MSc Urban Port and Transport Economics

The impact of the CO2 emissions from cruise ships on the port's air quality and the IMO legislation to reduce them: Case study Port of Piraeus.

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Abstract

Air pollution is one of the most critical environmental problems facing humanity in recent years. The emission rates of carbon dioxide and other pollutant gasses from ships are significant. Both the European Union and the International Maritime Organization have set multiple rules and regulations to enable ports and shipping companies to reduce emissions. This research concerns the main port of Greece, the port of Piraeus and specifically the cruise ships that docked at it. The main question of the research is the impact of emissions in the port and how it can react to the IMO legislation to decrease air pollutants.

In addition, it aims to calculate and compare the CO2 emissions in the port for the years 2018, 2019, and 2020. There are plausible causes for the differences between the years and the months. A representative example is the pandemic that shook the world at the beginning of 2020. There are differences between 2019, where cruise ship arrivals reached the number 622, and 2020, where due to the measures to reduce the spread of the virus in the port, only 76 cruise ships entered. Finally, in the last part of the work, four possible scenarios for the port's future are presented. These scenarios estimate both cost savings and emission reductions if land supply facilities are built in the cruise port of Piraeus.

1. Introduction

In general, global tourism has increased dramatically in the last decade due to technology. UNWTO International Tourism Growth Continues To Outpace The Global Economy report shows that 1.5 billion tourist arrivals were recorded in 2019 globally (UNWTO, 2019). That means a rise of 4% compared to the previous year. The same increase was also expected for 2020, and some of the most important reasons were the Olympic Games in Tokyo and other cultural events like the Expo 2020 in Dubai (UNWTO, 2019). However, people do not prefer to travel worldwide due to the coronavirus pandemic and Brexit in 2020 (UNWTO, 2019). The table below shows the global economic impact of the pandemic on the cruise industry. A vertical drop reached over 50% in all three cases (Cruise Lines International Association, 2022).

Year (millions)	Passengers Embarkations (millions)	Cruise-supported Jobs (millions)	Total Economic Contributions (billions of USD)
2019	29.7M	1.17M	$154B
2020	5.8M (-81%)	576K (-51%)	$63.4B (-59%)

Table 1: The Pandemic Highlights the Economic Importance of Cruises (Source: State Of The Cruise Industry Outlook. CLIA)

As a continent with numerous ports, Maritime transport is extremely strategically notable for the European Union. It manages 77% of EU foreign trade and 35% of total intra-Community trade in the EU (EMSA: European Maritime Safety Agency, 2021). Moreover, it maintains the smooth operation of the EU economy's supply chains. Converting the above percentages, we have about four billion tons of cargo handled in EU ports and 400 million passengers annually. In 2019, the first places in terms of gross weight and traded goods were held by the ports of Rotterdam, Antwerp, and Hamburg. Besides these, Algeciras, Piraeus, and Messina were the ports with the most port calls in the same year. In the same year, 46% of maritime traffic was domestic trips in the EU Member States (EMSA: European Maritime Safety Agency, 2021).

Suppose we want to make it more specific in Greece. In that case, tourism significantly influences the country's economy, especially from the seventies onwards, due to the coastline and the countless islands. Hundreds of tourists from all over the world choose Greece for their holidays, mainly during the summer months. Based on the OECD Tourism Trends and Policies 2020, the GDP of tourism in Greece accounts for 6.8% of the total GVA in 2017 (OECD, 2020). Also, the research emphasizes that 33.1 million tourists visited the country in 2018, an increase of 9.7% compared to the previous year. In addition, only 5.7 million tourists equate to domestic travel, and only 4.7% of them are related to business travel (OECD, 2020).

Maritime tourism is the industry's sector based on tourists and visitors taking part in active and passive leisure and holidays pursuits or journeys on (or in) coastal waters, shorelines, and immediate hinterlands (Jamshidi, 2015). Furthermore, this sector does not belong only to yachting and boating but also to cruise travel and coastal shipping. According to the Hellenic Ports Association, in 2017, about 3,400 cruise ships arrived in Greece, or in other words, 4.62 million passengers. In 2016, passengers in domestic transport reached 17.4 million while 1.52 million were passengers from international routes (Hellenic Port Association, 2019).

1.1. Fundamental impacts on the environment in general.

The critical impacts on the environment can be split into two main categories: emissions to the atmosphere and emissions to the water.

Nowadays, the most common environmental problem is air pollution. In addition to cars and factories, marine and air transport are essential contributors to global air pollution. Around 16% of worldwide SO2 from global shipping (or 1.63 million tonnes) in 2019 were from ships calling at EU ports (Prevljak, 2021).

The following diagram shows the five European countries with the highest percentages of GHG emissions and their comparison with the corresponding emissions from cars in 2017.

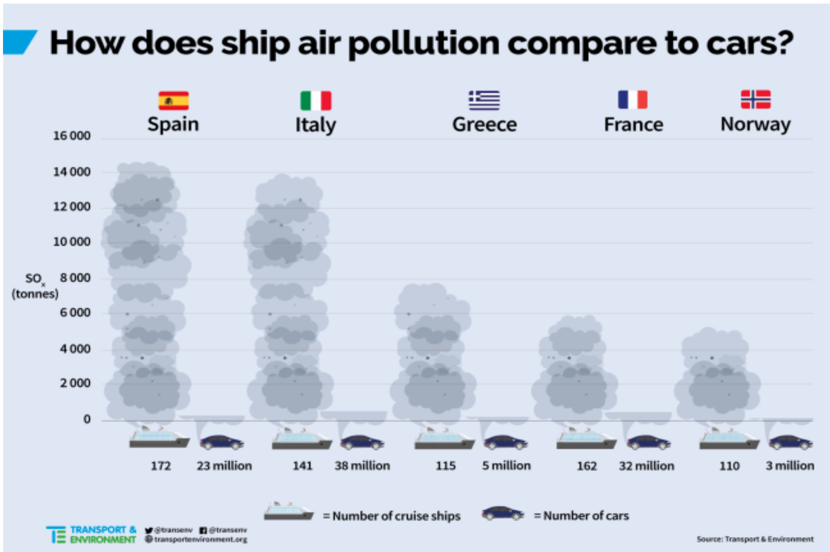


Figure 1:SOx emissions from cruise ships compared to the domestic automobile fleet in each nation. (Source: One Corporation Pollute them All. Transport and environment)

Moreover, 140 million tons of CO2 (18% of all emissions worldwide) were emitted when ships called at the European Economic Area and European Union in the same year. There are even more air pollutants such as Nitrogen oxides, Carbon monoxide, Particulate matter, Methane. Although there are not only these impacts on the environment from the maritime industry (Prevljak, 2021). Since we will not deal with them, we can namely mention them:

- Oil pollution or oil spills.
- Sound pollution: underwater and not.
- Water pollution: wastewater, bilge water and ballast water.
- Solid waste.

