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Comparative analysis of fuel consumption and CO_2 emission estimation based on ships activity and reported fuel consumption: the case of short sea shipping in Crete

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Abstract: The main objective of this paper is to perform a comparative analysis between fuel consumption and CO_2 emissions estimation and actual fuel consumption. A few years ago, detailed actual fuel consumption reports were collected from ship owners for determining the expenses on each trip but these reports were not publicly available. Nowadays ship owners report specific data including fuel consumption and CO_2 emissions as per the requirements of EU MRV regulation. As a consequence, EMSA/MRV-THETIS database is publicly available and provides annual reports of fuel consumption and CO_2 emissions. The current study follows the bottom-up methodology presented in detail in a recent publication where the fuel–energy consumption and air emissions (CO_2, SO_X, NO_X, PM) of ships were calculated and presented for previous years. A detailed comparative analysis of results from calculated methodology and reported emissions data from EMSA/MRV-THETIS database (MRV) was performed, which showed that there was a small difference in the results (about 6–12%), proving the reliability of the bottom-up methodology for this geographic area and ships in study. © 2022 Society of Chemical Industry and John Wiley & Sons, Ltd.

Keywords: Maritime; Bottom-up; SFOC, CO_2 Emissions; EU MRV

Introduction

In modern times, the effects of global climate change are constantly increasing and already have observable consequences on the environment. Many people believe that climate change and global warming are synonyms. This is not correct, as the term "climate change" is used to describe the complex changes that are now affecting our planet's weather and climate systems, which include not only rising average temperatures but also extreme weather events which occur in areas where no such climatic behavior had occurred so far.

The Intergovernmental Panel on Climate Change (IPCC), is the United Nations' body for assessing the science related to climate change, and it forecasts

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temperature rise for decades to come, largely due to greenhouse gas (GHG) emissions produced by human activities. This is one of the main global challenges that humanity will have to face urgently and adopt measures to mitigate the effects of climate change.

Reducing greenhouse gas (GHG) emissions is the key to avoiding the most catastrophic impacts of climate change. GHG emissions can come from a range of sources and human activities and climate change mitigation can be applied across all sectors and activities by limiting or preventing GHG emissions. Countries have committed to reducing their GHG emissions under the Paris Agreement, which aims to limit global warming to below 2°C above pre-industrial levels and to pursue efforts to limit the increase to 1.5°C. These include energy production, transport of people and goods, buildings construction and operation, all kinds of industries, waste management, agriculture, forestry and land management in general. Although shipping belongs to the transport sector emissions from international shipping cannot be attributed to any particular national economy, due to its global nature and complex operation. Due to which international shipping was excluded from the Paris Agreement and the International Maritime Organization (IMO) was forced to develop its own strategy to reduce GHGs from ships.

In terms of emitted GHG, total shipping CO_2 emissions have increased by 9.3% between 2012 and 2018, whereas its share of global CO_2 emissions over this period grew incrementally from 2.76% to 2.89%. A smaller increase of 5.4% in absolute terms was observed in CO_2 emissions due to international shipping, which throughout the years represents a relatively constant share of global CO_2 emissions, fluctuating around 2%.[1]

Maritime transportation

International shipping is considered as the backbone of global trade since around 80% of world trade in goods is carried out by this sector.[2] Never more than in the recent years we have understood the importance of shipping to maintain the supply of essential goods. However, as the industry's development continues, it generates increasing carbon emissions and shipping industry is considered as a hard-to-abate sector. Fourth IMO GHG Study projected that according to a range of realistic long-term economic and energy business-as-usual scenarios, emissions could represent 90–130% of 2008 emissions by 2050.

IMO has been energetically pursuing the limitation and reduction of GHG emissions from international shipping, in recognition of the magnitude of the climate change challenge and the intense focus on this topic. IMO agreed on an initial GHG emissions reduction strategy with the main objective to reduce total annual GHG emissions from shipping by at least 50% by 2050 compared to 2008 levels, while cruising industry was the first to publicly commit, as a maritime sector, to reduce total carbon emissions by 40% by 2030 compared to 2008 levels.[1,3]

IMO has addressed ship pollution under the MARPOL convention and required a gradual decrease of air emissions (NO_X, SO_X and particulate matters) originating from consumption of maritime fuel oil. In addition, major energy efficiency improvements for vessels have been proposed through the application of the Energy Efficiency Design Index (EEDI) and Ship Energy Efficiency Management Plan (SEEMP). Also, Emission Control Areas (ECAs) were first introduced including European sea areas, North American area and the US Caribbean Sea.

Concerns about the impact of maritime transport on air quality were expressed through the Strategy for Sustainable Development, published in the EU White Paper on Transport Policy.[4] As a consequence EU actually adopted the enforcement of IMO MARPOL Annex VI sulfur cap to all European seas by establishing the EU Regulation 2016/802 for sulfur content in marine fuels and setting the same sulfur cap as IMO (0.5%). The Regulation also provides that during port stays, all ships should consume low sulfur marine fuel with 0.1% sulfur content if it stays longer than 2 h or the ships should use shore-side electricity connection. The year 2020 was a milestone year for the target of reducing air emissions from shipping due of the implementation of above directives and regulations.

