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An investigation into green ports in Bodrum

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ABSTRACT

Anthropogenic energy consumption has been constantly increasing due to technological progress, population growth, commercial relations, and the transfer of goods using transport. The increase in energy consumption, particularly in the maritime sector where ships consume a large share of energy, has been accompanied by the release of harmful products into nature such as sulfur oxides (SOX), nitrous oxides (NOx), and airborne particulate matter (PM), as well as such greenhouse gases as carbon dioxide (CO_2) and methane (CH_4). Studies carried out in this field have revealed harmful products such as CO_2 to increase average global temperatures by inhibiting the reflection of the sun rays that fall onto the Earth and creating a greenhouse gas effect in the world atmosphere. Meanwhile, SOX, organic emissions (HC), and NOX have direct negative effects on human health. This paper uses the engine power calculation method as a bottom-up approach to estimate the emissions from ships that have spent time and maneuvered in Bodrum Cruise Port and Yalikavak Marina between 2021–2022. Ship transit information has been taken from the port employees and Ports Database. Ships were examined according to several criteria such as type, gross tonnage, engine type, and installed engine power. As a result, the study estimates total fuel consumption by finding the engine load and usage time of the ships based on engine type and primarily uses publications from the European Monitoring and Review Program (EMEP) and the US Environmental Protection Agency for the emission factors. For the local-scale effects of emissions, the article has taken the limits for NOx and SOX as introduced in MARPOL Annex VI regarding compliance with the current situation. As for the preliminary results, an increase was found at Bodrum Cruise Port for NOx emissions while a decrease was registered for SOX emissions. This study has also carried out a comparison of Bodrum Cruise Port and Yalikavak Marina with other existing studies.

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1. INTRODUCTION

The need for monitoring and reducing emissions in shipping has arisen as a result of the effects emissions have on air pollution and global warming. One of the main causes of air pollution in port cities is the exhaust emissions from the ships that dock there. The European Union (EU) and the International Maritime Organization (IMO) have modified their laws for reducing emissions from ships. The main pollutants related to maritime traffic are carbon dioxide (CO_2), which has a global effect, and nitrogen oxides (NOx), carbon monoxide (CO), volatile organic compounds (VOCs),

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airborne particulate matter (PM), and sulfur dioxide (SO_2), which have more local effects (Ünlügençoğlu et al., 2019; Ergin et al., 2019). According to Agenzia Nazionale Stampa Associata (ANSA), air pollution in ports comes from:

- Exhaust emissions from private vessels in the port
- Exhaust emissions from the heating of buildings, spaces, and water
- Exhaust emissions from trucks, personal vehicles, and equipment used to handle cargo
- Exhaust emissions from ships while anchoring and using their main and auxiliary engines to generate energy, heat the ship, and operate its cargo (Han 2010; Vafaki & Palantzas, 2008)
- Volatile emissions produced by shipbuilding and building paints, vented gases, and suspended particles
- Dust emissions during site operating and construction activities and ozone-depleting particle emissions from the operation of storage units (e.g., refrigerators and freezers)
- Volatile compound emissions from the refueling of ships, automobiles, and port equipment
- Chemical emissions from ship cargo.

