

Carbon Emissions from Cruise Ships: A Case Study in The Ports of Souda and Heraklion, Crete, Greece

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ABSTRACT: Modern cruise ships consume considerable amounts of energy and emit large quantities of greenhouse gases during their luxury trips compared with other types of tourism. During the last years the ports of Souda and Heraklion, Crete host a large number of cruise vessels. The carbon emissions of cruise ships during their mooring in the abovementioned ports have been estimated using data from the existing literature. The alternative fuels which can be used in these cruise ships decreasing their emissions have been also examined. The carbon emissions from the mooring of cruise vessels in Souda port in 2024 have estimated at 16,505 tCO₂ while in Heraklion port at 30,537 tCO₂. Cruise ships face mounting pressure to reduce their environmental impact and alternative fuels are central to this transformation. Several alternative fuels including LNG, biofuels, hydrogen, ammonia, methanol, and electricity can be used in cruise ships substituting the fossil fuels currently used like heavy fuel oil. The ports of Souda and Heraklion should develop the necessary infrastructure to provide alternative fuels and on-shore electricity to cruise vessels approaching these ports in the near future. The current study could be useful to ports' authorities in Crete, to cruising companies as well as to the stakeholders of Cretan ports.

KEYWORDS: alternative fuels, carbon emissions, Crete-Greece, cruise ships, ports

1. INTRODUCTION

Luxury cruising is expanding rapidly nowadays although it consists one of the most polluting types of tourism. The energy consumption and the gas emissions per passenger in cruising vessels are very high compared with the emissions in other types of tourism. [1], [2], [3]. The air pollution from cruising ships including the emissions of CO₂, SO₂, NO_x and particulate matter have been estimated in several studies [4], [5], [6]. Mitigation of climate change requires the replacement of the polluting fossil fuels currently used in cruising ships with low- or zero-carbon emission alternative fuels [7], [8], [9], [10].

The aims of the current study are:

- a) *An estimation of carbon emissions from large cruise ships,*
- b) *An estimation of carbon emissions of cruise ships approaching the ports in Chania (Souda) and Heraklion in Crete, and*
- c) *Examination of the alternative fuels which can be used by cruise ships to reduce their carbon emissions.*

The structure of the text is as follows: After the literature survey the energy consumption and carbon emissions in large cruise ships are stated. In the next two sections the carbon emissions from cruising vessels in the ports of Souda and Heraklion, Crete are estimated followed by the presentation of the alternative fuels that can be used in cruising ships substituting the fossil fuels currently used. The text ends with discussion of the findings, the conclusions drawn and the citation of the references used.

The text fills the gap regarding the climate impacts from the increasing number of cruising vessels visiting the main ports in Crete while it highlights the alternative fuels which should be used in cruising ships to minimize their carbon footprint in the future. It could be useful to ports' authorities in Crete, to local municipalities, to stakeholders of Cretan ports, to cruising companies as well as to policy makers who are developing appropriate policies to achieve the elimination of the net-carbon footprint in Crete by 2050.

2. LITERATURE SURVEY

A report on energy use and CO₂ emissions from cruise ships has been published [1]. The report stated that cruise ship tourism is the fastest growing type of tourism worldwide. It is also mentioned that around two thirds of the energy use and the resulting CO₂ emissions by cruise vessels are from the transportation task and the remaining one third is from the electrical demand on board of the vessels. The report stated that CO₂ emissions from cruise ships have been calculated in the range of 93-615.7 kgCO₂ per