1.2. Problem: Case of Piraeus Port

Despite the economic advantages maritime tourism has in Greece, there are several disadvantages that are mainly related to the environment. A survey conducted in 2019 by Transport & Environment showed that luxury cruise brands had more Sulfur oxide emissions than all passenger cars in Europe in 2017 (Abbasov, Luxury cruise air emissions in Europe, 2019). Moreover, in the list of countries with the highest rates of air pollution from cruises are also Greece. More specifically, the country in 2017 was infected with 7,674 tons of Sulfur oxide, while the port of Piraeus with twenty-one tons. This is because most ships use a type of fuel called heavy fuel oil, which is economical but highly polluting.

Since the port is close to the city of Piraeus, all the emissions caused various problems. Firstly, cruising is a significant cause of pollution and damage, affecting the air, water, soil, vulnerable ecosystems, and wild animals. Moreover, the cruise ship industry and its externalities may pose physical and mental health concerns to passengers, crew, and land-based citizens living near the port or working in the shipyard (Lloret, Carreno , Caric, San, & Fleming, 2021).

Nowadays, due to climate change, more and more industries are trying to find more sustainable solutions to operate. They attempt first to protect the environment and people's health since they understand how urgent it is. If we want to be more specific, emissions and pollutants in general within ports are a problem that bothers all cruise harbors worldwide. For that reason, ports desire to become Green in diverse ways. For example, authorities use different measures to monitor the air and water quality in the harbor and the life quality. Moreover, there is signed legislation from EU members to reduce emissions within specific territories.

1.3. Research Questions

This research aims to analyze already existing data based on the port of Piraeus during the years 2018, 2019 and 2020. The leading research question is: What is the implication of new IMO legislation on CO_2 related to cruise ships?

There are three main objectives of our central question:

1. Understand the extent to which the port environment and the city of Piraeus are affected by the continuous emissions from cruise ships.
2. More evident and vital is how the European Union's or the International Maritime Organization's (IMO) legislation affects the port.
3. In what ways the problem can be eliminated.

However, to be able to answer our focal question, the following sub-questions must first be asked and answered. In this way, the research will be conducted better as there will be a better view of both the problem and its solutions. Moreover, the whole framework of his study is based on these sub-questions, and the answers to each one will take us step by step to the conclusions of the main question.

- What are the current emissions? Are there differences between the years? If yes, which are probable factors?
- What is the current and further IMO legislation?
- Looking forward: how will be the future of the emissions at the port?
- Are there some recommendations to solve the problem?

The above questions could be divided into two categories, quantitative and qualitative and theoretical analyses.

The first sub-question belonged to the category of quantitative questions since in that part of the research, the necessary calculations will be made that will bring us close to the situation that prevails in the port. We will examine any differences and where that may be due (Disruptive Scenarios or "Black swans") and compare years and months between them to reach more conclusions.

The next three sub-questions belong to the qualitative/theoretical category of questions. For the first one, the literature review will provide a detailed analysis of the current and future legislation already established and announced by the International Maritime Organization. Shortly before the end, we will try to estimate the future of the port of Piraeus if future legislation comes into force. The last part of this research will list recommendations that could be implemented for the port not to run any risk of sanctions from the European Union.

Based on the legislation of both the IMO and the E.U., which will be explained in more detail in the next section, on reducing greenhouse gas emissions, we will try to provide solutions in the port of Piraeus to comply and become more sustainable. More specifically, except for the literature review, the current and future legislation of the IMO and the E.U. are described in the second section. In addition, it is necessary to explain specific terms for a better understanding of the methodology followed and why specific data were obtained. The third section of the study is related to research, data collection and the methodology used to extract the results. The specific results are listed and explained in the fourth section through diagrams and tables. The fifth section of the paper will describe workable solutions to the problem based on the data of 2019 and investment amounts that will make the construction of shore supply facilities easier. In the last part of the research, general conclusions for the whole research area in the last section.

2. Literature Review

A large number of investigations examine the emissions in the shipping industry. Most of them are for global or national level and have to do with ocean-going merchant ships. Two well-known techniques can be used to test and calculate gas emissions, which are used in many studies; nominally bottom-up and top-down approaches. (Miola , Ciuffo, Giovine, & Marra, 2010; Tichavska & Tovar, 2015).The first is also known as the activity-based approach. The bottom-up approach is used to examine the pollution emitted at a specific location by a single vessel. If the same technique is applied to all ships eventually the total emissions will be calculated. In contrast, the top-down approach does not consider ship characteristics when calculating emissions. These are usually added to the analysis later. Finally, they note that the geographical factors must be calculated for the combination of the two techniques to be possible. In other words, both the number of emissions and where they are emitted (Miola , Ciuffo, Giovine, & Marra, 2010).

Wan et al., in their research on some of China's largest ports, used the bottom-up approach to examine emissions based on diverse types of ships, operating modes and discharge equipment (Wan, et al., 2020). Chang and Jhang, 2016 also use the bottom-up approach (or activity approach). They examine the extent to which air pollutants are reduced based on two scenarios: a boat speed reduction of 12 knots 20 nm away from the port, a second speed reduction of the boat at 12 knots, and fuel transfer 20 nm away from the port (Chang & Jhang, 2016).

In research of 2015 on the social cost of cruise ship emissions in the largest ports of Greece, A. Maragkogianni and S. Papaefthimiou used the bottom-up technique to estimate emissions for its five main ports. In addition to emissions, the monetary cost was also calculated to reflect the social impact. A key conclusion was that future costs are commensurate with industry efficiency, port traffic and growth (Maragkogianni & Papaefthimiou, 2015). Another paper investigates the effects of transport in the Adriatic-Ionian region on air quality using an approach that integrates emission index, statistical modeling, and experimental measurements with high and low temporal resolve (Merico , 2017). Through regression equation analysis, Toscano and Murena (2019) tried to examine whether emissions from passenger ships are correlated with traffic data (Toscano & Murena, 2019). The most basic of these conclusions to be taken into account is that the cruise ship category has the best correlation with the transport data and that there is generally a high degree of correlation uncertainty (Toscano & Murena, 2019).

