2. Methodologies

This paper is composed by two parts, the first related to the bottom-up estimation of shipping impacts in the area of the Channel of Procida and the second related to the experimental evaluation of the ships's contribution to the air quality.

2.1 Bottom-up calculations

This approach determines the effects of ships emissions in the area by defining: i) representative emission factors for the different kind of particulate matter; ii) data on average marine traffic in the area and iii) average climate conditions during winter and summer seasons.

The model starts from the estimation of particles emissions in marine diesel engines fueled with different kind of fuels as shown in several recent papers [17,18,26–33].

The authors [28–30] reported data for several engine loads, but we referred only to the values at the emission factors used in this study were reported in **Table 1** for two reference loads of 25% and 75% ($EF_{25\%}$ and $EF_{75\%}$ in the following), representing maneuvering and full-load typical operations. Ntziachristos et al. [28], compared the emissions of particulate matter for a four-stroke, four cylinder medium speed diesel engine with a bore x stroke of 320 mm x 350 mm at constant speed of 750 rpm and a brake nominal power of 1640 kW fueled with a Nest HFO 420 low Sulphur grade (1%wt) fuel and a Shell Thermocity distillate oil (conforming to EN 590:2009 specifications) containing 0.0008%wt of Sulphur, indicated as LFO in the following. The authors reported particle size distribution under different testing conditions and allowed finding that the use of a porous tube diluter operated at 12:1 dilution ratio and an ageing chamber provided the sampling conditions that better represent the characteristics of the ships' atmospheric plumes. The same engine was used by Ristimaki et al [29] with a <0.05%wt S LFO and to HFOs (0.89%wt S and 2.42%st S). Sippula et al. [30] reported data for a four-stroke single-cylinder direct injected diesel engine with a nominal speed of 1500 rpm and a bore x stroke of 150 mm x 180 mm, equipped with a common-rail system and an exhaust gas turbo-charger.

In particular, in this paper we reported reference data for distillate fuels from several experiments referring to modern laboratory engines with a good level of maintenance (also in terms of optimal quality of lube oil) and an optimal tuning [17,18,27–30]. These conditions are far better than those expected for this case study, due to the ships' age of construction and to the real navigation conditions.

As a comparison, we also reported data referring to two-strokes slow-speed marine diesel engines with two kinds of HFO fuels, which were mostly measured on real ship plumes and are more representative of the emissions of large vessels. Data were averaged for two classes of HFOs with different Sulphur levels: 0.5-1% [17,27–29,32] and 2.0-3-5% [16,17,27,29,33,35–37].

Table 1. Reference ships emission data used in this paper [16,17,33,35–37,18,26–32]

	N, 10^{15}/kWh	PM, mg/kWh	OC, mg/kWh	BC/EC, mg/kWh

LOAD	25%	75%	25%	75%	25%	75%	25%	75%
LFO,	1.1	1.3	225	120	110	66	43	15
HFO 1%	1.9	1.5	360	500	250	160	38	23
HFO 2-3.5%	4.5	1.7	1200	1100	380	315	80	30

The particle size distribution measured by Ntziachristos et al. [28] are shown in **Figures 1 and 2** as an example of four stroke marine diesel engine emissions fueled with LFO (Diesel fuel) and HFO 1%S fuels respectively. As a comparison, the size distribution of particles emitted by a HFO 2.8%S fuel as reported by Petzold et al. [34] at 25% and 85% load. As these last data show little effect of engine load increase from 50% and 85%, on particles emissions we have assumed that the 75% load case can be characterized by the 85% case.