Since January 2015 marine fuel for all ship operations in ECAs, must have 0.1% sulfur content while the sulfur limit for all other areas is 0.5% due to IMO regulations framework, initiated from January 2020 (see Fig. 1A). This limitation is called the IMO's global fuel sulfur cap and it is a decisive step caused by global environmental concerns due to harmful emissions from international shipping. Climate Change in the Baltic sea 2021 Fact Sheet, published by Helsinki Commission[5] reports what is the impact of the implementation of ECA 0.1% SO_X limit for ships in

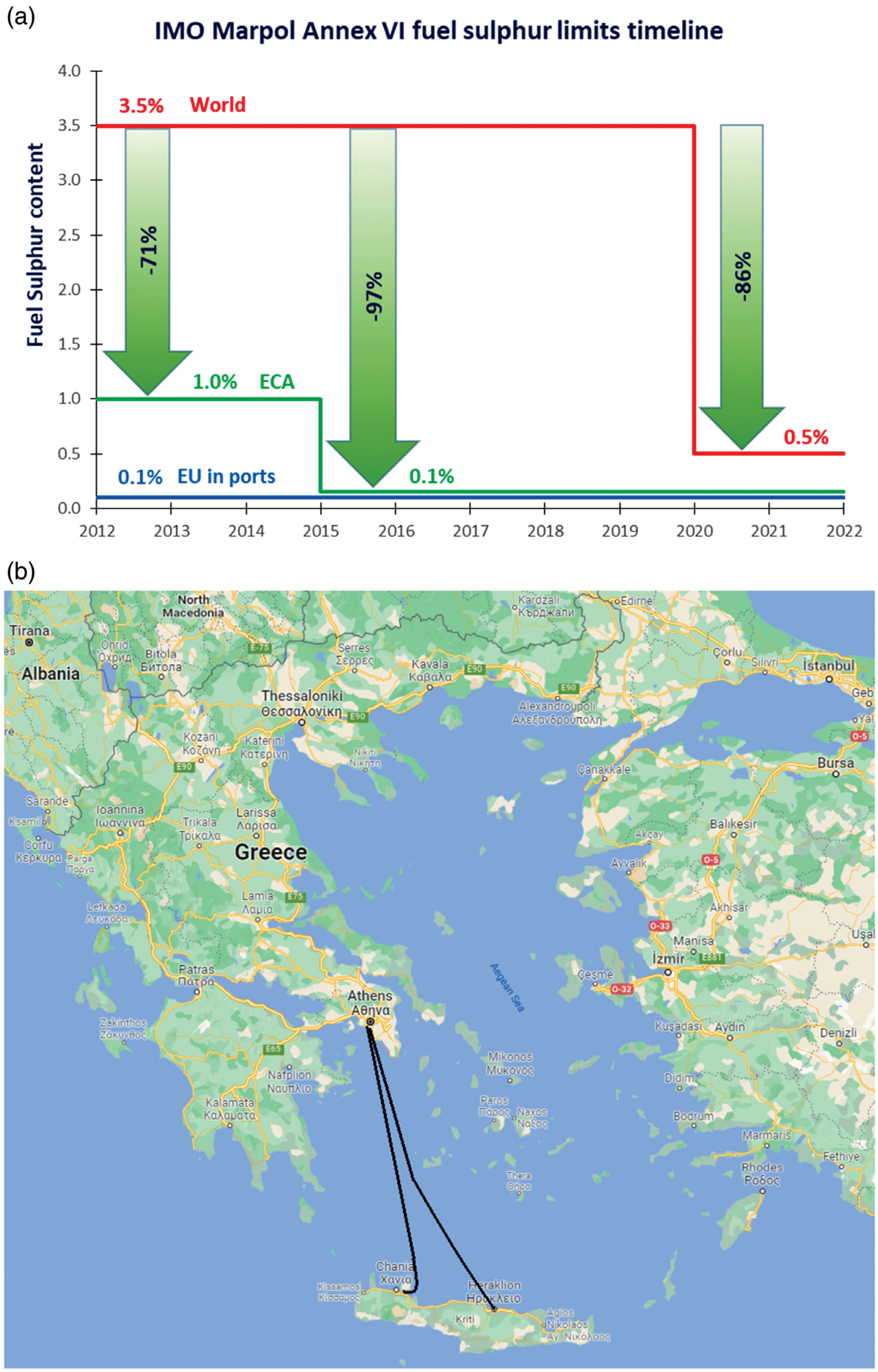

Figure 1. **(A)** IMO Marpol Annex VI fuel sulfur limits timeline. **(B)** Map of Greece: Ships route from Piraeus to two major Crete ports (Souda and Heraklion).

this area. The conclusion shows that measures to reduce air emissions from ships can be effective, for example, since the limit has been introduced, the air quality in the Baltics has improved by 70%.