Jieling and Haibo (2018) studied these subjects by investigating harmful PM coming from ship auxiliary engines in ports in China and comparing shore-powered and non-shore-powered ships in ports. Their study examined emissions from power generation in Chinese ports and found that having ships use onshore power while in port would result in an annual reduction of 16 million tons of SO_2, 128 million tons of NOx, and 1.435 billion tons of CO_2 emissions. Sun et al. (2018) calculated the emissions from ships entering ports in Qingdao, China, in five modes of operation: cruise, preparation, deceleration, steering, and hoteling operations. Their results also compared three ports in terms of their HC, PM, SO_2, and CO_2 levels in emission control area (ECAs) and highlighted the need to take precautionary measures. Chen et al.'s (2016) article estimated the emissions levels of 8,690 vessels arriving at the port of Tianjin in 2014. Their study on emissions showed ship emissions in 2014 to be 29.3 million tons of SO_2, 41.3 million tons of NOx, 4.03 million tons of PM_{10} (less than 10 μm in diameter), 3.72 million tons of $PM_{2.5}$ (less than 2.5 μm in diameter), 1.72 million tons of non-methane VOCs (NMVOC), and 3.57 million tons of CO, which respectively are equivalent to 11.07%, 9.40%, 2.43%, 3.10%, 0.43%, and 0.16% of the non-ship anthropogenic totals in Tianjin. Tichavska et al. (2019) calculated ship emissions over 12 months in three different regulated ports (EU, Sulphur Emission Control Area [SECA], and non-EU/non-SECA) in accordance with the ship traffic emissions assessment model (STEAM) and compared it to Automatic Identification System (AIS) data. Ledoux et al., (2018) studied Calais Port in northern France, measured emissions over a period of three months, and analyzed the effects of emissions on the local air quality. They arrived at the conclusion that the effects of Port of Calais maritime transport on mean concentrations were 51% for SO_2, 2% for PM_{10} 15% for NO_2, and 35% for NO. Chu-Van et al. (2018) carried out measurements at the ports of Newcastle and Gladstone on dry cargo ships to compute emissions when stationary, maneuvering, and at sea, with separate readings being derived from the main engine and exhaust. Nunes et al. (2017) numerically calculated emissions from ships for four major ports in Portugal (i.e., Setubal, Leixo, Sines, and Viana do Castelo) during three phases (i.e., steering, hoteling, and cruising). Tzannos (2010) calculated NOx, SO_2, and $PM_{2.5}$ emissions from passenger ships docked at the Greek port of Piraeus during 2008–2009, with total emissions of 2,600 tons per year being calculated. International shipping produces 900 million tons of CO_2, or about 7% of all CO_2 emissions, with a fleet of around 100,000 ships operating in 45,000 ports across the world.

All environmental, economic, and social considerations have equal weight in sustainable business operations. The idea of green ports aims to include ecofriendly practices in port movements, administration, and activities. Green ports intend to use their resources to reduce their negative effects on the environment in the region, to improve environmental management, and to improve the quality of the port area's natural surroundings (Anastasopoulos et al., 2011). Most ports must achieve these goals in order to be given the designation of "green". These include environmental protection, sustainable development, which enhances the environmental performance of port facilities while maximizing long-term economic benefits, and waste management, which reduces waste from port operations through material reuse, recycling, and composting.

Nowadays, many applications are found for the concept of green ports, and these are gaining more volume lately. Applications for green ports include soil, air, and water quality management to reduce energy consumption and noise pollution, achieve sustainability, minimize soil and sediment pollution, increase the quality of wildlife and marine life, and improve water quality. These applications also aim to gain environmental aspects for green ports and to enhance weather monitoring.

The Green Port/Eco Port Project was created in accordance with a protocol signed at the end of 2014 by the Turkish Standards Institution (TSE), Directorate General of Merchant Marine, and the Ministry of Transport, Maritime Affairs, and Communications (UDHB; Akgul, 2017; European Sea Ports Organization (ESPO), 2012; Satır & Doğan-Sağlamtimur, 2018). The four headings of the Green Port/Eco Port Project sectorial criteria are: the general requirements for all port facilities, the requirements for environmental management in ports, the requirements for occupational health and safety in ports, and the requirements for the handling, packing, and storing of dangerous goods in ports. The main goals of this study are to develop a strategy for the port facility's integrated quality management system, improve or prevent the degradation of the quality of the seawater near the port facility, maintain the highest level of energy efficiency in port operations, provide the greatest possible energy savings, decrease hazardous and greenhouse gas emissions from

Table 1. Estimated average ship ratio of auxiliary engines-to-main engines by ship type (Kwon et al., 2023)

Ship categories	Fleet 2010 average	World average
Liquid bulk	30%	35%
Dry bulk carriers	30%	39%
Container	25%	27%
General cargo	23%	35%
Ro-ro cargo	24%	39%
Passenger	16%	27%
Fishing	39%	47%
Other	35%	18%
Tugs	10%	

port-related activities, improve renewable energy projects, provide garbage recycling to lower the amount of waste coming from port operations, implement essential changes, and guarantee adequate workplace health and safety during port operations. The world has many green ports, and their numbers are still growing. The main ones are the Port of Hamburg, the Port of Rotterdam, the Port of Piraeus, and the Port of San Diego (Visvardis, 2019).