A regression analysis to determine the relationship between emission indicators (CO2, NOX, SOX, and PM) and independent factors (passenger capacity, dock time, vessels Gross Tonnage) was conducted by De Melo Rodriguez et al. (2017). The investigation was based on 30 cruise ships at Barcelona's port and occurred through surveys and interviews with related shipping companies. Moreover, they measure the load factor, working duration of the thrusters, hoteling electric power and used fuel type. Finally, inventory emissions per port time gross tonnage, port time passenger and port time are the most relevant metrics (De Melo Rodríguez, Alcalde, González, & Saurí, 2017).

One more time, a bottom-up approach has been devised in this article to estimate the quantity of the air pollutants on the Naples' port's atmosphere and their influence on it. In-port operations considered, were arrivals and departures, maneuvering into it and hoteling for 2016. These were used to compute SOx and NOx emission amounts. In addition, the Gaussian puff model was utilized to evaluate the cruise ship emissions in the urban region. At the end of the research and after the necessary calculations, the authors concluded several uncertainties in the model, especially when comparing the results with other older research. In addition, they suggest some solutions so that the analysis can be as accurate as feasible in the future. One of the most critical is that studying and examining other pollutants in distinct types of ships would be vital (Murena, Mocerino , Quaranta, & Toscano, 2018).

The following investigations concern the emissions at port level and specifically have to do with the port of Piraeus.

Fewer of these surveys focus on cruise ships or smaller passenger ships that operate on island routes. More specifically, for the port of Piraeus, two surveys have been carried out, one for the terminal of containers (Tzannatos & Kilic, Ship Emissions and Their Externalities at the Container Terminal of Piraeus - Greece, 2014) and one for the passenger and cruise ships (Tzannatos, Ship emissions and their externalities for the port of Piraeus – Greece, 2010). However, important conclusions have been drawn from them. For example, in the second article, Tzannatos pointed out that air emissions within the port are about twice less for cruise ships than coastal passenger shipping. Moreover, he mentioned that seasonality plays a vital role because, in the summer months, the traffic is increased in Greece (Tzannatos, Ship emissions and their externalities for the port of Piraeus – Greece, 2010).

2.1. Legislations - Regulations

However, to achieve the goal and reduce pollution, the ports, the shipping companies, the port authorities, and the governments, both locally and nationally and globally, must agree. For many years now, the European Union and the International Maritime Organization (IMO) have issued numerous laws signed and enacted by many countries (and ports) worldwide to make them more sustainable.

2.1.1. International rules already established.

The IMO is responsible for protecting the environment from pollutants and the safety of ships. It is also responsible for better collaboration and contact between the Member states in shipping. All Member States of the European Union are also members of the IMO. As a result, they take part in discussions on changes to international agreements and the adoption of the necessary legislation. Nevertheless, only the E.U. is responsible for the decisions and laws in matters related to Europe.

The primary goal of IMO is the International Convention for the prevention of Pollution from the ships (MARPOL), *which is the fundamental regulation for the prevention of the pollution of the maritime environment from the ships or marine accidents* (International Maritime Organization, 2022). It includes six annexes that negotiate with different topics. The first was introduced in 1983 and is related to oil pollution, while the sixth and most recent entered into force in 2005 and deals with air pollution from ships. There have been several agreements from the founding of the organization until today (International Maritime Organization, 2022). The most recent is that of Hong Kong (2009), on recycling of ships after the end of their operations to ensure the safety of humans and the environment but is not yet unto force (EMSA: European Maritime Safety Agency, 2021).

Another critical committee that operates under the auspices of the IMO is the Marine Environment Protection Committee (MEPC). It is responsible for the environment, in particular of pollution from ships, covered by the MARPOL treaty, and includes the following: *emissions from ships, including air and greenhouse gas pollutants; oil, chemicals carried in bulk, garbage and sewage* (IMO, Marine Environment Protection Committee (MEPC), 2022). In 2018, in order to mitigate climate change, the IMO's Marine Environment Protection Committee (MEPC) developed a first plan for reducing GHG emissions. Commensurate with the Paris Agreement (12 December 2015) temperature targets (limit international warming to well below 2, preferably to 1.5 degrees Celsius) (UNFCCC, 2015), it mentions explicitly as a “pathway” of CO2 emissions reduction (Abbasov, Initial IMO GHG Strategy , 2018). In short, the above strategy states that it is necessary for emissions from ships to peak as quickly as possible so that by 2050 they can be reduced by up to 50% compared to 2008. In addition, efforts will be made to eliminate them in general. Finally, besides the mentioned above plans, IMO MEPC in 2018 agreed to another plan with 30 measures to decrease marine plastics and micro plastics from ships (EMSA: European Maritime Safety Agency, 2021).

2.1.2. European Rules already Established

A set of applications for ships sailing in E.U. seas or going to or from E.U. ports have been adopted by the European Union since the late 1990s. In addition, the specific laws also apply to ships traveling on domestic routes, in contrast to IMO laws that apply only to international transport and apply to all the ships regardless of the country in which they are registered. Some E.U. rules go beyond the IMO as it has a prominent position in the influence of global ambitions. Although, most Eu laws follow the same "path" as those of the International Maritime Organization (EMSA: European Maritime Safety Agency, 2021).

Most of them have to do with neighboring countries, such as agreements under the auspices of the United Nations Environment Program (UNEP) for the Regional Seas Program for the Mediterranean and Black Sea, or multilateral agreements on countries of the Baltic Sea and Northeast Atlantic. All these agreements between neighboring countries aim to better cooperation between them to protect the environment enclosed in specific water territories. Finally, these instruments aim to increase the effectiveness of the national response and improve the coherence of law enforcement (EMSA: European Maritime Safety Agency, 2021).

This study has to deal with air pollution; thus, we will focus on rules already in place and how to decrease or even eliminate these problems.