Due to the latest ESPO Environmental report[6] air quality has been the highest environmental priority for ports every year continuously since 2013 and is regarded as the main parameter towards public acceptance of port activities which mainly take place very close to populated port cities. As shipping is the main activity of ports it is obvious that this is the major source of air emissions in port areas.

An alternative way to comply with fuel sulfur standards is by removing sulfur dioxide from the air emissions instead of using lower sulfur fuels which are more expensive. This can be done by the use of exhaust gas cleaning systems (EGCSs also known as scrubbers) attached on the exhaust of the ships since IMO accepts this as an equivalent compliance option. Ships with scrubbers can continue to use cheaper high-sulfur heavy fuel oil (HFO) while scrubbers are expected to reduce sulfur dioxide emissions by the same, or more, as using compliant fuels.

International Council on Clean Transportation (ICCT) published a report which provides expert advice to Environment and Climate Change Canada to enable them to update their Marine Emission Inventory Tool such that air and water pollution discharges from ships equipped with scrubbers can be estimated for ships. In this report ICCT compiled eight different studies containing 23 representative samples providing information on scrubbers' air emissions and finally they presented that for a ship using HFO 2.60% (HFO global average as of 2019) the relative emissions reduction by using scrubbers in the ship's exhaust are: −98% for SO_X, −79% for PM (10 or 2.5), no change for NO_X and +2% for CO_2. It is obvious that there is a significant reduction of SO_X and PM air emissions by using scrubbers and a small increase for CO_2.[7] Even if direct CO_2 emissions from ships with scrubbers and HFO fuel consumption are slightly higher, in another point of view[8] total CO_2 emissions (direct and indirect) increased due to the fuel demand switch from HFO to low sulfur fuel. This topic is complex and is not a scope of this study to investigate further. For future research, Life cycle assessment is a valuable tool for quantifying the change of GHG emissions after the implementation of the new sulfur cap policy.

It is clear from the above that both EU and IMO have the will to implement policies to reduce emissions from ships and especially the air emissions of SO_X and PM, since this is the result of consuming fuel with lower sulfur. CO_2 emissions depend on fuel consumption and as a result of this, two similar data collection schemes have been implemented:

- EU MRV implemented in accordance with the regulation 2015/757[9] collecting fuel consumption and CO_2 emissions (data collection started 1 January 2018)
- IMO DCS collecting fuel consumption (data collection started 1 January 2019)

The above data collection schemes are mandatory for the shipping companies to follow their data reporting requirements and intend to be the first steps in a process to collect, analyze and report emissions data related to the maritime sector. These first steps are towards cutting emissions by understanding the emitted quantities and where these emissions occur. Through EU MRV a large amount of CO_2 emission data and other relevant information are publicly available every year and an annual report is published, providing a comprehensive and granular understanding of CO_2 emissions for ships covered by the Regulation, providing also, analysis on the characteristics and energy efficiency of ships, adding value and helping identify the various factors influencing CO_2 emissions.

EU MRV regulation

The scope of this paper is not to analytically present the EU MRV regulation 757/2015 for maritime transport. Details are included in regulation document[9] and analysis done in our recent book chapter.[10] EU MRV regulation applies to all ships above 5000 GT regardless of their flag, for incoming or outgoing voyages to an EU port and refers to CO_2 emissions. The regulation has an exception for warships, naval auxiliaries, fish-catching or fish-processing ships and government ships used for noncommercial purposes.

For each ship covered by the Regulation, shipping companies shall monitor the distance traveled, time spent at sea, cargo carried and transport work on per-voyage basis and also the amount for each type of fuel consumed by main engines (ME), auxiliary engines (AE) and all other machinery on board (gas turbines, boilers, etc.). Finally in conjunction with CO_2 emission factor, the emitted CO_2 quantity is reported. In the case that during the reporting period the ship's voyages are more than 300, then there is no need for reporting on a per-voyage basis but only summarized yearly on per-ship basis.

Until 30 June of each year, the European Commission makes publicly available the data for each ship under the scope of the Regulation. Currently 2020 is the most recent year that MRV report is available for and all the data are available at EMSA/THETIS-MRV Database.[11]

The latest 2020 Annual Report on CO_2 Emissions from Maritime Transport[12] compiling data of 2019, confirms that maritime transport is a substantial CO_2 emitter, representing 3–4% of total EU CO_2 emissions. The monitored journeys emitted over 144.6 million tons of CO_2 originated from 12,117 ships representing around 38% of the world merchant fleet above 5000 gross tonnage, at about similar quantities compared to 2018, where CO_2 emissions reported in the EU MRV system represent 15% of the total CO_2 emissions from international and domestic shipping.