2. EMISSIONS

This study uses a bottom-up method to calculate emissions from ships while maneuvering and hoteling in port. This method is in contrast to the top-down method, also known as the basic calculation approach. According to the top-down method, the emission coefficients for a particular fuel type are multiplied by the amount of fuel consumed and then the total amount of that pollutant type is calculated.

Meanwhile, the bottom-up method was created after IMO's tests revealed different emission values to be observed under different engine loads (Lepkowski, 1995). This method should be examined in two sub-headings as an assumption based on known ship types and an assumption based on known engine power.

The method of the assumption based on the known ship type is used for calculations when the main and auxiliary engine powers of the ship whose emissions are being calculated are unknown while the class of the vessel is known. According to the type of ship and engine, powers are taken as average values. Like the top-down method, fuel consumption values for the desired pollutant are calculated based on the fuel used for a particular ship type (European Monitoring and Review Program (EMEP), 2019).

Based on the bottom-up calculations assumed for a known ship's engine power, at least the movement data (distance, speed, and time) and installed engine onboard information (engine type and power, fuel used) should be known for each ship (ESPO, 2012; Ergin, 2011; Ertuğrul, 2023). The general equation for obtaining emissions during a general trip is the sum of three contributions: hoteling, maneuvering, and cruising.

Table 2. Combustion-sourced emission factors

	MSD		HSD	
	MDO (g/kWh)	BFO	MDO (g/kWh)	BFO
CO	4.45	4.25	4.34	4.34
PM_{10}	1.07	5.21	0.96	5.01
$PM_{2.5}$	0.91	4.43	0.82	4.26
BC	0.95	0.09	0.04	0.08

MSD: Medium-speed diesel; HSD: High-speed diesel; MDO: Marine diesel oil; BFO: Bunker fuel oil.

Table 3. Combustion-sourced emission factors for main engine during maneuvering and hoteling

Phase	Engine type	Fuel type	NOx EF 2005	NMVOC	SFOC
			(g/kWh)		
Main engine	HSD	BFO	9.3	0.6	234
		MDO	9.9	1.5	223
	MSD	BFO	10.8	1.5	234
		MDO	10.2	1.8	223
	LSD	BFO	14	1.8	215
		MDO	13.1	0.3	204

NMVOC: Non-methane VOCs; SFOC: Specific fuel oil consumption; HSD: High-speed diesel; MSD: Medium-speed diesel; LSD: Low-speed diesel; BFO: Bunker fuel oil; MDO: Marine diesel oil.

Values for each contribution can be obtained from Equation 1, where t_p is the time during different phases of a trip, P_{engine} is the installed engine power with a load factor equal to LF_{engine}, which is the ratio of average used engine load to installed main power, and EF is the emission factor (chosen as a function of engine, fuel used on board, and the particular pollutant i:

$$E_{pollutant}=\Sigma_m (t_p \Sigma_{engine} (P_{engine*}LF_{engine*}EF_{engine,fuel,pollutant})) \quad (1)$$

While doing the calculations, data were obtained from the port, with the Istanbul Technical University (ITU) database being used to obtain Pengine according to their IMO numbers. Auxiliary engine power was estimated based on the estimated average ship ratio between the auxiliary and main engine as a function of ship categories (Table 1). The data include departure date and arrival date for each ship and assume 12 h spent in port. Basically, the ratio of average speed to service speed provides a good approximation for engine loads.

