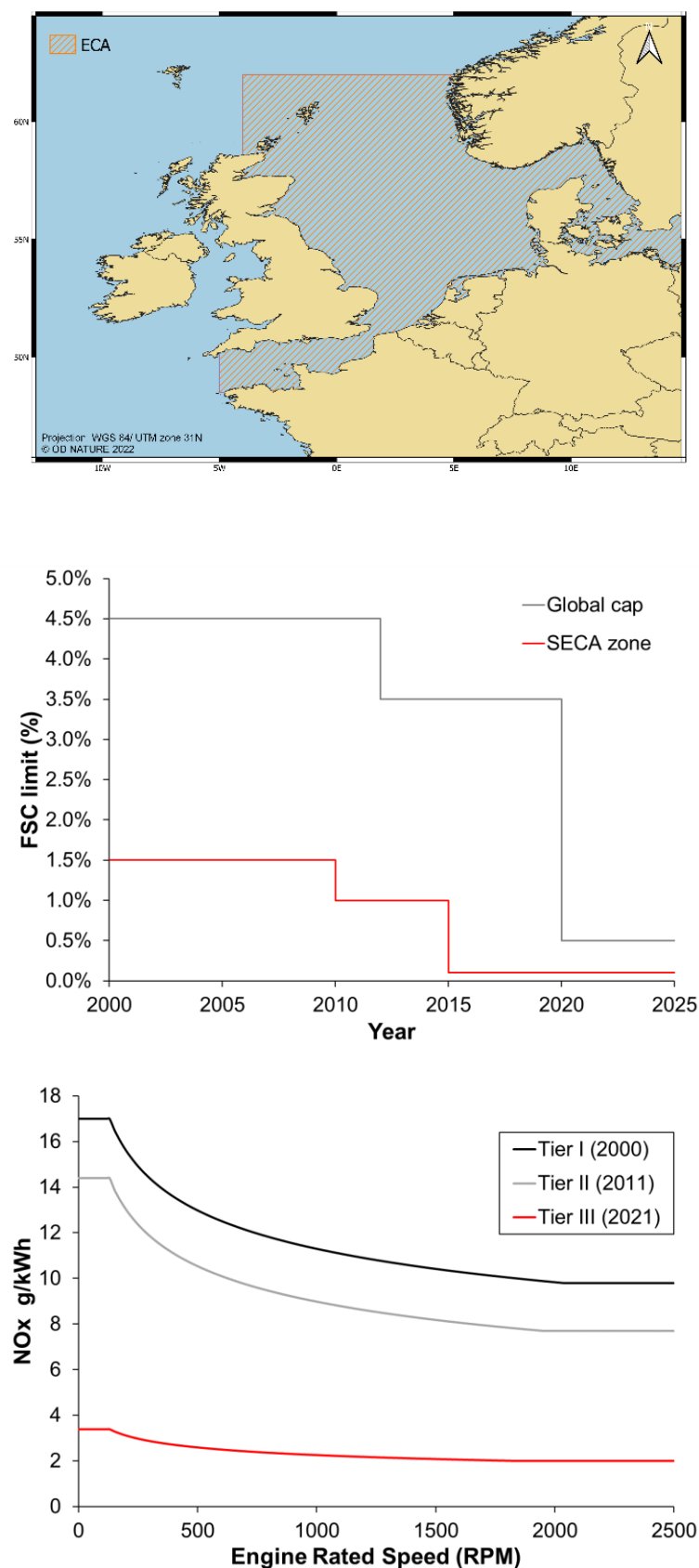


Figure S1. Emission Control Area (ECA) as defined by MARPOL Annex VI (**Upper**). Limits on the Fuel Sulfur Content of marine fuels according to the MARPOL Annex VI regulation 14 (**Middle**). NOx emission limits according to MARPOL Annex VI Regulation 13 (**Lower**).