Air emissions estimation methodologies

There are various studies regarding the existing methodologies for estimating ship's air emissions with many accompanying relevant case studies.[13–25] Various stakeholders and/or researchers may face difficulties in selecting the best appropriate methodology and specific criteria are needed which vary depending mostly on the availability of relevant data and technical parameters. The precision level of the calculated results within any study depends on the approach applied (bottom-up, top-down) and the specific objectives of the analysis, while two components must be considered when evaluating shipping air emissions: the quantity and the area where the air emissions are produced.[26]

Environmental European Agency's (EEA) air pollution emission inventory guidebook[25] presents a procedure to select (depending on each case study and data availability) the most appropriate approach between three (called Tiers). Fuel sales reports are used from Tier 1 and 2 as the main parameter for the evaluation of the ships' activity and for the emission characteristics they assume an average vessel in order to estimate the emissions inventory. A more accurate methodology is introduced in Tier 3 approach which is recommended when technical data/parameters (e.g. engine power and technology, total power installed, fuel type consumed) and detailed data of ships movements are available.

In a recent publication a bottom-up methodology has been described in detail and this is followed in the current study.[13] Thus the fuel and energy consumption of each ship are calculated and in conjunction with specific emission factors (per fuel or energy consumption) depending on the air pollutant, engine, duty cycle and type of fuel, the air emissions are finally calculated. The total air emissions for a trip (E_{Trip}) are estimated through the following equation:

$$E_{\mathrm{Trip},e,i} = \sum_{p} \left(\mathrm{MCR}_e \cdot \mathrm{LF}_e \cdot \mathrm{T}_p \cdot \mathrm{SFOC}_e \cdot \mathrm{EF}_i\right) \qquad (1)$$

where, e is the the specific engine for which the calculations are made, i is the type of air emission (CO_2 in this study, but the procedure is the same for other type of air emissions like NO_X, SO_X, $PM_{2.5}$, PM_{10}) and p is the ship's operational phase. The quantities of ship's air emissions largely depend on the following major factors of Eqn (1):

i. MCR is the maximum continuous rated power of ship's engine (kW) which in most cases is not publicly available. The technical characteristics of the ships under study, that is, type or model of main and auxiliary engines, were available from the DNV GL database.[27] Since for now, DNV GL is the only major international accredited registrar and classification society that provides free public access to basic ships' data (IMO number, year of build, flag, vessel length, width, draught, propulsion system, engines model).
ii. Load factor (LF) is the engine load factor, which typically due to lack of data are based on the professional or empirical assessment of the researchers. As described in our recent publication[13] LF is significantly affected by local climate conditions, especially on auxiliary power demand during mooring. We tried to use engine load factors for passenger ferries and cruise vessels available from studies focused on Greek ports.[16,17,28,29] The load factors for the mooring and maneuvering phases in port are depicted in Table 1.

The LF of the propulsion system for the main engines on normal cruising speed is typically between 0.8–0.85, depicting the most efficient operation range for the engine.

For lower speed (e.g., navigating in the port) the determination of the load factor for the propulsion system is based on the theoretical fact that the propulsion engine's load is equal to[30]:

$$\mathrm{LF} = \left(\mathrm{Actualspeed}/\mathrm{Maxspeed}\right)^3$$

iii. T is the duration in hours of each operational phase of the ship. The accurate estimation of this parameter is very critical since air emissions are calculated separately for each operational phase in

Table 1. Load factors for ME and AE engines.

	Cruise ships				Passenger ships			
	Summer[a]		Rest of the year		Summer[a]		Rest of the year	
	ME	AE	ME	AE	ME	AE	ME	AE
Maneuvering	0.20	0.75	0.20	0.60	0.20	0.75	0.20	0.60
At berth	0	0.60	0	0.40	0	0.45[b]	0	0.30[c]

[a]In Mediterranean region June, July and August is characterized as summer period.
[b]0.70 for 50% and 0.20 for the rest 50% of the duration while at berth phase.
[c]0.40 for 50% and 0.20 for the rest 50% of the duration while at berth phase.

conjunction with specific LF. All data regarding ships arrivals and duration of port calls were collected and validated from port authorities and additionally, in order to determine the required duration of each operating phase, an extensive search in the related Marine traffic database has been conducted for the specific ships/itineraries in study.

iv. Specific fuel oil consumption (SFOC) in g/kWh. The role of accurate calculation of SFOC is very important for the estimation of fuel/energy consumption. SFOC values at various engine load levels are calculated in the literature either by using adjustment factors[31,30] or based on scientific reports of IMO[32] and/or ENTEC UK.[33] The used methodology is based on the estimation of SFOC values through regression analysis, that leads to accurate and reliable results.[13]

v. Emission factor (EF) is calculated for each specified air emission based on expressions, like the one that follows for CO_2[1,32]:

$$CO_{2\ (g/kWh)} = (3.114 \text{ or } 3.206) \cdot SFOC_{\ (g_{fuel}/kWh)} \tag{2}$$

where 3.114 is for 0.5% low sulfur fuel that ME consume and 3.206 is for 0.1% MGO fuel that AE consume.