passenger per day and of 198.9-1,314.5 grCO₂ per passenger per kilometer. A report regarding the GHG emissions from ships has been published [2]. The report stated that shipping is a small contributor to the world total CO₂ emissions representing only 1.8% of world total CO₂ emissions in 1996. It is also mentioned that technical and operational measures have a limited potential in reducing emissions from ships. The carbon emissions from international cruise ships passengers' travel to and from New Zealand have been estimated [3]. The authors stated that the weighted mean energy use per passenger night for the "hotel" function of these cruise vessels was estimated at 443 kWh per visitor night that is 12 times higher than the value in a land-based hotel. A report regarding the carbon footprint of vacations comparing the cruising versus land vacations focusing on Seattle, USA has been published [4]. It is stated that the average carbon footprint in a cruise ship is at 421.43 kgCO₂ per passenger per day while the average carbon footprint in land vacations is at 51.88 kgCO₂ per day per person. A report regarding the return of the cruise tourism after the pandemic has been published [5]. The report stated that the total CO₂ emissions of cruise ships in 2022 in EU ports were at 8,126,036 tnCO₂ compared to 6,965,227 tnCO₂ in 2019. It is also mentioned that a single LNG cruise ship emits as much methane (CH₄) as 10,500 cows in a year. An assessment of the emission impacts of cruise ships during 2019-2020 has been conducted [6]. The authors stated that carbon emissions from cruise ships at birth correspond at around one third of their total carbon emissions. They also mentioned that emissions were sharply decreased in 2020 due to the pandemic. The use of alternative fuels in shipping industry has been explored [7]. The authors studied the advantages and drawbacks of LNG, hydrogen (H₂), methanol (CH₃OH) and ammonia (NH₃). They stated that there are economic, technical, environmental and social barriers hindering their use in ships. A survey of alternative fuels and technologies for ships has been published [8]. The report stated that international shipping accounts of approximately 2-3% of the global CO₂ emissions during 2012-2018. It is also mentioned that LNG can be used as a transitional marine fuel towards decarbonization. However, they mentioned, LNG can be only used in some sectors of the shipping industry. The maritime fuels of the future have been studied [9]. The authors using multi-criteria analysis stated that upgraded bio-oil, Fischer-Tropsch diesel and liquefied bio-methane can be considered as the most promising maritime fuels of the future. A report comparing various alternative marine fuels has been published [10]. The authors examined several parameters of biofuels such as: energy density, energy cost, capital cost and well-to-wake GHG emissions. They also conducted a multi-criteria analysis of the conventional and non-conventional fuels such as HFO, low Sulphur fuels, LNG, methanol, LPG, advanced biodiesel, NH₃, H₂ and electricity. The impacts of emissions from cruise ships focusing on Piraeus port, Greece have been calculated [11]. The authors stated that in 2018 the total carbon emissions by cruise ships in Piraeus port were 14,769.49 tnCO₂ while in 2019 16,612.47 tnCO₂. The environmental impacts in cruise seaports in northern Europe have been assessed [12]. The author examined the ports' strategies to monitor and reduce the pollution from ships. He stated that ports use several indexes such as: a) the environmental ship index, b) the energy efficiency design index, and c) the environmental clean index to monitor the pollution. The cruise ship emissions and their externalities in Dubrovnik and Kotor ports in Adriatic Sea have been examined [13]. The authors estimated the emissions in NO_x, SO₂ and total PM. They proposed that the pricing policy in cruise ships should include a pollution fee according to the principle that "the polluter pays". The environmental impacts of passenger ferries and cruise vessels in Crete, Greece during 2018-2020 have been assessed [14]. The authors stated that the mean mooring duration of cruise ships in the ports of Souda and Heraklion is in the range of 9 hours and 6 minutes to 15 hours and 6 minutes. They calculated the CO₂ emissions during 2019 in Souda port at 6,005 tnCO₂ and in Heraklion port at 8,385 tnCO₂. The optimization of fuel saving in ships has been studied [15]. The authors stated that their proposed optimization method achieves fuel saving of up to 3.3% with conventional engines and 2.7% with next generation engines. The optimal design and operation of cruise ship multi-energy systems using appropriate models have been investigated [16]. The authors stated that using solid oxide fuel cell technology significant reductions of GHG emissions are achieved compared to using internal combustion engines. The pollutant emissions in cruise ships in western Mediterranean have been analyzed [17]. The authors analyzing data from 292 cruise routes stated that cruising activities accounts at 1% of the total CO₂ emissions associated with maritime transport at European level in 2019. The energy consumption and gas emissions in ships have been estimated [18]. The authors stated that the effective prediction of the energy consumption and emissions in ships is essential to achieve energy savings and reduction of their emissions. They also mentioned that the goal is to reduce carbon intensity by at least 40% until 2030 and 70% by 2050. The use of alternative fuels in fishing vessels has been examined [19]. The authors stated that methanol is the most suitable alternative fuel having 22.4% lower GHG emissions and 23.3% lower costs compared to diesel-powered fishing vessels. A report related to alternative maritime fuels has been published [20]. The report stated that currently only 4% of the ships consume alternative fuels while in shipyards 20% of the new ships are manufactured to use alternative fuels. It is also mentioned