According to EMEP 2019, the engine load during the different phases should be considered as 20% for the main engine and 50% for the auxiliary engine while maneuvering, 40% for the auxiliary engine while hoteling, and 80% for the main engine and 30% for the auxiliary engine while cruising.

EF is usually given in units of g/kWh or of kg/ton of fuel. The current list of EMEP/EEA (European Environment Agency) is given in Tables 2, 3, and 4 (EMEP, 2019) for medium-speed diesel (MSD), high-speed diesel (HSD), and for different fuels (marine diesel oil [MDO] and bunker

Table 4. Emission factors for NOx, NMVOC, PM and specific fuel oil consumption (SFOC) for auxiliary engine / fuel combinations and ship trip phases

Engine type	Fuel type	NOx EF 2005	TSP PM_{10} $PM_{2,5}$ EF	NMVOC	SFOC
HSD	BFO	11.2	0.8	0.4	227
	MDO	10.5	0.3		
MSD	BFO	14.2	0.8		
	MDO	13.5	0.3		

NMVOC: Non-methane VOCs; EF: Emission factor; TSP: Total suspended particulate; HSD: High-speed diesel; MSD: Medium-speed diesel; BFO: Bunker fuel oil; MDO: Marine diesel oil.

fuel oil [BFO]). The average amount of sulfur in fuel before 2020 was 2.7%, so this percentage has been used for the calculation (Herdzik, 2021; Zetterdahl et al., 2016).

2.1. Greenhouse Gases (GHGs)

Due to the emission of other GHGs such as CO, CH_4, and N_2O, equivalent or conjugated CO_2 emissions were sometimes been used. Each of these secondary GHG pollutants can be characterized according to the Intergovernmental Panel on Climate Change (IPCC) with a global warming potential (GWP) based on the heat retention coefficient of CO_2, which is calculated by the cumulative radiative forcing over a specified time horizon caused by a unit emission of a pollutant relative to an equivalent mass of CO_2. Carbon conjugates ($Conj_{i,j}$ can be obtained by multiplying the total emissions [the mass of the selected emission type] for its warming potential annual global emissions [$GWP_{i,j}$] by [i] 20 or by [j] 100). In this study, the main GHGs being selected are CO_2 (GWP20=1, GWP100=1) and CO (GWP20=10, GWP100=3; Herdzik 2021).

3. MATERIALS AND METHODS

3.1. Ports chosen as the case study

This study investigates and compares Bodrum Cruise Port and the Yalikavak Yacht Marina in terms of the emissions produced over a year. The first port can accommodate two large or four smaller cruise ships simultaneously along its cruise pier and also contains three ferry boat ramps and quays that can accommodate up to 30 mega-yachts. Bodrum Cruise Port lastly offers complete terminal services, marine services, and ancillary services (https://www.bodrumcruiseport.com/general-information). Not including Bodrum Cruise Port, Yalikavak Yacht Marina is Türkiye's first large-capacity superyacht marina and was named the World's Best Superyacht Marina in 2022, International Marina of the Year for 2020 and 2021, and World's Best Superyacht Marina in 2018 and 2019. Yalikavak Yacht Marina can host 620 ships and offers first-rate living options, unparalleled services, and facilities for boats up to 140 m L_{OA}. Each year, more than 100 superyachts dock in Yalikavak Marina (https://yalikavakmarina.com).

Bodrum Cruise Port and Yalikavak Yacht Marina were monitored for one year from 2021–2022 in order to estimate the NOx, SO_2, CO_2, VOC, PM, and CO emissions from the vessels that arrived at the ports. Bodrum Cruise Port started to host cruise ships in 2021, and the data show 73% of the cruise ships visiting the port to have medium-speed engines and the remaining 27% to have high-speed engines. For Yalikavak Yacht Marina, the data show 94% of the yachts and passenger ships to have high-speed engines and the rest to have medium-speed engines. The study has taken ship type, construction year, gross tonnage, main engine power, and auxiliary engine power into consideration, as well as the number of arrivals and the amount of time ships spent during the maneuvering and mooring phases when arriving at the Bodrum Cruise Port and Yalikavak Yacht Marina over the one-year period. Actual ship data (power and speed of main engine, power of auxiliary engine, year of construction, gross tonnage, flags, arrivals, speed, hoteling, and maneuvering) were used for the calculations. The duration of each operational phase at port was calculated. Ship traffic information such as port entry and exit dates and ship speeds were obtained from the port employees and the Ports Database and matched with the ship characteristics that were accessed through AIS using the known ship parameters. The study arrived at the total fuel consumption this way by finding the engine load and usage time of the ships based on engine type.