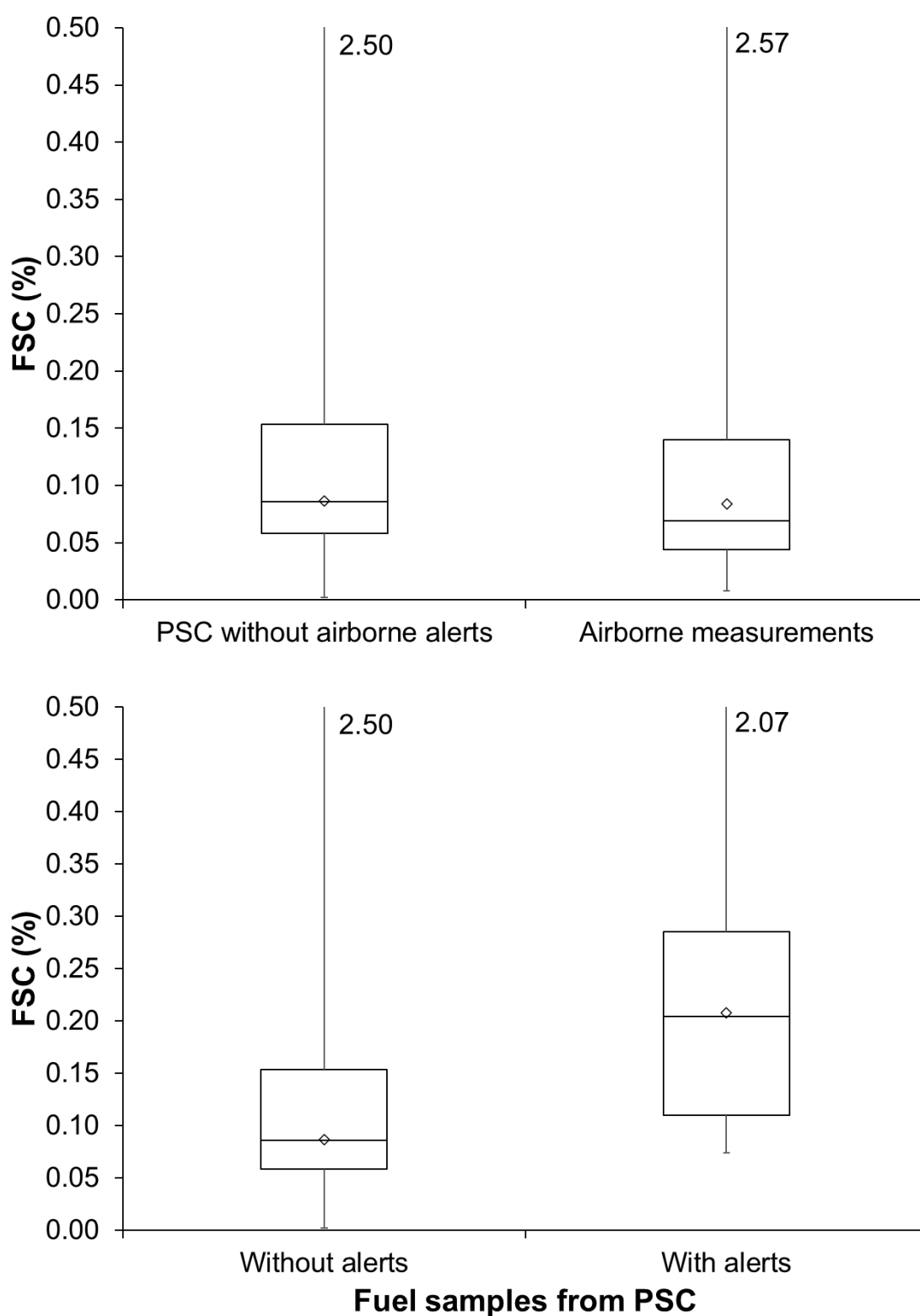


Figure S2. Boxplot comparison of results of fuel samples executed without airborne alerts and the results of the airborne measurements, with minimum, maximum median, average (♦), 25 and 75 percentiles (**Upper**). Comparison of results of fuel sample analysis executed by Belgian port inspection authorities initiated without and with the use of airborne alerts (**Lower**).