that the required amount for a full transition to zero-emission fuels in shipping industry would be 440 mils. TN/year methanol, 470 mils. TN/year ammonia, 180 mils. TN/year LNG and 70 mils. TN/year hydrogen. The use of alternative fuels for eliminating the carbon emissions in container ships has been investigated [21]. The authors studied the use of bio-LNG, bio-methanol and green ammonia as alternative fuels. They stated that bio-methanol and green NH_3 are appropriate fuels while a single alternative fuel cannot achieve decarbonization in the examined scenarios. The challenges and opportunities for alternative fuels in the maritime sector has been explored [22]. The authors stated that LNG and LPG are low cost fuels while biofuels are considered as the next generation of maritime fuels. They also mentioned that other renewable, bio-based fuels such as methanol and green ammonia can be used in ships in the future. The decarbonization of cruise ships using energy saving technologies and hydrogen focused on cruise ships in Mediterranean region has been studied [23]. The authors stated that the use of various energy saving technologies can reduce the heavy fuel oil (HFO) consumption by 18.7% while the additional use of hydrogen machinery can achieve an overall fuel reduction by 25%. A study on the use of ethyl alcohol and methyl alcohol as alternative fuels in shipping has been published [24]. It is stated that both alcohols are available in significant quantities and they have many environmental advantages compared to conventional fuels. The cost of methanol is lower than the cost of conventional fuels while the cost of ethanol is higher. A report on next-generation energy efficient technologies for cruise ships has been published [25]. These technologies comprise: a) ship management system modeling and simulation, b) propulsions power optimization, c) bulbous bow optimization, and d) on-board fuel cells. The cruise vessels and the cruise passengers in the ports of Souda and Heraklion in 2023 and 2024 have been reported [26]. The alternative sources of power in maritime transport have been reviewed by the EU Maritime Safety Agency [27]. These power sources include: synthetic fuels, wind energy, hydrogen, on-board battery energy storage systems, biofuels, ammonia, shore-side electricity and nuclear power. The carbon emissions due to tourism in the island of Crete, Greece have been estimated [28]. The author stated that the calculated average carbon emissions were 488.77 kgCO_2 per visitor. The energy consumption and the use of RES in five summer operating hotels in Crete, Greece have been estimated [29]. The author stated that their mean energy consumption was 19.4 kWh per night spent (p.n.s.) while their average carbon emissions were 12.1 $\text{kgCO}_2/\text{p.n.s.}$

3. ENERGY CONSUMPTION AND CARBON EMISSIONS IN LARGE CRUISE SHIPS

Cruise tourism has grown significantly over the past few decades, transforming from a niche activity into a mainstream vacation option for millions of people worldwide. Modern cruise ships are often described as "floating cities," offering restaurants, theaters, shopping centers, pools, and even amusement park rides. However, this level of luxury and convenience comes at a steep environmental cost. Among the most pressing concerns are the high levels of energy consumption and carbon emissions associated with the operation of large cruise ships. These vessels, while symbols of leisure and global travel, are also some of the most energy-intensive forms of transportation per passenger. Understanding the scale of their fuel use, their carbon footprint, and the measures being taken—or neglected—to mitigate these impacts is crucial in assessing the sustainability of the cruise industry.