4. RESULTS

The results being reported are an estimate of ships' emissions during the hoteling and maneuvering phase in Bodrum Cruise Port and Yalikavak Yacht Marina using the assumptions based on the known engine method.

Combustion-sourced emissions include CO_2, CO, NOx, PM_{10}, $PM_{2.5}$, NMVOC, polychlorinated-p-dioxins (PCDD/F), hexachlorobenzene (HCB), and polychlorinated biphenyl (PCB) elements, with the last three being negligibly produced by the maritime sector. According to the obtained results, the combustion-sourced emission values during the maneuvering phase are relatively low (Fig. 1). For example, NOx emissions for the Yalikavak Yacht Marina were 356.17 tons for hoteling and 2.226 tons for maneuvering. CO_2 emissions were 24,894.08 tons for hoteling and 154.15 tons for maneuvering. With the sole exception of CO_2, Table 5 shows the breakdown of the percentage of the main selected pollutants. Clearly, attention is drawn to the sustainability of the Bodrum port, particularly with regard to NOx emissions, which for hoteling was calculated as 5.349 tons for Bodrum Cruise Port and 356.17 tons for Yalikavak Yacht Marina.

The fuel-sourced emissions from ships while hoteling at Bodrum Cruise Port came from the production of SOX, lead (Pb), cadmium (Cd), mercury (Hg), arsenic (As), chromium (Cr), copper (Cu), nickel (Ni), selenium (Se), and zinc (Zn) elements. Also in this case, the most prevalent emission were SOX, with about 90% of the total SOX emissions occurring during the hoteling phase (Table 6).

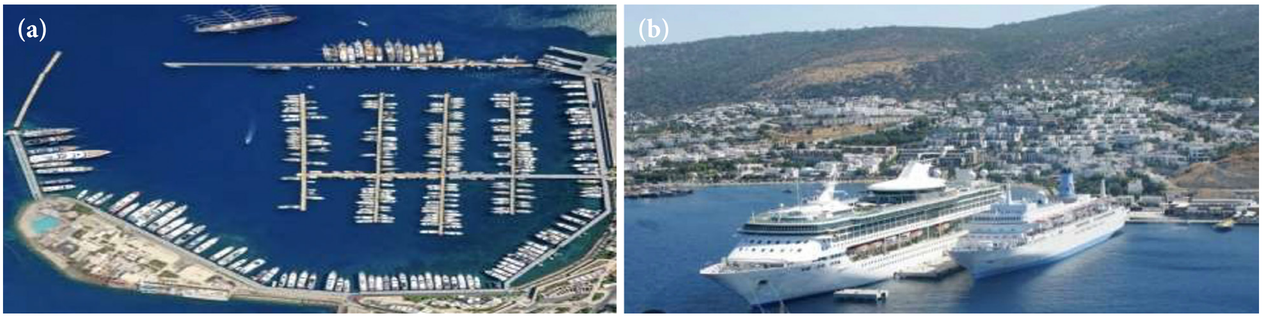

Figure 1. (a) Yalikavak yacht marina, (b) Bodrum Cruise Port.