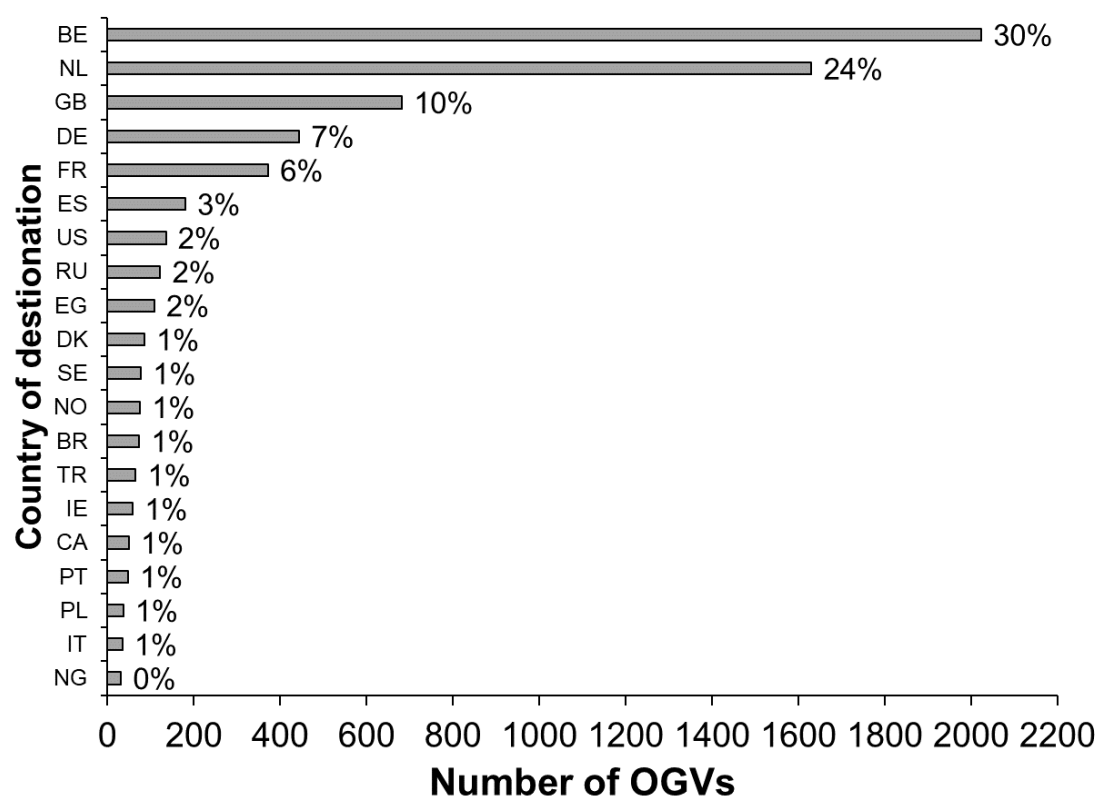