3.1 Energy Consumption in Large Cruise Ships

The primary driver of energy demand on cruise ships is propulsion. Most large vessels are powered by massive diesel engines, typically burning heavy fuel oil (HFO), also known as bunker fuel. This type of fuel is one of the dirtiest fossil fuels available, with high sulfur content and significant carbon intensity. Depending on size and design, a large cruise ship can consume between 150 and 250 tons of fuel per day while at sea. To put this into perspective, a single day's fuel consumption on one cruise ship can equal that of thousands of cars over the same period. But propulsion is not the only contributor to energy consumption. Cruise ships also need enormous amounts of electricity to maintain the comfort and amenities expected by passengers. Air conditioning systems, lighting, entertainment facilities, elevators, kitchens, laundry, and waste treatment all require power. It has been reported that around two thirds of the energy use and the resulting CO_2 emissions by cruise vessels are from the transportation task and the remaining one third is from the electrical demand on board of the vessel [1], [6]. For example, a modern mega-ship can carry nearly 7,000 passengers and over 2,000 crew members. Providing electricity, heating, cooling, and water services for nearly 9,000 people at sea is akin to supplying a small city. This makes energy management a central challenge in cruise ship design and operation. Table 1 indicates the energy consumption per passenger-kilometer for different modes of transport.



Table 1. Energy consumption per passenger-kilometer for different modes of transport

Mode of transport	Direct energy use (MJ per passenger-kilometer)
Passenger car (diesel)	0.829
Passenger car (gasoline)	0.940
Express bus	0.710
Regional train	0.598
Boeing 737 (400 km)	2.599
Boeing 737 (950 km)	2.160
Cruise ship (Norwegian case study)	1.8 – 11.94

Source: [1]

3.2 Carbon Emissions and Environmental Impact

The high energy demand of cruise ships translates directly into substantial carbon emissions. According to the International Council on Clean Transportation, a single large cruise ship can emit more carbon dioxide (CO₂) per passenger kilometer than a commercial airplane. While planes are often criticized for their carbon footprint, cruise ships combine both long travel distances and continuous hotel-like operations, resulting in disproportionately high emissions. A single cruise ship can emit over 250,000 tons of CO₂ annually, depending on its size and itinerary. To provide perspective, this is comparable to the annual carbon footprint of tens of thousands of households in developed countries. In addition to CO₂, cruise ships emit nitrogen oxides (NO_x), sulfur dioxide (SO₂), and particulate matter, all of which contribute to air pollution, acid rain, and respiratory problems in port cities. One particularly concerning factor is the reliance on heavy fuel oil. Even with the International Maritime Organization (IMO) enforcing stricter sulfur limits in 2020 (reducing the maximum sulfur content in marine fuels from 3.5% to 0.5%), many ships continue to rely on "scrubbers" to comply. Scrubbers allow ships to continue burning high-sulfur fuel by cleaning emissions before release. However, this often results in sulfur-rich wastewater being discharged into the ocean, shifting the environmental burden from air to sea. Port cities and coastal regions are especially vulnerable to the emissions of cruise ships. For example, studies in European ports such as Barcelona and Venice have shown that cruise ships are often among the largest single contributors to local air pollution. This is particularly problematic when ships idle in port for hours or days, running engines continuously to maintain onboard services. According to the existing literature the average carbon emissions in cruising vessels is 421.43 kgCO₂ per passenger per day [4] while other studies indicate that the carbon emissions fall in the range of 93 - 615.7 kgCO₂ per passenger per day [1]. Table 2 indicates the CO₂ emissions per passenger-kilometer for different modes of transport.