Table 5. Combustion-sourced emissions (tons)

Pollutant	Hotelling Bodrum Cruise Port	Manoeuvring Bodrum Cruise Port	Hotelling Yalikavak Marina	Manoeuvring Yalikavak Marina	Bodrum Cruise Port	Yalikavak Marina
CO_2	8,559.87	832.87	24,894.08	154.15		
CO	19.794	0.0019	57.56	0.0003	40%	13%
NOX	5.349	0.0083	356.17	2.2257	11%	78%
PM_{10}	8.350	0.8125	24.28	0.143	19%	5%
$PM_{2.5}$	–	–	–	–	0%	0%
NMVOC	13.355	1.2887	18.71	0.1176	30%	4%

NMVOC: Non-methane VOCs.

Table 6. Main fuel-sourced emission (tons)

Pollutant	Hoteling Bodrum Cruise Port	Maneuvering Bodrum Cruise Port	Hoteling Yalikavak Marina	Maneuvering Yalikavak Marina
SOX	5.35	0.52	0.78	0.01

SOX: Such as sulfur oxides.

Table 7 presents the results obtained for the main carbon conjugates with a GWP of 20 and 100 years. For example, the GWP20 values for the pollutant CO_2 were 9,392.7 tons/year for Bodrum Cruise Port and 25,048.2 tons/year for Yalikavak Marina. The total GWP20 values were obtained as 9,590.6 tons/year for Bodrum Cruise Port and 133,142.6 tons/year for Yalikavak Marina. Table 7 shows the GWP100 values to be slightly less than the GWP20 values.

Table 7. Main carbon conjugates (tons/year)

Pollutant	Port	GWP20	GWP100
CO_2	Bodrum Cruise Port	9,392.7	9,392.7
	Yalikavak Marina	25,048.2	25,048.2
CO	Bodrum Cruise Port	197.9	59.3
	Yalikavak Marina	575.6	172.7
Total	Bodrum Cruise Port	9,590.6	9,452.0
	Yalikavak Marina	133,142.6	12,0195.7

GWP: Global warming potential.

5. CONCLUSION

This study has calculated emission values for ships for the ships passing through the Aegean Sea close to Bodrum that hoteled in Yalikavak Yacht Marina and cruise ships staying in Bodrum Cruise Port in 2021 and 2022 using the bottom-up calculation method of the assumption based on the known engine approach. The emission amounts for such pollutants as CO_2, CO, NOx, PM, NMVOC, were calculated, as well as the direct results of combustion- and fuel-sourced pollutants. The first issue was the increase in NOx emissions at Bodrum Cruise Port, as it had not hosted any Cruise ships in the previous years. This increase can be explained by the fact that the ships arriving in 2022 used more medium-speed engines, most of the ships had been manufactured before 2010, and these ships had higher ratios of gross tonnage to engine power. The second point involves the decrease in SOx emissions, especially in comparison to the studies in other marinas from past years, with sulfur levels in fuels being reduced to 0.1% in 2020, regardless of the opposite phenomena mentioned in the first point. This decrease brought along a decrease in PM_{10} values. Compared with the dates of construction, gross tonnage, and installed engine power of the passing ships, the GT / kW ratios of the ships built before 2000 were approximately equal to 2/1. This value increased to 2/3 for 2000–2010 and to 3/7 after 2010. This means all ships that will pass through the ECA will use low sulfur fuels, and thus an approximately 70% improvement was expected to be calculated in SOX emissions. In addition, PM levels decreased in proportion to the sulfur content in the fuel. However, because PM formation depends on combustion parameters as well as sulfur content, the effect was not as pronounced as had been for SOX emissions. These improvements are expected to increase with the increase in the number of regions declared as ECA. When comparing the calculation results in the final stage of the study while considering port type, all calculations show that being a green port such as Bodrum Cruise Port has many advantages for nature and sustainability, as Yalikavak Yacht Marina was shown to have much higher emissions compared to Bodrum Cruise Port.

DATA AVAILABILITY STATEMENT

The published publication includes all graphics and data collected or developed during the study.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

USE OF AI FOR WRITING ASSISTANCE

There is no usage of AI for writing assistance.

FINANCIAL DISCLOSURE

The authors declared that this study has received no financial support.

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