Results and discussion

The main scope of this study is to perform a comparative analysis between the actual fuel consumption and CO_2 emissions and the quantity estimation based in our methodology. Since detailed actual fuel consumption for ships is not publicly available, as actual we assume the data from the EMSA/MRV-THETIS database[11] which provides annual reporting of fuel consumption and CO_2 emissions.

Since EMSA/MRV-THETIS database reports annual fuel consumption and CO_2 emissions, for reliable results this study refers to vessels that operated throughout 1 year between ports under the EU MRV regulation. After studying the itineraries for passenger ferries and cruise vessels for two major Greek ports (Souda and Heraklion, both located on Crete) for year 2020 (most recent available data) the presented results hereafter focus on five passenger ferries which operated from Souda to Piraeus and Heraklion to Piraeus (Fig. 1B).

Table 2(A) depicts the vessels that meet the above criteria and their MRV data available from EMSA/THETIS-MRV database. These ships do not use scrubbers and they consume fuel with 0.5% sulfur content for ME and 0.1% for AE, using two different monitoring methods of fuel consumption, which correspond to:

A. Bunker fuel delivery note (BDN) and periodic stocktaking of fuel tanks and
B. Bunker fuel tank monitoring on board

To fully understand the type and size of ships in study, Table 2(B) depicts some more technical parameters (length, width, GT, ME power, AE power, and percentage of each engine type to total).

During cruising (between ports) all engines (ME and AE) operate in a relatively high rate (0.85 for ME, 0.75 for AE at summer period (Jun-Jul-Aug) 0.60 for AE for all other months). This is reflected in fuel consumption

Table 2(A). MRV data of passenger ferries exclusively operated during 2020 between major Crete ports and Piraeus port.

IMO Number	Ship Name	Monitoring method	Time spent at sea annually (h)	Total fuel consumption (t)	CO_2 emissions within ports (t)	CO_2 emissions between ports (t)	Total CO_2 emissions (t)
7814046	F/B KRITI I	A	781.48	2652.90	2319.86	6007.84	8327.70
7814058	F/B KRITI II	A	2739.52	9482.68	3854.53	25778.13	29634.66
7907673	F/B EL.VENIZELOS	A	1210.72	3485.59	2251.85	8674.30	10926.18
8616336	F/B BLUE HORIZON	B	1960.00	5354.22	1963.00	14788.00	16751.00
9035876	F/B BLUE GALAXY	B	2651.38	9214.79	1819.31	26929.39	28748.70

(B) Technical characteristics of passenger ferries in study.

IMO Number	Ship Name	Length (m)	Width (m)	Gross Tonnage	Main Engines		Auxiliary Engines		Total power (kW)
					power (kW)	%	power (kW)	%	
7814046	F/B KRITI I	192.0	29.4	27239	24,800	85.5	4,200	14.5	29,000
7814058	F/B KRITI II	192.0	29.4	27239	24,800	85.5	4,200	14.5	29,000
7907673	F/B EL.VENIZELOS	175.5	28.5	38261	29,828	86.6	4,610	13.4	34,438
8616336	F/B BLUE HORIZON	187.0	27.0	27320	22,400	83.8	4,320	16.2	26,720
9035876	F/B BLUE GALAXY	192.0	27.0	29992	29,160	90.0	3,240	10.0	32,400

Source EMSA/THETIS-MRV Database.[11]

Table 3. CO_2 emissions variation within ports and between ports.

IMO Number	Ship Name	CO_2 emissions occurred within ports (t)	Participation to Total CO_2 Emissions	CO_2 emissions between ports (t)	Participation to Total CO_2 Emissions	Total CO_2 Emissions (t)
7814046	F/B KRITI I	2319.86	27.86%	6007.84	72.14%	8327.70
7814058	F/B KRITI II	3854.53	13.01%	25778.13	86.99%	29634.66
7907673	F/B EL.VENIZELOS	2251.85	20.61%	8674.30	79.39%	10926.18
8616336	F/B BLUE HORIZON	1963.00	11.72%	14788.00	88.28%	16751.00
9035876	F/B BLUE GALAXY	1819.31	6.33%	26929.39	93.67%	28748.70

and CO_2 emissions and as it is normal, there is a big difference in the quantity of CO_2 emissions occurred within ports and between ports.

This is depicted in Table 3 and represented in Fig. 2 where we can observe that CO_2 emissions between ports are more than 70% in total and depending on each ship these emissions range from 72.14 to 93.67%. Thus, it is critical to estimate as accurately as possible the fuel consumption and CO_2 emission especially during the normal cruise operational phase, because this phase constitutes the major part.

