Calculation of CO_2 emissions from engines on board service vessels at the Moroccan port of Mohammedia

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Abstract. Service vessels are essential for ensuring the smooth functioning of port operations, yet their environmental footprint remains largely underestimated compared to larger commercial ships. The goal of this study is to measure the carbon dioxide (CO_2) emissions produced by service vessels, such as pilot boats and tugboats, in the port of Mohammedia, Morocco. Throughout 2024, information on fuel consumption and operational profiles was gathered from seven representative vessels. According to the analysis, two tugboats accounted for more than 65% of the 1,124 tonnes of CO_2 emissions from service vessels in 2024. Emissions peaked in January and averaged 93.5 tonnes per month. These results draw attention to a little-known source of greenhouse gas emissions in port regions and emphasise the necessity of mitigation measures like switching to alternative propulsion technologies and optimising operations. This study backs Morocco's pledge to cut greenhouse gas emissions and encourage environmentally friendly coastal growth.

Keywords: Service vessels; Carbon dioxide emissions; Greenhouse gases; Energy efficiency; Maritime sustainability; Fuel consumption

1 Introduction

Maritime transport, a key driver of global trade, is also a major source of greenhouse gas emissions, particularly CO_2. According to the International Maritime Organisation (IMO), the maritime sector accounted for approximately 2.89% of global anthropogenic CO_2 emissions in 2018 [1]. While commercial vessels such as container ships and oil tankers attract most of the attention, service vessels such as tugs also play a significant role, particularly in port operations. Their operational cycle, characterised by frequent manoeuvres at low speed and high instantaneous power, results in high energy consumption and emissions that are disproportionate to their size [2].

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Energy efficiency, defined as the ability to maximise operational performance while minimising fuel consumption and associated emissions, has become a crucial issue for the sustainability of maritime transport. Standardised tools such as the Energy Efficiency Design Index (EEDI) for new ships and the Energy Efficiency Existing Ship Index (EEXI) for existing ships, introduced by the IMO, aim to promote significant improvements in this area [3]. For example, the EEDI sets energy consumption thresholds based on ship size and type, thereby encouraging the adoption of more efficient technologies and designs [4]. For its part, the EEXI extends this approach to ships already in service, requiring operators to consider technical or operational modifications to comply with the requirements.

Chen et al. used a machine learning approach to predict emissions from harbour vessels [5]. Jinggai et al. compared multiple bibliographic studies in different port areas to investigate GHG reduction through shore power [6]. In a Mediterranean port, González examined the emissions of SO_x, CO_2, PM, and NO_x from auxiliary vessels [7].

In the Moroccan context, the port of Mohammedia, the country's main energy hub, is characterised by intense towing activity, particularly for oil tankers [8]. However, the emissions generated by these operations remain poorly studied.

The objective of this study is, on the one hand, to quantify the CO2 emissions of service vessels operating in the port of Mohammedia through a comparative approach and, on the other hand, to propose concrete solutions to improve their energy efficiency. By combining standardised IMO methodologies with empirical analyses based on local data, this research aims to contribute to the reduction of port CO2 emissions while aligning local activities with global climate commitments.

2 Methodology

2.1. Study area

The port of Mohammedia is located on the Atlantic coast at 7°24' west longitude and 33°43' north latitude, 23 km from the port of Casablanca. Situated in the southern part of Mohammedia Bay, it is naturally protected from swells.

It consists of:

- An old basin for all liquid bulk cargo other than hydrocarbons (oils, molasses, etc.). This basin can accommodate ships up to 120 metres long and with a maximum tonnage of 8,000 tonnes. This old basin also houses a fishing port and a marina;
- An oil terminal equipped with two berths with a depth of 18 metres, enabling it to accommodate large oil tankers and gas tankers.[9]