Table 2. CO₂ emissions per passenger-kilometer for different modes of transport

Mode of transport	CO ₂ emissions (grCO ₂ per passenger-kilometer)
Passenger car (diesel)	61.6
Passenger car (gasoline)	69.4
Express bus	52.2
Train (electric)	0
Boeing 737 (400 kilometers)	191
Boeing 737 (900 kilometers)	158
Cruise ships (Norwegian case study)	139 - 920.15
Cruise ships (average Norwegian cruises)	285
Cruise ships (several studies)	198.9 - 1,314.5

Source: [1]

3.3 The Ethical Dilemma of Cruise Tourism

The cruise industry faces a fundamental tension: it markets itself as a sustainable way to travel while operating ships that are among the most polluting forms of tourism. This raises ethical questions about the responsibility of both companies and travelers. Should companies be allowed to profit from offering environmentally harmful vacations? And should travelers reconsider cruise tourism



given its disproportionate carbon footprint compared to alternatives such as rail or local tourism? While some cruise lines highlight their investments in cleaner technology and sustainability programs, critics argue that these measures often amount to greenwashing rather than systemic change. For example, even with LNG adoption, the overall emissions of a mega-ship remain extraordinarily high. Without substantial innovation and a shift in consumer expectations, the industry is unlikely to align with global climate goals.

4. CRUISE SHIPS IN CRETAN PORTS

During the last few years many cruise vessels are approaching the main ports in Crete, in Heraklion port and in Souda port, Chania. The number of cruise ships in Crete are increasing rapidly particularly after the end of the pandemic. Table 3 indicates the number of cruise ships and passengers during 2023 and 2024 in the ports of Souda, Chania and Heraklion in Crete.

Table 3. Number of cruise ships and passengers in the ports of Chania (Souda) and Heraklion in Crete

	2023	2024
Cruise ships in Souda’s port	122	131
Passengers in Souda’s port	217,552	279,754
Cruise ships in Heraklion’s port	371	266
Passengers in Heraklion’s port	453,852	518,575

Source: [26]

For the estimation of the carbon emissions from the cruise vessels during their mooring in the ports of Souda and Heraklion the following assumptions have been made:

- a) The average carbon emissions in cruise ships are 354 kgCO₂ per day per passenger [1], [4],
- b) The cruising ships remain in the ports of Souda and Heraklion on the average half day [14],
- c) The carbon emissions from cruise ships in the ports of Souda and Heraklion are due only to electricity consumption on the vessel, and
- d) Two thirds of the carbon emissions in cruise ships are due to transportation and one third to electricity use on board offering the luxury amenities to passengers [1], [6].

Table 4 indicates the carbon emissions from cruise ships in Souda and Heraklion ports during 2023 and 2024.

Table 4. Carbon emissions from cruise ships in Souda and Heraklion ports

	Souda port-Chania	Heraklion port
Average mooring time in the ports	0.5 day	0.5 day
Carbon emissions in the ports	59 kgCO ₂ per passenger	59 kgCO ₂ per passenger
Passengers (2024)	279,754	518,575
Total carbon emissions (2024)	16,505 tnCO ₂	30,537 tnCO ₂
Passengers (2023)	217,552	453,852
Total carbon emissions (2023)	12,836 tnCO ₂	26,777 tnCO ₂
Increase in carbon emissions 2024/2023	28.58 %	14.04 %

Source: own estimations

5. ALTERNATIVE FUELS FOR CRUISE SHIPS: PATHWAYS TO DECARBONIZATION

Modern cruise ships are powered primarily by heavy fuel oil (HFO), marine gas oil (MGO), or very low sulfur fuel oil (VLSFO), all of which emit significant amounts of carbon dioxide, sulfur oxides, nitrogen oxides, and particulate matter. The International Maritime Organization has set targets to reduce total greenhouse gas emissions from shipping by at least 50% by 2050 compared to 2008 levels, with a longer-term goal of achieving net-zero emissions. To meet these targets, cruise lines must transition away from traditional marine fuels toward cleaner alternatives.