Since the seventies, Europe has been trying to tackle one of its main environmental problems: air pollution. The general rules applicable to the reduction of air pollution in the European area are contained in the Ambient Air Quality Directive. These rules include raising fuel quality, forwarding, and incorporating environmental safety within transportation and energy sectors, and declining emissions from mobile sources. Moreover, Member States develop national air pollution plans that should aid in the successful execution of air quality projects developed under the Ambient Air Quality Directive (EU, DIRECTIVE (EU) 2016/2284 Of The European Parliament And Of The Council, On The Reduction Of Certain Atmospheric Pollutants, 2016). The alternative Fuels Directive is another legislation related to reducing air pollution. Alternative fuels are defined as all the other fuels besides fossil fuels and as well as all other sources of energy. In other words, the "substitutes" of fossil fuels that can contribute to reducing carbon and increasing environmental performance in the transport sector (EU, DIRECTIVE 2014/94/EU Of The European Parliament And Of The Council, On The Development Of Alternative Fuels Infrastructure, 2014). Reducing reliance on oil, improving energy security in Europe, and reducing GHG emissions from transportation will occur by creating a competitive market for alternative fuels.

Furthermore, should be a reduction of 40% from 2005 levels by 2050, and if achievable, by 50% of the E.U.'s CO_2 emissions according to t the European Commission’s 2011 White Paper on Transport (EC, WHITE PAPER Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system., 2011). The E.C. announced a phased plan in June 2013 to gradually integrate marine emissions into the E.U.'s domestic GHG emissions reduction program. This plan is divided into three parts:

1. Monitoring, reporting and verification of CO_2 emissions from big ships utilizing E.U. ports
2. GHG reduction objectives for the marine transport sector
3. Creation of medium - to long-term remedies.

The E.U. regulation on the Monitoring, reporting and verification of carbon dioxide emissions from marine transport was enacted in 2015 as the first step in this direction. Large ships (above 5,000 gross tons) and their CO_2 generated on trips to, from and within E.U. ports have been subject to these requirements since 2018. Moreover, the European Commission suggested in its 2030 climate change goal plan to increase the E.U.'s intention to reduce GHG emissions by at least 55 percent below 1990 levels by 2030, including at least transport in the EU ETS. As part of the proposal for a Climate Law (EC, 2020b; EC, 2020c) adopted by the European Council in December 2020, this aim has been transformed into a legal duty (EC, 2020d).

2.2. Future IMO Regulations

In June 2021, amendments to the International Convention for the Prevention of Pollution from Ships (MARPOL) Annex VI were adopted, which require reductions in greenhouse gas emissions, by the Marine Environment Protection Committee (IMO, 2021). According to the goals set by the IMO in the initial statistics in 2018, these transformations will combine techniques for developing the energy efficiency of ships. They also provide data on measures to reduce Greenhouse gasses in the future (IMO, INITIAL IMO STRATEGY ON REDUCTION OF GHG EMISSIONS FROM SHIPS, 2018).
Based on MEPC. These measures are:

1. The Energy Efficiency Existing Ship Index (EEXI) (MEPC, 2021).
2. The Carbon Intensity Index (CII) (MEPC, 2021).

All the above two measures will be applicable by the beginning of 2023. Moreover, amendments were discussed and agreed upon for the MARPOL Annexes I and IV and will come into operation on November 1st, 2022. For only Annex I, ships are prohibited from using or transporting heavy fuel oil in Arctic seas. Then, for both Annex I and Annex IV, the Unmanned Non-Self-Propelled (UNSP) barges are excluded from survey and certification procedures (MEPC, 2021).

To understand what the IMO proposes as future measures, it is necessary to explain them in more detail. Based on the article of IHS Markit Maritime: *IMO has a new plan to reduce shipping's carbon emissions; will it be enough?*; the following analysis of the terms will be presented (Brooks & Adler , 2021).

- Energy Efficiency Existing Ship Index (EEXI):

As the director of IHS Markit's Maritime Consulting Principal, Krispen Atkinson, has characteristically stated: *"EEXI will be a headache for many - there is reason in the industry that this could lead to an increase in ships withdrawing when implemented."* For this reason, the IMO announced that one of the permitted methods of conspiracy will be the Engine Power Limitation. It is most likely to be used by ships operating on traditional oil that contains high Sulfur content. In addition, the existing mechanical energy efficiency obligations are renewed for shipowners through the EEXI and aim to improve even the technology for existing ships. Finally, from now on, ships must be inspected annually. For the above rules, the owners have until January 1st, 2023, to take into account the different possibilities regarding the deduction of fuel consumption by the engines (Brooks & Adler , 2021).

- The Carbon Intensity Index (CII)

IMO emphasizes that this measure is related to and in line with the initial GHG strategy 2018, which aims to reduce coal by 40% between 2008 and 2030. For this measure, the owners should calculate the Carbon Intensity Index and find ways to reduce it if its levels are high enough. The competent authorities of each country in which the anchor is registered should compare the carbon intensity of a ship with a stop that has been set, set a score, and if it is low, they should find a plan to achieve the target. However, the most fundamental decision made was the reduction rates of CCI. With 2019 as the reference year, the reduction rates will be increased by 1% from 2020 to 2022 and 2% for 2023-2026. The prices for the following years will be decided later (DNV, 2021).

2.3. Established programs at Piraeus Port.

The port participates, and is obliged to obey the rules and the laws of the E.U. and the IMO since it belongs to the E.U. Member States and is a member of Ecoports. Moreover, join some programs designed exclusively for some countries or only for the port itself. Names of some of these programs are SUPER-LNG, POSEIDOMED II, NEORION, GREEN and CONNECTED PORTS, SEE MARINER (SEE). A few of them aim to control air or water quality in the port due to the substantial amounts of pollutants from the container ships. Others consider the quality of the environment from its activities and services that are evolving on the port, for example, how cranes are loading and unloading goods work. Some are active, while some have either already been implemented in the past and have expired or will be implemented shortly.

POSEIDOMED II is active and aims to reduce the negative environmental impact of heavy fuel oil supply and to implement the requirements of Annex VI of the IMO MARPOL Convention and Directive 2012/33 / E.U. Furthermore, it stipulates that from 2020, shipowners trading in European territorial seas and exclusive economic zones should burn fuel with a Sulphur content of less than 0.5%. Most of the partners in this project are shipping companies with passenger ships such as Minoan Lines Shipping S.A., Blue Star Ferries Maritime S.A., which are some of the largest and most famous companies in the industry in Greece.