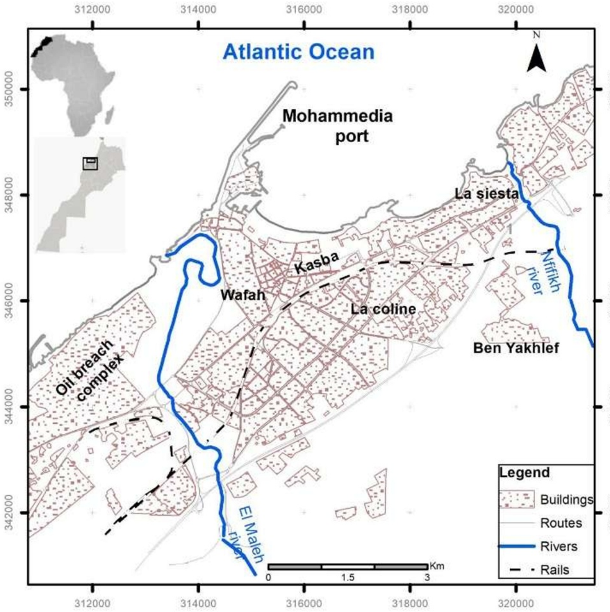

Fig. 1. Study area

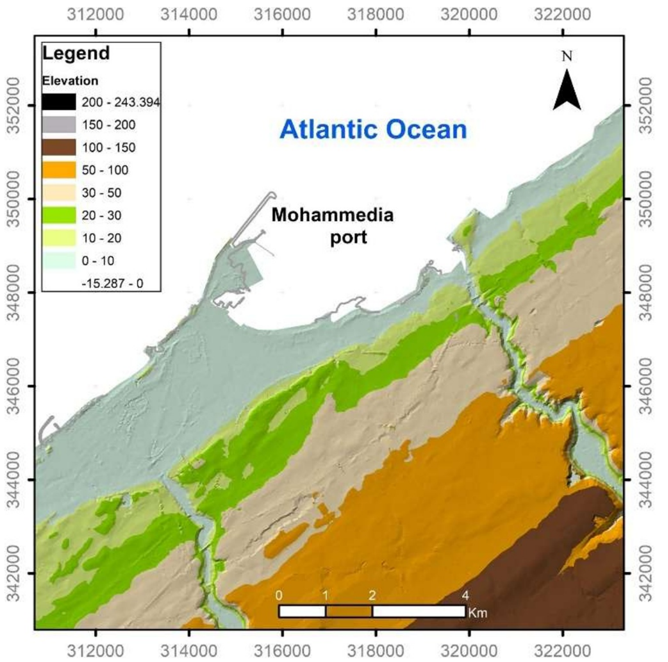

Fig. 2. Topographic map of the Mohammedia port area

History of Mohammedia port: the port of Mohammedia was built in 1913 by the Fedala Port Company. Originally a fishing port, it was transformed into an oil port with the establishment of Samir in Mohammedia in 1961.

In 1978, the port facilities were reduced to 290 linear metres of quays capable of receiving 6,000-tonne ships with a 53,000-metre pipeline network. At that time, crude oil was unloaded at sea using three sea lines:

The first was built in 1952 to accommodate 40,000 to 50,000-tonne oil tankers at the coast (18 m deep);

The second was built in 1971 to accommodate 60,000 to 100,000-tonne oil tankers at the coast (22 m deep);

The last was built in 1979 to serve 100,000-tonne oil tankers at the coast (25 m deep);

The port was extended following the expansion of Samir from 1980 to 1984; the oil terminal was built in 1987, with berths A and B covering 22 hectares of land and a 450-metre access breakwater to the terminal.[10]

Fig. 3. Mohammedia port [10]

2.2. Ship emission calculation

The bottom-up method was chosen for this analysis, it consists of calculating emissions based on detailed data specific to emission sources, then aggregating these calculations to obtain an overall estimate for the port.[11]

The first step is to collect activity data, which includes operating hours and the amount of fuel consumed by each of the seven units. Next, an emission factor is applied per unit of activity and expressed in kg CO_2 per litre of fuel consumed. For the fuel used by these maritime units, data from the EEDI 2018 guidelines (International Maritime Organisation, 2018) gives a CO_2 emission factor of 3.206 for marine MDO with a calorific value of 42.7 MJ/kg.[12]

CO_2 emissions are finally calculated by multiplying consumption in litres by the corresponding emission factor:

$$CO_2 \text{ emissions} = \text{Fuel consumption (L)} \times \text{Emission factor (kg } CO_2/L) \quad (1)$$

The estimated emissions for each maritime unit are added together to obtain the total emissions at the port of Mohammedia.

So, the MDO consumption is determined by obtaining the quantity of MDO consumed via: Bunker reports (quantity of fuel taken on board).
Flow meter data (continuous measurement).
Engine logs (hourly or daily consumption).

Knowing that MDO is a marine distillate similar to diesel, composed mainly of hydrocarbons (C_nH_{2n+2}). For simplicity, a representative average formula is used:

Carbon/hydrogen ratio: Approximately 1 carbon atom for every 2 hydrogen atoms (e.g., $C_{12}H_{26}$, a typical diesel hydrocarbon) with a carbon content of approximately 86.5% by mass, the rest is mainly hydrogen (H) and impurities (sulphur, etc) [13]. And knowing that complete combustion of carbon is expressed as:

$$C+O_2 \rightarrow CO_2 C+O_2 \rightarrow CO_2 \quad (2)$$

With : Molar mass of carbon (C) = 12 g/mol and Molar mass of CO_2 = 44 g/mol.