In order to determine the required duration of each operating phase (at port or at sea) after studying and validating ships itineraries, arrivals, and duration of

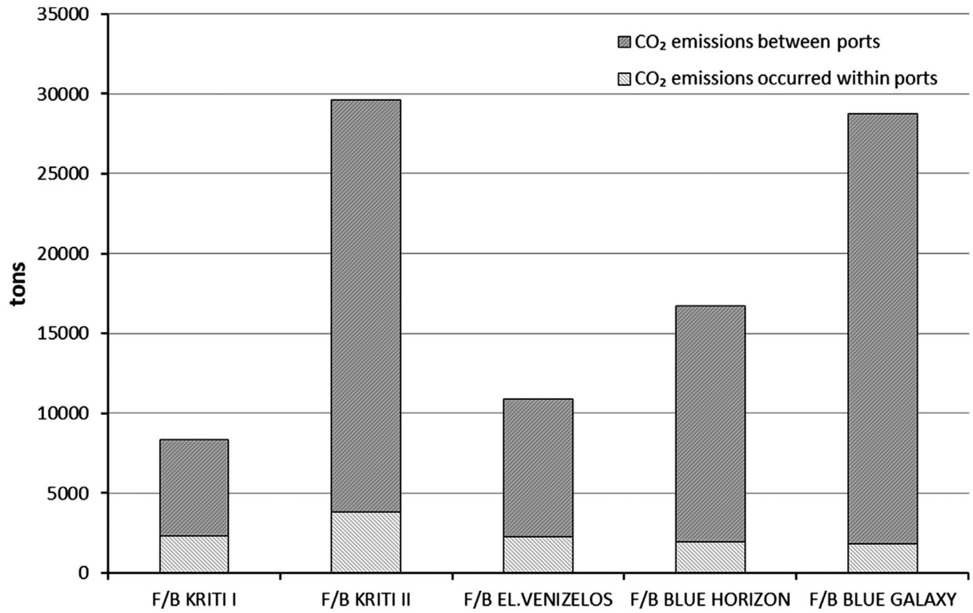

Figure 2. CO_2 emissions based on MRV within ports and between ports.

Table 4. Passenger ferries operational phase's duration.

IMO Number	Ship Name	Ship calls	Annual time at port (h)	Annual time at sea (h)	MRV Annual time spent at sea (h)	Difference (h)	Difference (%)
7814046	F/B KRITI I	81	1372.00	769.50	781.48	11.98	1.9%
7814058	F/B KRITI II	294	4293.75	2719.50	2739.52	20.02	0.7%
7907673	F/B EL.VENIZELOS	63	958.00	651.00	1210.72	559.72	46.2%
8616336	F/B BLUE HORIZON	177	2543.25	1829.00	1960.00	131.00	6.7%
9035876	F/B BLUE GALAXY	307	4415.00	2686.25	2651.38	–34:87	–1.3%

port calls and AIS activity, Table 4 depicts the variation of annual time spent at sea between the EMSA/THETIS-MRV Database and our study. MRV reports the duration of "Annual Time spent at sea" which is similar to the analytical itineraries presented here, except for F/B EL.VENIZELOS that has a significant variation on annual time spent at sea. As it will be explained in the results later, this is probably a mistake in EMSA/THETIS-MRV Database, since all other results for this ship have a much less difference. The small difference on annual time spent at sea duration is a first good sign that the validation of operational phase's duration that was performed during this study is correct. Also, this factor is used to calculate air emissions and it is thus important to be as accurate as possible.

Following the methodology described in paragraph four, the fuel and energy consumption of each ship and engine type (ME, AE) is calculated. Table 5 depicts the results of the methodology calculation. The annual total fuel consumption is presented separately for ME and AE. This separation is necessary later for accurate estimation of CO_2 air emissions, since ME and AE consume different type of fuel (0.5 and 0.1% sulfur content, respectively) with different emission factor for each of them (3.114 or 3.206, respectively).

As depicted in Fig. 3 there is increased consumption of fuel at ME (depending on ship it is from 62.27 to 86.99%) compared to total fuel consumption. This is normal as depicted in Table 2(B), ME engines are bigger in power (kW) and they need more fuel to operate (compared to AE). Actually, ME power

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Table 5. Annual calculated total fuel consumption comparison with actual reported by MRV.

IMO	VESSEL	ME Fuel (t)	AE Fuel (t)	Total (t)	MRV Total fuel consumption (t)	Difference
7814046	F/B KRITI I	1,940.132	925.942	2,866.074	2,652.90	–8.04%
7814058	F/B KRITI II	6,847.770	3,171.255	10,019.025	9,482.68	–5.66%
7907673	F/B EL.VENIZELOS	2,327.280	1,410.187	3,737.467	3,485.59	–7.23%
8616336	F/B BLUE HORIZON	4,613.600	1,064.552	5,678.151	5,354.22	–6.05%
9035876	F/B BLUE GALAXY	8,965.836	1,340.913	10,306.749	9,214.79	–11.85%