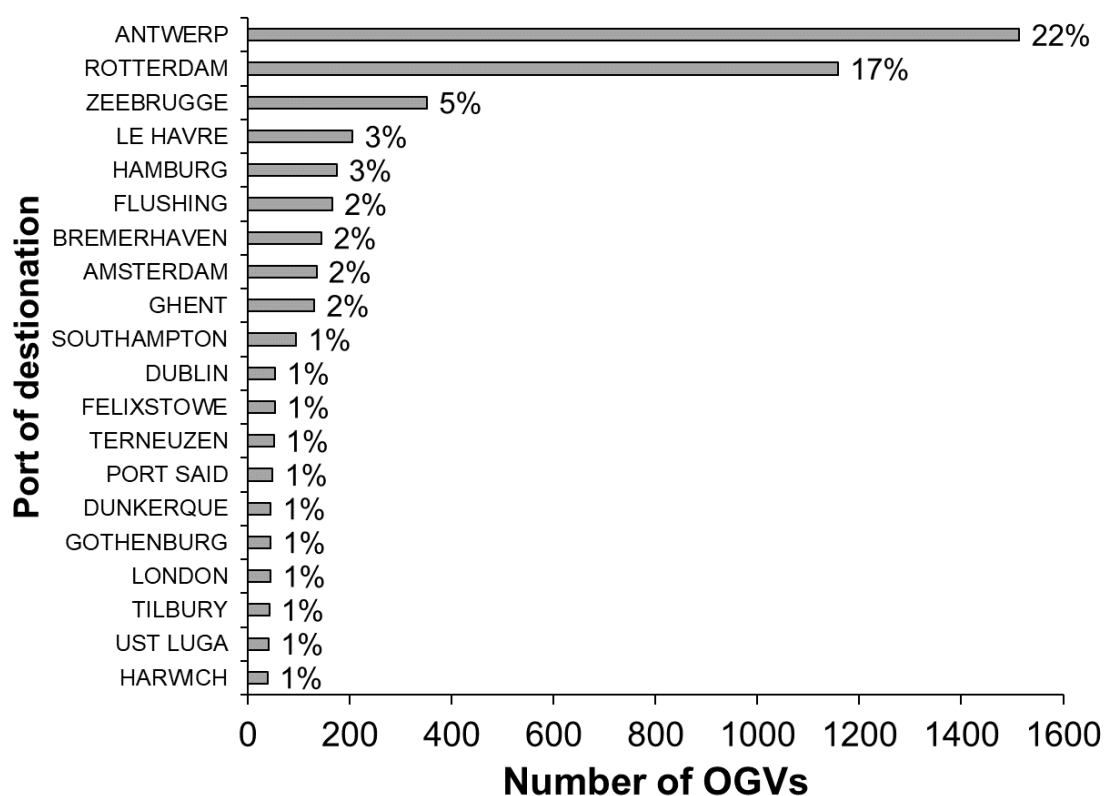