Applying this to the fuel used on board in our case (MDO), we obtain the CO_2 produced by the combustion of carbon by calculating the carbon emission factor.:

$$CO_2\,factor = Carbon\ content\ x\ (\frac{Molar\ mass\ of\ CO2}{Molar\ mass\ of\ C}) = 0{,}865\ x\ 3{,}67 \approx 3{,}170\ t\ CO_2/t\ MDO \quad (3)$$

This result is close to the official factor used in our study and officially adopted by the IMO, as it is a slightly adjusted value to take into account impurities and variations in composition. This factor, standardised by the IMO at 3.206 t CO_2/t MDO for maritime calculations, assumes that the lower heating value (LHV) is approximately equal to 42.7 MJ/kg for MDO and that the combustion efficiency is nearly 99% (complete combustion with minimal losses).[12]

3 Results and discussion

The data collected from the vessels is extracted from bunker reports (quantity of fuel on board), flow meter data (continuous measurement), and engine logs (hourly or daily consumption). It provides the results shown in Table 1 and Figure 4.

Table 1. CO_2 emissions in kg of the seven service vessels operating in Mohammedia port.

		MONTH											
		1	2	3	4	5	6	7	8	9	10	11	12
VESSEL	1	4652	4065	4924	4712	3461	4472	5416	5995	4671	7419	3943	5846
	2	2821	545	2405	1539	641	1609	641	321	1443	802	1282	962
	3	641	1443	2307	1218	1443	2885	1443	2437	1763	3492	3251	2084
	4	14328	10295	10069	11862	8650	5771	18760	15666	12372	21160	9941	10900
	5	14748	19877	8336	11542	8336	7374	13786	13468	14427	14427	12443	5450
	6	50947	21160	41317	31713	28854	29754	43281	38130	44611	45381	29319	26930
	7	49278	18346	43602	35330	27994	31056	7389	—	—	22225	31972	32549

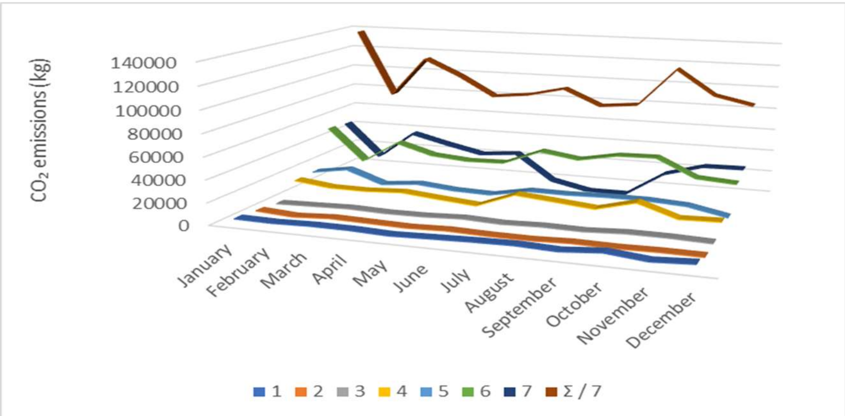

Fig. 4. Service vessels monthly CO_2 emissions in kg for Mohammedia port in 2024.

The monthly variation of ships CO_2 emissions from each vessel for Mohammedia port in 2024 is given in Fig. 4. It can be observed that significant differences existed among the ship emissions of the 12 months. The month with top emissions was January, with CO_2 emissions of 137,41 tonnes, ~1.8 times as much as the lowest-emitted month, February, with CO_2 emissions of 75,73 tonnes. It is due to the reduction of freight volume during this month, even though one of the seven service vessels was undergoing maintenance in dry dock during August and September. Emissions peaked twice more in March and October, but was relatively stable during the rest of the year.

4 Conclusion

The bottom-up method, which relies on specific and detailed data, has been shown to provide a high degree of accuracy for the data sought. However, it should be noted that this method often requires detailed data that is not always readily available.

However, based on the data we were able to collect, our analysis showed that January saw the highest activity during 2024, with more than 650 hours of sailing for all ships combined, resulting in the highest CO_2 emission rates in an area with a significant population density.

It has been demonstrated by our calculations that CO_2 emissions from service vessel in the port of Mohammedia have amongst other sources a significant share in regional air emissions. In order to demonstrate the contribution of various regional emission sources to urban concentrations of air polluting substances the usage of air transport models (Hysplit), air dispersion models (Aermod) in future studies is advocated.

Subsequent studies may be able to ascertain the degree to which the optimisation of towing operations and the introduction of novel alternative fuels, such as LNG or methanol, could result in a reduction of greenhouse gas emissions. The utilisation of biofuels, which are derived from plant matter, has the potential to serve as a provisional solution.

5 Data availability

The data that has been used is confidential.

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