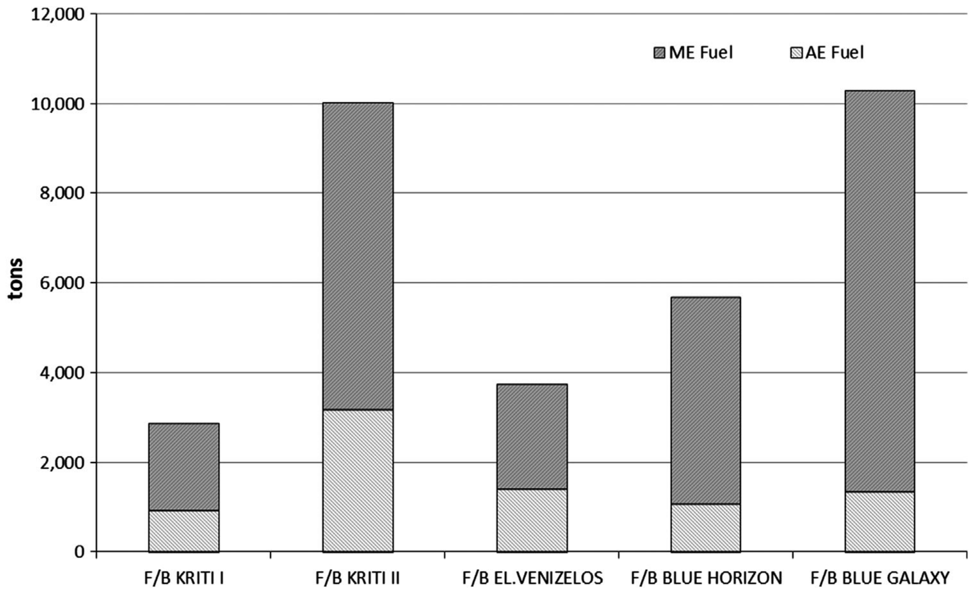

Figure 3. Bottom-up methodology results: Annual fuel consumption per ship and engine type.

accounts for about 83.8–90% of the total and the rest percentage belongs to AE.

Comparing the results of total fuel consumption from the bottom-up methodology and MRV report (Fig. 4) it is clearly inferred that total fuel consumption calculation has a small difference compared to reported fuel consumption to MRV. The variation is from −5.66 to −11.85% (see Table 5) and can be rated as particularly low.

By multiplying the fuel consumption of each engine type (fuel type) by CO_2 emission factor (per fuel type) we finally estimate CO_2 emissions of fuel, and the air emissions are finally calculated.

The estimation of CO_2 can allow the confirmation that the results of the presented methodology are very close to actual CO_2 emissions reported by MRV. These are depicted in Table 6 and presented in Fig. 5, where it is observed that the difference between estimated and reported CO_2 emissions is very small and at similar levels of fuel consumption difference. We can conclude that all parameters point to a successful application of the calculation methodology that leads to results very close to MRV reported CO_2 emissions for the ships and ports in study.

Conclusions

For any researcher involved in the calculation of air emissions in shipping, there is almost always the question regarding the accuracy of the results following a bottom-up methodological approach and specific determination of parameter factors that are included in

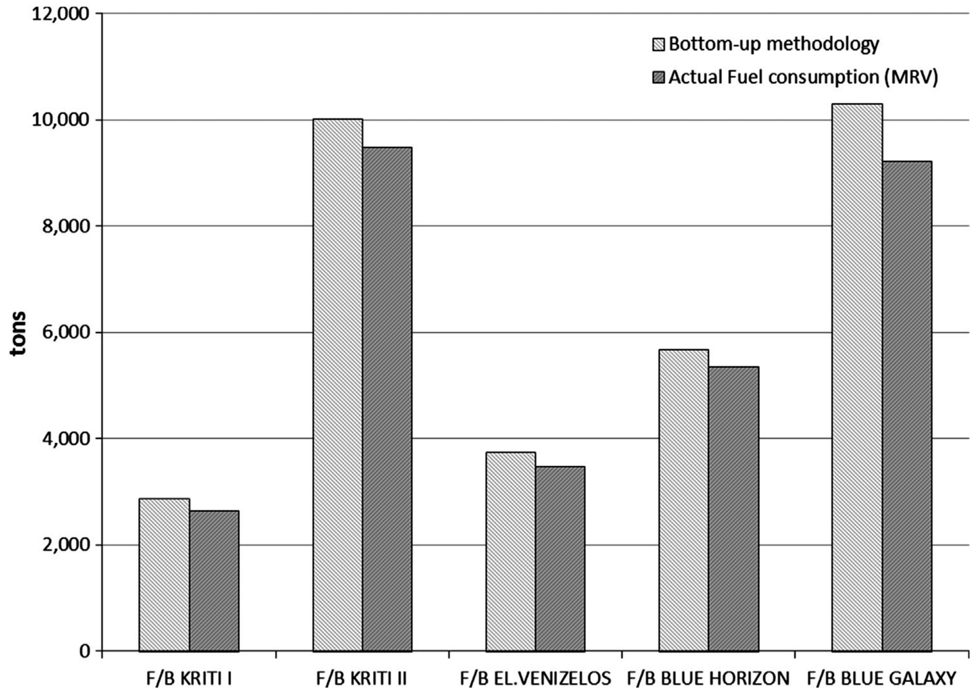

Figure 4. Comparison of total fuel consumption result of bottom-up methodology and MRV report.