5.1 Liquefied Natural Gas (LNG)

Liquefied natural gas has emerged as the most widely adopted alternative fuel in the cruise sector so far. Several of the largest cruise lines have already launched LNG-powered ships. LNG offers a cleaner combustion profile compared to residual fuels. It virtually eliminates sulfur dioxide emissions and reduces nitrogen oxides and particulate matter by up to 90%. Importantly, LNG can lower CO₂ emissions by approximately 20% on a tank-to-wake basis compared to heavy fuel oil. Despite these improvements, LNG remains a fossil fuel. Methane leakage, or “methane slip,” during production, transport, and combustion undermines its climate benefits, since methane is a potent greenhouse gas with a global warming potential more than 25 times higher than CO₂ over a 100-year timescale. Additionally, global LNG bunkering infrastructure is limited, though it is expanding in major cruise hubs such as Miami, Barcelona, and Singapore. From a long-term perspective, LNG is often considered a transitional rather than ultimate solution for decarbonization.

5.2 Biofuels

Biofuels, derived from organic matter such as used cooking oil, animal fats, or crop residues, offer the potential for significant lifecycle reductions in greenhouse gas emissions. Unlike LNG, biofuels can often be used as “drop-in” replacements in existing engines and fuel systems, requiring little or no modification of ship infrastructure. Pilot trials with blends of biodiesel and conventional marine fuels have demonstrated technical feasibility in cruise ships and other vessels. The sustainability of biofuels depends heavily on feedstock. If produced from waste oils or residues, biofuels can achieve meaningful carbon savings. However, large-scale reliance on first-generation biofuels made from food crops risks land-use change, biodiversity loss, and competition with food and animal feed production. Furthermore, global production volumes of sustainable biofuels remain limited, making it unlikely that biofuels alone can meet the long-term energy needs of the cruise industry.

5.3 Fuel Cells and Hydrogen in Cruise Ships

The cruise industry is actively exploring hydrogen and fuel cells as pathways toward zero-emission operations. Hydrogen, when used in fuel cells, produces only electricity, heat, and water, eliminating carbon dioxide and harmful air pollutants at the point of use. This makes it an attractive option for a sector under pressure to decarbonize. Fuel cells are highly efficient compared to internal combustion engines and can provide clean electricity for propulsion as well as hotel services onboard. Several pilot projects are testing hydrogen-powered fuel cell modules to support auxiliary loads. Over time, scaling these systems could significantly reduce emissions during port stays and short voyages. However, major challenges remain. Hydrogen has a low volumetric energy density, requiring either compression or liquefaction at extremely low temperatures, both of which demand heavy, insulated tanks that compete with passenger and service space. At present, most hydrogen is produced from natural gas, resulting in substantial upstream emissions. Only “green hydrogen” made through water electrolysis with renewable electricity, offers a truly sustainable solution, though it is costly and limited in availability. Therefore, hydrogen and fuel cells hold great promise for clean cruising but require further technological advances, infrastructure development, and cost reductions before large-scale adoption becomes feasible.

5.4 Ammonia

Ammonia has gained attention as a promising zero-carbon marine fuel. It contains no carbon and therefore emits no CO₂ when combusted. Ammonia can be used directly in modified internal combustion engines or in fuel cells, and it is already widely traded and stored globally for use in fertilizers and chemicals, which means some infrastructure exists. Unlike hydrogen, ammonia has a higher volumetric energy density, making storage and transport comparatively easier. The main drawbacks of ammonia are related to safety and emissions. Ammonia is highly toxic and poses health risks in the event of leaks. Its combustion can also produce nitrogen oxides, which must be controlled with advanced after-treatment systems. Furthermore, most ammonia today is produced from fossil natural gas, making it “grey ammonia.” Only when produced from renewable hydrogen and nitrogen captured from the air does it become “green ammonia,” capable of delivering true decarbonization. Costs are currently very high, and the technology is still at the early demonstration stage for large vessels.