A recent program funded by the E.U. and destined for the ports of Piraeus, Venice, Valencia, Wilhelmshaven, and Bremerhaven is the GREEN and CONNECTED PORTS, which entered into force in 2019 and will remain until 2023. It includes two phases. The first has to do with the design, supply, mechanical adaptation, and installation of the necessary mechanism for collecting environmental data (noise, air quality, meteorological information) and their transfer to a platform designed to receive real-time data. The second phase for all the above ports concerns the modeling of methods and big data analysis to predict the ports' environmental performance (noise, air quality) and the effects of the shipping activities (loading/unloading, port traffic, Etc.) both in the port and nearby areas.

2.4. Possible solutions

To better deal with this problem, there should be collective actions both at the international, European, national, or even at port level. Several measures have been taken since the second half of the twentieth century to reduce or even eliminate the impact of various pollutants from maritime activity and protect the environment. As is already known, the shipping sector is one of the crucial sectors for the better and more efficient operation of the supply chain as well as passenger transport. Especially in recent years, it has developed a lot, and as expected, it is extremely demanding to stop operating due to its importance. However, its prominent position in the transport sector does not negate its impact on the marine and air environment and society.

As already mentioned, the primary source of pollutants from all types of ships is fuel consumption. Therefore, this is where the ports and shipping industry should focus in order to reduce emissions and comply with International and European regulations.

This part of the work will describe some actions that can be done both by the ports and the shipping companies themselves to reduce pollution. In general, some actions that will contribute to the development of ports and companies to become more sustainable

2.4.1. Ship-based Solutions

As the name suggests, the first viable solutions concern shipping companies and, more specifically, ships. Therefore, what actions can companies take to become more environmentally friendly? In other words, how they can change and upgrade their existing fleet and develop ships that are under construction.

- Alternative energy sources

The table below presents some alternative energy sources as well as their advantages and disadvantages. On one hand, Biofuels, Ammonia, Hydrogen and LNG can be classified as alternative fuels which are substitutes for common fuels. On the other hand, wind power is in abundance and is naturally renewable. It could also be classified as an “alternative fuel” for the ships.

Alternative energy source	Advantages	Disadvantages
Biofuels	• Easily used • Compatible with existing engines	• Limited production volume • Expensive
Ammonia	• Compatible in several internal combustion engines • Stored in high temperature and low pressure	• Used together with Hydrogen is required • Dangerous and polluting if it leaks
Hydrogen	• Generated by electrolysis near ports • Almost zero emissions	• Storage at remarkably low temperatures • Quite costly • No machines and infrastructure to support it
Liquid Natural Gas (LNG)	• Existing infrastructure and machines that can use it • Relatively economical	• Need to be stored at specific shaped insulated tanks • Does not guarantee emission reduction of 50%
Wind Power	• Naturally renewable • Contributes to the emissions' reduction • There are already applications, with turbines and soft or grid sails	• Can mostly be used at ships that are now under contraction, so they can store this type of energy • Route plays vital role

Table 2: Alternative energy sources.

- Speed reduction

Another way to reduce fuel consumption and all other costs is to reduce speed. According to GL Reynolds, 2019, in this way, the efficiency of the engines increases and there is a contribution to the reduction of environmental pressures (GL Reynolds, 2019). Fluctuations in speed also cause the corresponding changes in carbon dioxide emissions. Therefore, there is a relative interdependence between speed and emissions. ESMA survey in 2019, 18% of ships that landed in EU ports significantly reduced their speed compared to 2008. In particular, the ships that have implemented speed reduction are cruise ships, oil tankers and cargo ships containers. However, there are some concerns about this strategy. The first has to do with the fact that ship engines are designed to operate within a speed range. If the speed drops below the threshold, it may negatively affect its performance. The second has to do with the fact that lower speed automatically means an increase in travel time. Therefore, the above travel time can offset the benefits of reduced speed. Finally, this solution reduces emissions when the ship is at sea and not during its stay in ports (EMSA, CO2 emission report, 2019).

2.4.2. Port-based Solutions

A port that creates the right conditions and invests in environmentally friendly operations in the shipping and port sector is called a green port. (Donnelly, 2021) In order to achieve the goals of the European Green Deal, green ports and their actions will play a key role. The main points that green ports focus on for their development are energy and fuel. The main reason is that they can contribute to the reduction of greenhouse gas emissions through appropriate actions. The availability of alternative fuel sources and the port's energy use are included in the plans to develop green ports in the fuel and energy sectors. Other activities are noise and wastewater management, mitigation of climate change, and more efficient inland and maritime transport links.

- Port-call Optimization

Even today, various ports worldwide use the logic of first come, first served. However, this has adverse effects on both the carbon footprint and efficiency. Reducing fuel consumption through door call optimization can only be achieved if ports and ships work well together. IMO's key point is the best cooperation and the optimal coordination between the possibilities of serving the ship from the port and the plan of the ship for arrival. Better shipping requires collective action. For example, optimizing time and speed leads to a cleaner environment and a gradual reduction in costs. Because everything is a chain, port call optimization also affects inland transport. Assuming that a ship arrives on time at the port, traffic congestion will be prevented. Thus, indirectly reducing emissions, and more efficient transportation will be achieved. This is especially true for container ships. Finally, suppose such a ship is significantly delayed in reaching its destination. In that case, it makes sense that it should be reloaded in a shorter time, generating more pollutants.

- Liquefied Natural Gas supply facilities

As already mentioned in ship-based solutions, Liquefied Natural Gas (LNG) is an alternative fuel solution. Based on the ESPO 2020 Environmental Report, from 2016 to 2020, there is a gradual increase in the percentage of countries that have liquefied natural gas bunkering facilities. The continuous increase of this percentage shows positive signs regarding implementing alternative fuel infrastructure with the bunkering of liquefied natural gas until 2025 (ESPO, 2020). It is known that LNG is transported by trucks or, in some cases, by barges. However, the ports should have the necessary facilities nearby so that it is easy to refuel ships that operate with it as a primary fuel.

- Shore-supply Facilities

Another proposed solution for ports is to set up onshore refueling facilities to help reduce emissions and become more sustainable. When ships are in port, they need electricity for various functions such as hotel operations for cruise ships. Shore-supply facilities replace the auxiliary engines, and it is one of the solutions to reduce the environmental impact proposed by the competent bodies. So as the ships are connected to the shore power supply, they continue to operate normally and eliminate the adverse side effects. Even today, few ports and ships already have such facilities installed. However, many activities are underway, due to pressures from environmental agencies, focusing more on emissions from ports than shipping. Nevertheless, besides the advantages that shore supply has, the upcoming costs must also be considered. Such an investment requires a lot of capital, consultation, and cooperation of several stakeholders.