Table 6. Passenger ferries total estimated CO_2 emissions comparison with actual reported by MRV.

IMO Number	Ship Name	ME CO_2 (t)	AE CO_2 (t)	Total CO_2 (t)	CO_2 MRV (t)	Difference
7814046	F/B KRITI I	6,041.570	2,968.569	9,010.141	8327.700	−8.19%
7814058	F/B KRITI II	21,323.956	10,167.044	31,490.999	29634.660	−6.26%
7907673	F/B EL.VENIZELOS	7,247.151	4,521.060	11,768.209	10926.180	−7.71%
8616336	F/B BLUE HORIZON	14,366.750	3,412.953	17,779.704	16751.000	−6.14%
9035876	F/B BLUE GALAXY	27,919.614	4,298.967	32,218.580	28748.700	−12.07%

the calculations. Since actual fuel consumption and air emissions were not publicly available a few years ago, EMSA/MRV-THETIS database is a very useful tool to provide actual fuel consumption and CO_2 emissions from ships.

In Doundoulakis and Papaefthimiou[13] we examined four alternative scenarios on fuel consumption and air emissions estimation. In the current paper, we followed the methodology described as basic scenario (determining SFOC through regression analysis and ME, AE based on manufacturer's data). The rest three scenarios were using different typical methodologies for determining SFOC (through adjustment factors) ME, AE power, and AE/ME ratio (using data based either on average World fleet or Mediterranean Sea fleet).

Different estimations on main parameters of the calculation methodology lead to different results and in the case of using the scenario for estimating SFOC through adjustment factors, provides higher fuel consumption values for both ME and AE. There is significant difference for ME while for AE the values seem to be similar. This is also in terms of air emissions where we see slightly higher air emissions values in total. In the case of scenarios for estimating SFOC through adjustment factors and ME, AE power, and AE/ME ratio using data based on average World fleet and Mediterranean Sea fleet, both fuel and energy consumption is significantly underestimated and thus resulting in significantly reduced air emissions.

In the current study the basic bottom-up methodology scenario was followed to calculate the

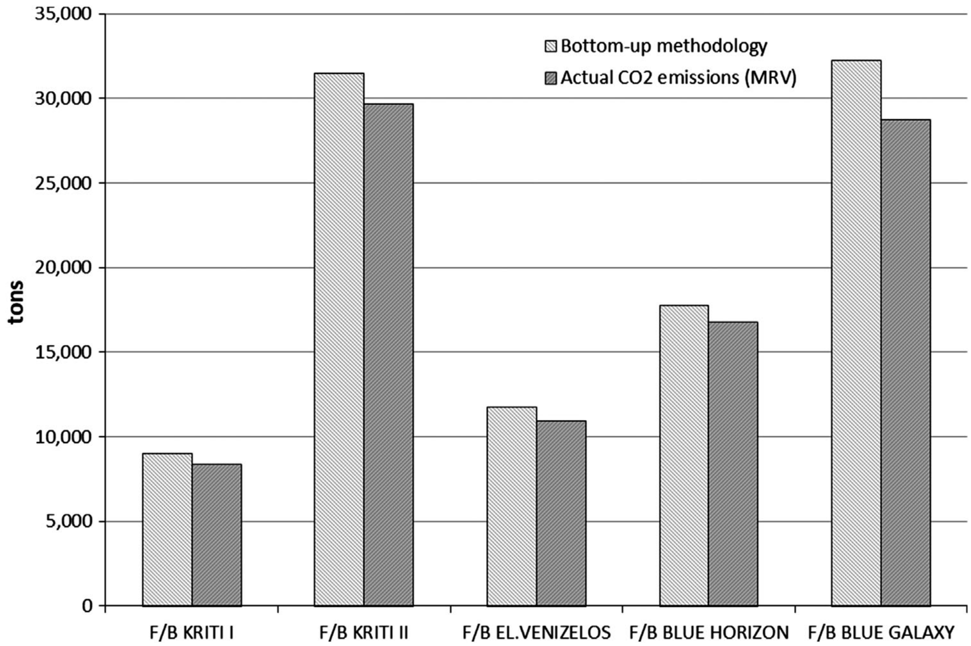

Figure 5. Comparison of total CO_2 emissions of bottom-up methodology and MRV report.

fuel consumption and CO_2 emissions of ships for the year 2020 and to compare the results to reported emissions data from EMSA/MRV-THETIS database. The total fuel consumption difference is about 6.14–12.07% and the difference for total CO_2 emissions is about 5.66–11.85% and as we understand from the comparison of the alternative scenarios, none of them is appropriate to be used for air estimation based on the itineraries, ships, and ports of our study.

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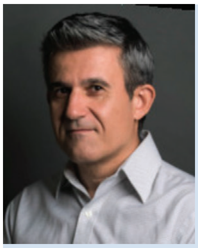

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