5.5 Methanol

Methanol is a liquid at ambient temperatures, making it easier to store and handle compared to hydrogen or LNG. It can be produced from natural gas (grey methanol), biomass (bio-methanol), or renewable electricity combined with captured CO₂ (e-methanol). When produced from renewable sources, methanol offers a potentially carbon-neutral fuel pathway. Several large shipping companies are already investing heavily in methanol-powered ships, signaling growing confidence in the fuel. Methanol has about



half the energy density of conventional marine fuels, meaning ships need larger fuel tanks or more frequent refueling. Current methanol supply chains for marine use remain small, and the cost of “green methanol” is substantially higher than fossil fuels. Nevertheless, the relative ease of retrofitting existing engines to run on methanol makes it an attractive near-term option.

5.6 Electricity and Hybridization

For short-distance passenger ferries, battery-electric propulsion has already been deployed successfully. Batteries eliminate local emissions and can be charged with renewable electricity. Hybrid systems, which combine batteries with conventional engines, allow cruise ships to reduce fuel consumption during maneuvers, in port, or on short legs, improving efficiency and lowering emissions. The sheer scale of energy demand on cruise ships makes fully electric operation unrealistic with today’s battery technology. Large ships require several gigawatt-hours of energy storage capacity for a single voyage, far beyond what current lithium-ion batteries can deliver in terms of weight and volume. However, as battery technologies improve and charging infrastructure expands in ports, hybridization will likely play a growing supporting role in emission reduction strategies.

5.7 Solar and Wind Energy in Cruise Ships

Renewable energy sources such as solar and wind are often highlighted as potential solutions in cruise vessels. While neither can fully meet the enormous power demands of modern cruise liners, solar and wind energy offer opportunities to supplement traditional fuels, improve efficiency, and reduce emissions. Solar energy has been tested on several ships, mainly through solar photovoltaic panels integrated into decks, rooftops, or shading structures. The electricity generated can power lighting, navigation systems, and auxiliary equipment. For instance, some cruise companies have experimented with solar panels to supply part of its hotel load. However, the space available for panels on a cruise ship is limited compared to its total energy demand. Even a large solar installation may only cover a fraction of the daily electricity requirement, which can exceed several megawatt-hours. Intermittency is another challenge, as generation depends on weather conditions and daylight. Nevertheless, solar energy remains attractive for reducing fuel consumption incrementally and for symbolic value in promoting sustainability.

Wind energy offers additional potential, especially through modern wind-assist technologies. These include rigid sails, kites, and rotor sails that harness wind power to reduce the load on engines. For example, rotor sails have already been deployed successfully in commercial shipping, demonstrating fuel savings of 5–15%. Applied to cruise ships, such systems could cut fuel consumption on favorable routes, particularly transoceanic voyages with consistent wind patterns. Unlike traditional sails, these technologies can be automated and designed to minimize interference with passenger amenities. The main challenge is scale: neither solar nor wind energy can replace the gigawatt-hours of energy required to power propulsion, air conditioning, and hotel services on a cruise ship. Instead, they should be viewed as complementary solutions that reduce reliance on fossil fuels. Combined with alternative fuels and efficiency measures, solar and wind energy can help the industry take incremental steps toward decarbonization. Therefore, while solar and wind energy alone cannot solve the cruise sector’s emissions challenge, they represent important components of a broader strategy. By integrating these technologies, cruise lines can improve efficiency, cut operating costs, and demonstrate commitment to sustainable innovation. Table 5 indicates the alternative fuels which can be used in large cruise ships.