Figure S3. Number OGVs and relative amount of 20 most observed ports of destination (**Upper**) and country of destination (**Lower**).

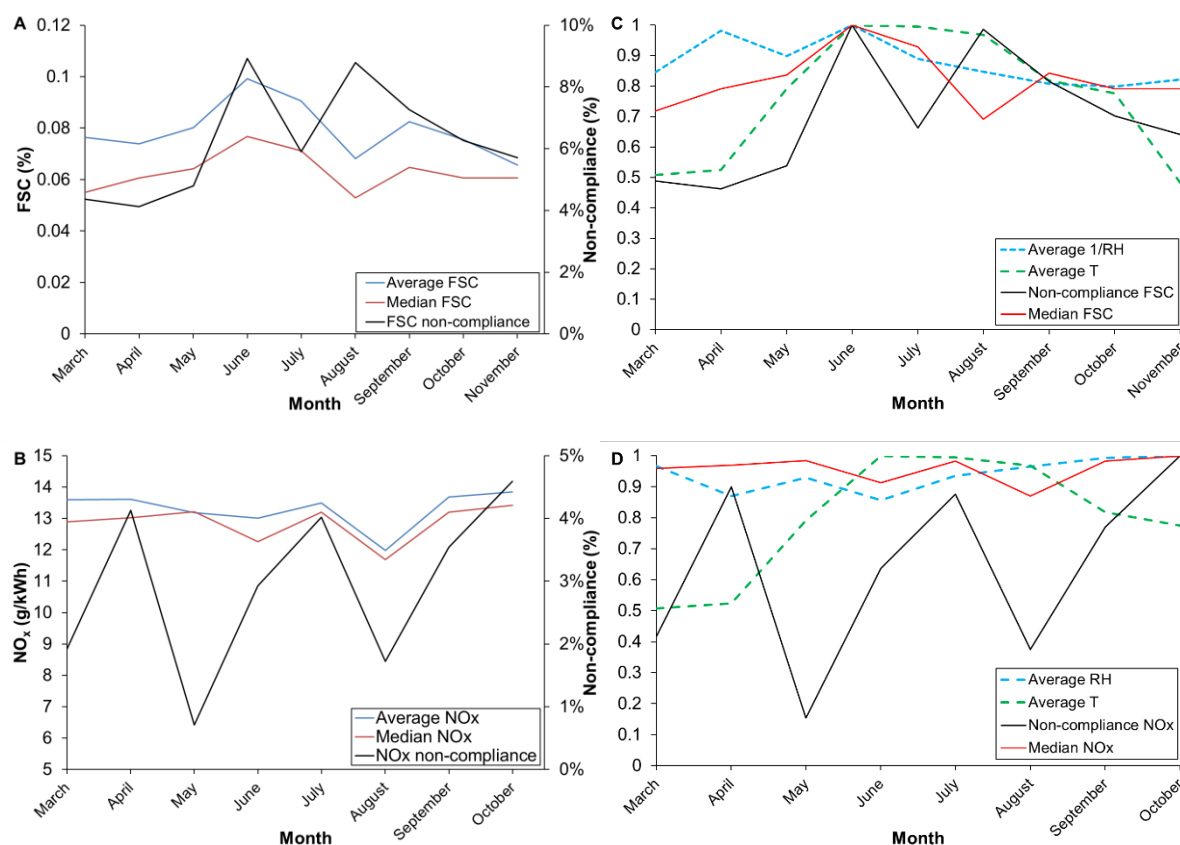


Figure S4. Monthly average, median and non-compliance values for FSC (A) and NO_x (B). Normalized values for median and non-compliance for FSC (C) and NO_x (D) compared to the normalized monthly values for *T* and *RH*. The months January, February and December were not included for FSC and additionally the month of November was not included for NO_x due to the low amount of measurements for these months.

Table S1. Emission ratios for EGCS systems (MEPC, 2015).

Fuel oil sulfur content (% m/m)	Ratio emission SO ₂ (ppm)/CO ₂ (% v/v)
4.5	195
3.5	151.7
1.5	65
1	43.3
0.5	21.7
0.1	4.3

Table S2. Test cycles and weighting factors according to the NO_x Technical code (MEPC, 2008b).

	Speed	100%	100%	100%	100%
E2	Power	100%	75%	50%	25%
	WF	0.2	0.5	0.15	0.15
	Speed	100%	91%	80%	63%
E3	Power	100%	75%	50%	25%
	WF	0.2	0.5	0.15	0.15

Table S3. R^2 values for the linear regression between the monthly values for: average FSC, median FSC, FSC non-compliance, average NO_x, median NO_x, NO_x non-compliance, relative humidity (RH) and temperature (T).

R ²	RH	T	Average NO _x	Median NO _x	FSC non- compliance	NO _x non- compliance	Average FSC	Median FSC
Average FSC	0.28	0.38	0.03	0.05	0.10	0.03	-	-
Median FSC	0.29	0.26	0.01	0.03	0.08	0.08	-	-
FSC non-compliance	0.00	0.55	0.37	0.45	-	0.00	0.10	0.08
Average NO _x	0.02	0.20	-	-	0.37	0.32	0.03	0.05
Median NO _x	0.06	0.08	-	-	0.45	0.17	0.01	0.03
NO _x non-compliance	0.00	0.00	0.32	0.17	0.00	-	0.03	0.08

Table S4. Cost breakdown of the Belgian Sniffer program 2016–2022.