2.5. Used Variables Description

It is vital to understand the meaning of different variables used in our research.

First, this report has to deal with passenger ships. IMO (2022) states that a passenger ship is "*a ship carrying more than 12 passengers - on international voyages must comply with all relevant IMO regulations, including those in the SOLAS and Load Lines Conventions*." (IMO, Passenger ships, 2022). More specifically, it will deal with cruise ships and not with Ferries. Although both above categories belong to passenger ships, they have noteworthy differences, and the most obvious one is the size. Cruise ships *are enormous passenger ships designed for leisure travel. They usually embark on round-trip cruises to numerous ports of call, where passengers can participate in excursions on the mainland.* A ferry is *a vessel that usually transports people and sometimes also cars and freight over point-to-point scheduled destinations at seas, rivers, or lakes.*

Furthermore, one of the most critical factors for the investigation is the emissions. Based on the public emission report from EMSA (THETIS-MRV), we withdraw information on carbon dioxide emissions only for cruise ships. One specific variable from this report is extremely useful for this research: *CO_2 emissions which occurred within ports under a MS jurisdiction at berth.* To better understand this term, we will divide it into two definitions.

1. CO_2 emissions at berth are related to the carbon dioxide emissions from the ships during their stay at the port and when they move in it, for example, when maneuvering.
2. Ports under a MS jurisdiction: refers to ports located within the borders of Europe, and all the European Union's laws are valid. The European Union Member States countries are the following: Belgium, Bulgaria, Croatia, Republic of Cyprus, Denmark, Estonia, Finland, France, Germany, Greece, Ireland, Italy, Latvia, Lithuania, Malta, Netherlands, Poland, Portugal, Romania, Slovenia, Spain, Sweden, and the UK, thus all their ports are applicable to the research. Gibraltar is also an EU port. Moreover, the laws are also applied to the European Economic Area (EEA), so Iceland's and Norway's (except those ports on Svalbard) must be considered. EU MRV applies to the EEA's outermost regions as well. These regions are the following: Acores, Canary Islands, French Guiana, Guadeloupe, Madeira, Martinique, Mayotte, Reunion, and Saint Martin (Verifavia Shipping, 2017).

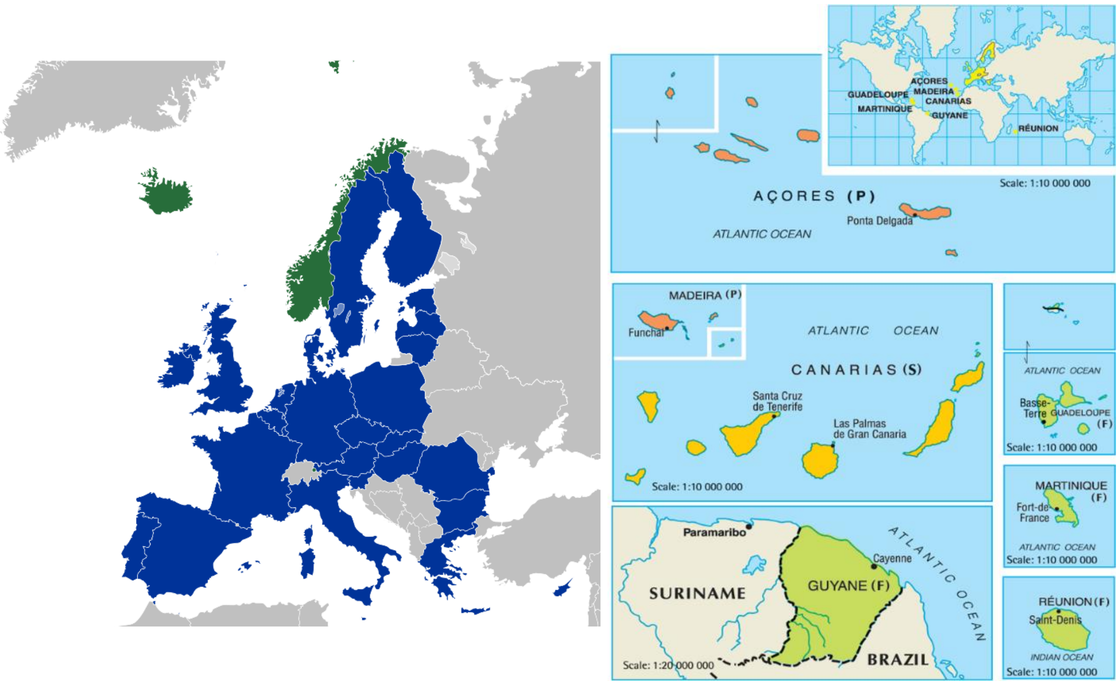


Figure 2:The EEA countries (EU countries + Iceland + Norway + Liechtenstein) and Outermost regions of the EU (Saint Martin is also included). (Source: Verifavia Shipping)

3. Outermost regions (OMR) are territories forming part of a European Union member state but are located far from mainland Europe. In these regions, some of the EU laws are implemented, for example, to monitor CO2 (Verifavia Shipping, 2017).

The above information was deemed necessary to be examined for two main reasons. On the one hand, since we are researching a port that belongs to a country in the Member States, it would be interesting to check which other ports have the same regulations. In other words, as far as the territories in which the European Union legislation on pollution reduction applies. A notable finding was the fact that there are ports that are overseas but belong to EU countries, and the laws apply even there. On the other hand, we had to find this information to proceed with the relevant calculations due to a lack of data on the total hours of ships staying in the ports of the Member States. In the public report from MRV of data related to carbon dioxide emissions, there were only the total annual hours that the ships spent at sea, which were not included in the anchorage hours.

3. Research Area: Piraeus Port

This study is based on the most important port of Greece, Piraeus. Just for history, the harbor was called “Porto Leone” initially because of a lion-shaped status in the dockyard. Originally, the cruise port served ferry ships that connected the largest islands of Greece with the mainland and is in the Saronic Gulf. Its centralized location allows the connection of three continents, Europe, Asia, and Africa. It has three terminals for containers with a total capacity of 6.7 m; it is ranked in the biggest container and the largest passenger port in Europe. Based on the Presentation of the Financial Results 2019, the port has three terminals for passenger ships and cruise ships with a total quay length of 2.8 km and draft up to 11 m (Demopoulos , 2019).