Table 5. Alternative fuels which can be used in large cruise ships

	Fuel
1	Liquefied Natural Gas -LNG
2	Biofuels
3	Hydrogen and fuel cells
4	Ammonia
5	Methanol
6	Electric batteries and hybrid vessels
7	Shore-side electricity
8	Solar photovoltaic energy
9	Wind energy
10	Nuclear power

Source: various authors



6. DISCUSSION

The energy consumption and the carbon emissions of cruise ships have been estimated and their carbon emissions during their staying in Souda port and Heraklion port, Crete have been evaluated. Additionally, the alternative fuels that can be used in cruise vessels have been explored. The published research stated that cruise ships consume approximately double amount of energy in transportation than the electricity consumption on the vessel offering luxury amenities on board to their guests. Our estimated carbon emissions in 2024 in the ports of Souda and Heraklion at 16,505 tCO₂ and 30,537 tCO₂ were significantly higher than the emissions estimated in the same ports by [14] in 2019 at 6,005 tCO₂ and 8,385 tCO₂ correspondingly. They can be also compared with the carbon emissions in 2019 in Piraeus port at 16,612.47 tCO₂ [11]. The difference can be explained from the sharp increase of cruise ships' arrivals in these two Cretan ports during the last years. In the port of Heraklion, the cruise passengers have been increased from 307,043 in 2019 [30] to 518,575 in 2024 (table 3), a 68.89% increase during this period. The ports of Souda and Heraklion should be able to offer on-shore power in the future, preferably based on renewable energies, to the cruise vessels to reduce their emissions during their mooring. This requires significant financial resources for developing the necessary energy infrastructure in these ports. The estimated carbon emissions from cruise ships during their half-day staying in the ports of Souda and Heraklion, at 59 kgCO₂/p.n.s. (table 4), is almost five times higher than the carbon emissions in on-land hotels in Crete, at 12.1 kgCO₂/p.n.s. [29]. The large number of tourists arriving in the cities of Chania and Heraklion with cruise ships for one day increases the existing high number of tourists contributing in over tourism in these two cities in Crete. The accuracy of our estimations depends on the accuracy of the data used and the assumptions made. Taking into account that the carbon emissions in cruise ships depend on many factors our estimations should be considered as indicative. Future work should be focused on the description of the ports' energy systems required to provide on-shore green power and alternative fuels to the cruise vessels during their mooring in these two ports.

7. CONCLUSIONS

The energy consumption and the carbon emissions in cruise ships focusing on the ports of Souda and Heraklion, Crete, Greece have been estimated. Additionally, the use of alternative fuels for reducing the carbon emissions in cruise ships has been explored. The carbon emissions from the mooring of cruise vessels in Souda port in 2024 have estimated at 16,505 tCO₂ while in Heraklion port at 30,537 tCO₂. Unfortunately, the necessary infrastructure for providing on-shore electricity or alternative fuels in cruise ships in these two ports are lacking. Large cruise ships embody the paradox of modern tourism: they provide comfort, entertainment, and the promise of exploration while simultaneously imposing a massive environmental cost. Their energy consumption and carbon emissions are disproportionately high relative to other forms of transportation and tourism, making them significant contributors to climate change and local pollution. While mitigation strategies such as LNG, shore power, and efficiency improvements offer some progress, they remain insufficient given the scale of the challenge. Ultimately, achieving meaningful reductions will require not only technological innovation and stricter regulations but also a cultural shift in how society perceives cruise travel. The question is whether the luxury of cruising can ever be reconciled with the urgency of decarbonization—or whether the model of the mega-ship is fundamentally incompatible with a sustainable future. Cruise ships face mounting pressure to reduce their environmental impact, and alternative fuels are central to this transformation. While traditional heavy fuel oil has dominated the past century, the next decades will see a gradual diversification of marine energy sources. Each alternative fuel—LNG, biofuels, hydrogen, ammonia, methanol, and electricity—comes with trade-offs in terms of cost, infrastructure, scalability, and emissions performance. The challenge for the cruise industry is not simply technological but also strategic. Cruising companies must invest in flexible ship designs that can adapt to evolving fuel options, while governments and regulators must support the development of global bunkering infrastructure and renewable fuel production. Consumers, too, may need to accept higher prices for more sustainable cruising. Ultimately, the adoption of alternative fuels is not optional; it is essential if cruise ships are to reconcile the luxury of sea travel with the imperative of climate action.

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