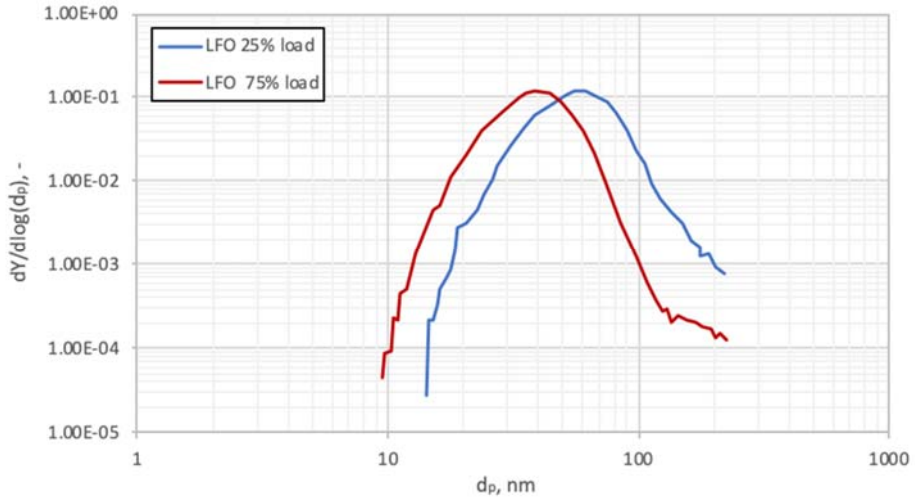

Figure 1. Normalized particle size distribution of LFO (DF) fuel in mid-speed marine diesel engine [28].

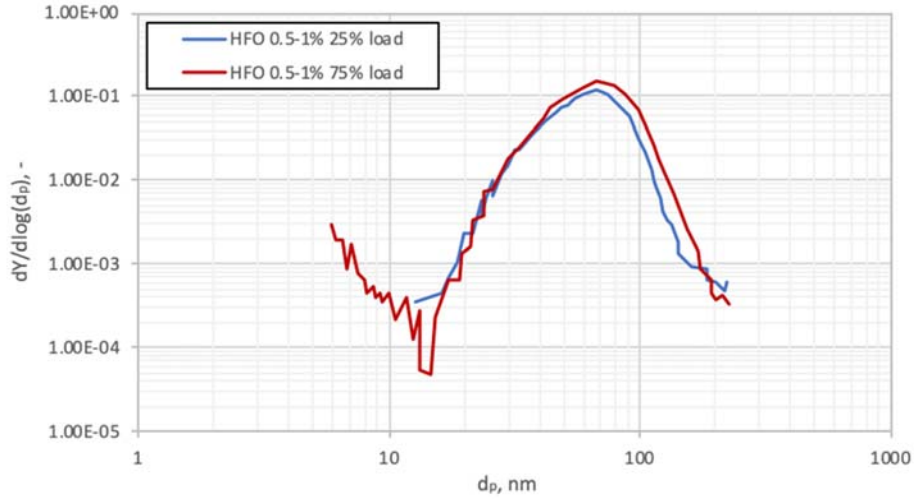

Figure 2. Normalized particle size distribution of 1%wt Sulphur HFO fuel in mid-speed marine diesel engine [28].

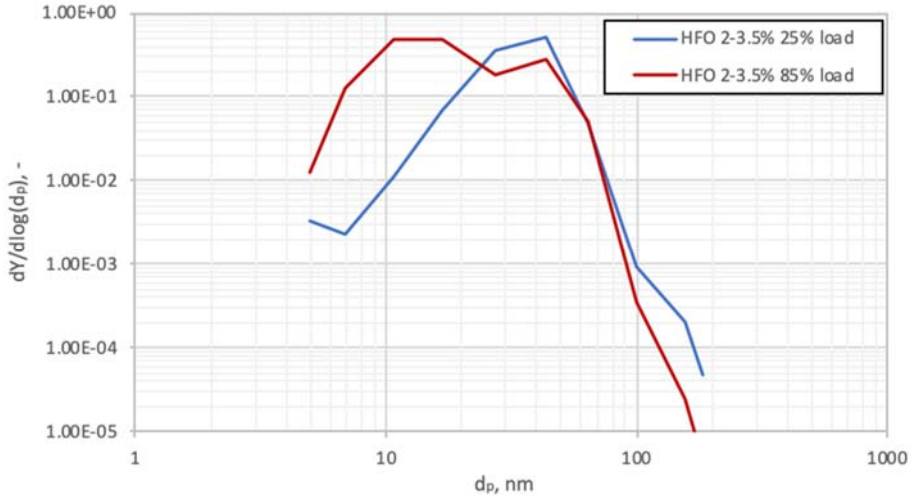

Figure 3. Normalized particle size distribution of HFO 2.21% S fuel in mid-speed marine diesel engine [34].

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