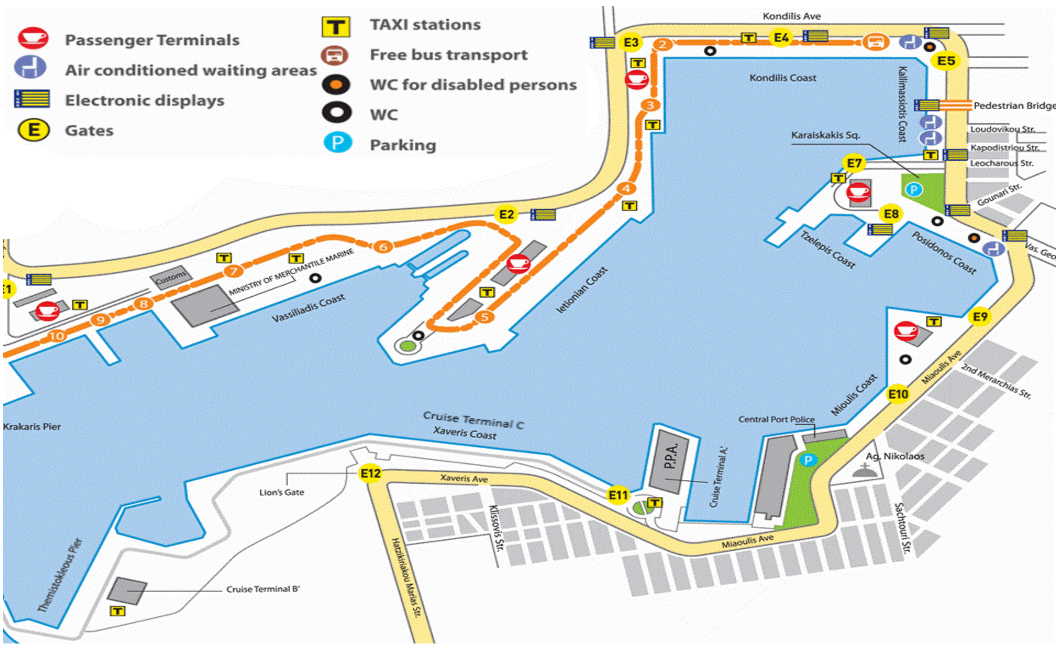


Figure 3: Port of Piraeus Map. (Source: Cruismapper)

More specific:

- Terminal A - Miaoulis: The main terminal and is the closest to the center of Piraeus Municipality. It is capable of handling 1.200 passengers per hour, and two medium size ships up to 2000 passengers can dock concurrently. (2 berths)
- Terminal B - Themistocles: Was built in 2013 and can handle mega cruise ships (4,500 passengers), with draft up to 11m. It is located away from domestic ship traffic and its check in area can serve over 1.500 passengers per hour (2 berths).
- Terminal C - Alkimos: Was built in 2003, expanded in 2016 and can handle 700 passengers per hour (7 berths)

All terminals have extra facilities such as arrival and departure halls, Police, immigration desks and security services, duty-free shops, and currency exchange. Moreover, there are taxi and limo ranks, free shuttle buses to transfer passengers between piers and quays, luggage handling and buses from and to the center of Athens as well as to the airport.

Apart from the fact that most islands in the Aegean are connected to Piraeus, hundreds of cruise ships arrive at it during the year. Many expansions started to happen after selling a significant percentage of the port to COSCO. The new COSCO administration intends to make Port Piraeus a major cruise hub for the developing Chinese market.

Piraeus is routinely ranked among Europe's and the Mediterranean's top ten cruise destinations. Studies have shown that the port is one of those that have the highest passenger traffic in Europe because it serves around 20 million passengers annually. According to Port Piraeus cruise shipping traffic data, 524 calls with 961,000 passengers were handled in 2018 while 622 calls with 1.1 million passengers were handled in 2019 (of which approximately 410,000 cruisers). In 2019 there was an increase of 5.7% compared to 2018 in the total passenger traffic on domestic routes (from 15,657,368 to 16,551,054). In the same year, the cruise ships arrivals surged by 18.7% compared to the previous year.

Due to the vast number of cruise/passenger ships, combined with the container, gas and cargo ships, it is reasonable to have high emissions. It is also logical that all these gas emissions, apart from the environment, harm the health of the inhabitants as well, especially when it comes to ports located next to cities, coastal areas or islands and have direct contact with each other.

Consequently, it is essential to examine both the air quality and the control of emissions because they directly affect the quality of life of Piraeus and the whole of Attica.

Considering the importance of maritime tourism in Greece and the impact of the CO_2 emissions from cruise ships, this chapter aims to introduce the tools used to assess the impact of them. This quantitative tool will focus on the total calculation of the emissions for 2018, 2019, and 2020 and the comparison between them.

As is already mentioned, 2020 was one of the most challenging years worldwide. Maritime tourism, or tourism, in general, was one of the most affected sectors due to the Covid19 pandemic. Since this thesis tries to cover the concept of the impact of CO_2 emission for the Port of Piraeus it needs to be more specific. The differences between 2019 and 2020 are huge. For instance, in 2019, more than 550 cruise ships docked at the port contrariwise: in 2020, only 76. That means that there is a remarkable difference as well in the emissions.

4. Data and Methodology

4.1. Data Collection.

Gathering data for this research has been quite challenging due to the lack of published data on cruise ship arrivals in the Port of Piraeus.

It was crucial to collect data for the CO_2 of each ship and their characteristics. To fill up all the characteristics of the ships, length, beam, depth, engines, speed, and capacity, two websites were considered: scheepvaartwest.be and nedcruise.info. Further, for the CO_2 emissions, the public emission report from EMSA (THETIS-MRV) was used. Over and above that, it was necessary to have the schedule of the cruise ships, time of arrival and departure, to have a better overview.