Cost Category	Year							
	2016	2017	2018	2019	2020	2021	2022	Total
Instrumentation								
Sensor and installation	€ 233,010.00	€ 1,624.00	€ -	€ 63,479.49	€ 23,587.77	€ 51,263.64	€ 15,542.19	€ 388,507.09
Calibration and gases	€ 9,509.97	€ 4,651.87	€ 7,829.61	€ 9,913.42	€ 6,966.36	€ 12,676.03	€ 9,800.25	€ 61,347.51
General Equipment	€ 2,614.76	€ -	€ 639.83	€ 1,809.47	€ 1,167.47	€ -	€ 744.93	€ 6,976.46
Software	€ 23,000.00	€ -	€ -	€ 501.83	€ -	€ -	€ 1,689.16	€ 25,190.99
Hardware	€ 20,790.04	€ 1,007.65	€ 561.74	€ 717.35	€ -	€ 6,795.52	€ 162.87	€ 30,035.17
Total Instrumentation cost	€ 288,924.77	€ 7,283.52	€ 9,031.18	€ 76,421.56	€ 31,721.60	€ 70,735.19	€ 27,939.40	€ 512,057.22
Platform								
Fuel for sniffer Flight Hours (FH)	€ 31,219.67	€ 17,167.05	€ 20,301.17	€ 68,753.38	€ 7,751.34	€ 23,005.80	€ 28,771.99	€ 196,970.40
Regular Maintenance	€ 98,915.52	€ 99,792.92	€ 78,709.51	€ 89,076.17	€ 78,210.00	€ 74,301.00	€ 87,656.54	€ 179,233.85
Part Regular Maintenance for sniffer FH	€ 39,199.93	€ 27,497.48	€ 23,774.49	€ 27,221.00	€ 12,583.22	€ 23,147.09	€ 25,810.64	
Major Maintenance (unit cost per flight hour)								
Engine overhaul (2800 EH)		€ 48.70						
Propeller overhaul (2800 EH)					€ 3.93			
Repaint (2800 EH)		€ 15.04						
500 (EH) maintenance	€ 56.61			€ 30.61				
1000 (EH) maintenance			€ 27.25			€ 33.62		
Other unscheduled major parts (2800 EH)		€ 4.97	€ 14.53		€ 9.73		€ 7.04	
Part Major Maintenance for sniffer FH	€ 7,693.62	€ 5,496.73	€ 3,687.30	€ 2,941.12	€ 502.20	€ 3,323.24	€ 638.26	€ 24,282.47
Total Platform cost	€ 78,113.22	€ 50,161.25	€ 47,762.96	€ 98,915.50	€ 20,836.76	€ 49,476.14	€ 55,220.89	€ 400,486.72
Labour								
Operator cost for sniffer FH	€ 10,552.95	€ 5,356.83	€ 7,096.89	€ 7,627.37	€ 2,219.92	€ 8,739.20	€ 8,197.59	€ 49,790.76
Part Mission cost for sniffer FH	€ 1,641.67	€ 979.87	€ 1,080.92	€ 1,215.30	€ 475.24	€ 1,278.08	€ 1,338.40	€ 8,009.48
Pilot cost for sniffer FH	€ 1,090.34	€ 1,403.61	€ 2,253.68	€ 2,305.11	€ 725.62	€ 1,783.25	€ 1,942.41	€ 11,504.02

Total Labour cost	€ 13,284.95	€ 7,740.32	€ 10,431.49	€ 11,147.78	€ 3,420.78	€ 11,800.53	€ 11,478.41	€ 69,304.26
Total	€ 380,322.94	€ 65,185.09	€ 67,225.63	€ 186,484.84	€ 55,979.14	€ 132,011.86	€ 94,638.70	€ 981,848.20
Total/flight hour	€ 2,798.21	€ 814.81	€ 761.76	€ 1,940.87	€ 1,523.24	€ 1,335.70	€ 1,043.81	€ 1,567.20
Number of measurements	1219	887	1138	1232	405	1015	965	6975
Total/measurement	€ 312.00	€ 73.49	€ 59.07	€ 151.37	€ 138.22	€ 130.06	€ 98.07	€ 140.77