Therefore, data retrieval related to the ships' itineraries during 2018 and 2019 was done through Crew-center.com. However, the year 2020 was inquiring in all terms. Because of the pandemic, cruise companies and Piraeus Port did not upload cruise ships' schedules. Besides that, travel companies made changes to their itineraries all year based on the measurements each country took to avoid overcrowding and to reduce the spread of the virus. Thus, to construct the database for this year, a Greek article: 2020: Which cruise ships visited Piraeus the year of the pandemic was taken into account (Psarras, 2020). Moreover, a vital insight was from the Hellenic Ports Association statistics: the docked cruise ships that year were only 76 (ELIME, 2021). Finally, through each cruise company website and greekcruises.gr, we collected and created the database for 2020.

In order to be able to calculate the annual hours spent by ships within the ports of the Member States, first of all, research had to be carried out on which ports belong to the MS. Based on the ports that have been mentioned in the literature review, we calculate them. The specific data was exported through the following two websites, ships.cruisett.com and deluxecruises.com, as well as individually from the websites of each cruise line.

4.2. Methodology

For this research, a quantitative analysis will be used to conclude.

First, it is necessary to make some assumptions. Firstly, all ships' itineraries are the scheduled ones. Although, we will assume that is the exact one and the times of arrivals and departures are accurate. In addition, few cruise ships must be dropped off the sample due to the lack of data for the CO2. Also, the Star Flyer operates with sails, so there are no emissions and must be dropped off the sample. Thus, a second assumption will be that the model comprises all cruise ships that docked during these years, even if the numbers are not precisely the same. A third assumption deals with the total hours spent at the MS ports. We assume that the sum of the hours spent by each ship in the ports of the Member States is accurate and not what was expected. Moreover, we do not have information on the hours when the ships are maneuvering and the corresponding gas emissions; we will only use the total time spent at the MS ports and CO_2 that occurred in ports under the MS jurisdiction at berth. Finally, we suppose that the cruise ships do not use shore supply when they are at berth for this research.

First, we want to look at the port's annual and monthly carbon dioxide emissions, and to do this, the following equation will be applied.

$$E_{Pi} = \frac{CO2_{MSi}}{TH_{MSi}} * PH_{Pi}$$

Equation 1: Emissions Function

Examining the contents of this mathematical formula in more detail, it follows that E_{Pi} is the emissions at Piraeus for the cruise ship i, $CO2_{MSi}$ is the CO_2 that occurred in ports under the

MS jurisdiction at berth for a corresponding ship i. Then, TH_{MSi} refers to the Total Hours that a ship i spent at MS ports and PH_{pi} refers to the hours that ship i is docked at Port of Piraeus.

The yearly total annual CO2 emissions which occurred in ports under the MS jurisdiction at berth for each ship i are divided by the total hours spent at all MS ports. This calculation gives us the hourly emissions at berth for the same cruise ship and then multiplied by the hours that it was docked at Piraeus ports, will return the total CO2 emission within the port.

Due to the lack of data for 2020 and specifically, regarding the hours when the ships were anchored in ports of Member States, we had to determine at least the specific times somehow. As shown in APPENDIX III, there are significant differences between the total emissions of cruise ships in 2020. These differences can be due to two main reasons. The first is that the companies inform the continuation or not of the cancellation of their itineraries every month. This means that we cannot be sure whether all the ships completely shut down their engines (cold ironing condition) or continued to operate some of them to be on alert if they returned to the planned routes immediately. Another explanation for these differences could be that some of the companies are not European, so they may have sailed and anchored in non-EU countries, which are included in the MRV monitoring regulations and methods and therefore not recorded. It makes sense that ships' emissions should not vary immensely from year to year. Based on this data and the data of the previous two years, we tried to calculate the approximate hours of the anchorage for 2020. Average hourly emissions for 2018 and 2019 in the port of Piraeus were calculated and based on this we found the hours of stay in MS ports. Of course, there were two ships on which we had no data for both years, and we relied only on one year to have some results in these cases.

Once all the necessary calculations have been made, both the total annual emissions and monthly rates can be considered. Through tables, in the next section, the differences between the months of the same year as well as between the years become more understandable. In addition, from the exported charts we can see in which months the arrival of cruise ships in the port was higher. In other words, in which months are arrivals reaching a peak and consequently carbon dioxide emissions.

On top of that, it would be fascinating to see the differences between 2020 and the two previous years. In 2020, due to the covid19 pandemic, all sectors, tourism, were destroyed. Therefore, it is vital to compare 2020 with 2019 and 2018, where cruises operate normally. Moreover, it would be essential to extract the monthly emissions to understand better which months there are the most docks at the port and consequently the most emissions.

Another crucial piece to think about is the CO_2 savings. The help of the OPS calculation tool from the World Ports Sustainability Program was necessary for their calculation. Furthermore, based on the following report "*European Commission Directorate-General Environment Service Contract on Ship Emissions: Assignment*, *Abatement and Market-based Instruments*", decisions were made on the amounts to be invested in each of the three terminals (De Jonge, Hugi, & Coper, 2005). The calculations were made based on the data for 2019. In more detail, how many ships moored in the port at each terminal and the average number of engines that have their consumption in kilowatts. In addition, the interest rate (6%), the depreciation years (20 years) and the investments for both the port and the existing vessels were essential elements for its calculations. It is known that electricity and fuel prices are different between countries and between years. For this reason, the valid prices during the year 2019 were used, i.e., 0.11 euros/kilowatt hour and 1623 euros/ton, respectively.

The PMT formula was applied to perform the calculations for the Investment costs for each terminal and Investment costs ships. PMT is an economic function that calculates the payment for a loan/investment based on a fixed interest rate, the number of periods, and the loan/investment amount. For more information on the equations of PMT look at the Appendix VI.

Regarding the operating costs and specifically the electricity costs, the following formula was applied:

$$EL_c = +(EL_p + Tax) * Con * NR_s * AvCalls_y * AvHB_y$$

Equation 2: Electricity Cost (Source: World Ports Sustainability Program)

where, EL_p is Electricity Price (€/ kWh), Con refers to Consumption (kW), NR_s is the number of ships that docked at each terminal, $AvCalls_y$ refers to the average calls that its ships have annually at the terminal and $AvHB_y$ are the average annual ports hours. Moreover, per simplicity we assumed that the taxes are zero.

The following equation was used to calculate maintenance savings.

$$MS = +M_e * NR_e * NR_s * AvCalls_y * AvHB_y$$

Equation 3: Maintenance Savings (Source: World Ports Sustainability Program) where M_e refers to Maintenance per engine (€/ h) and NR_e is the number of engines, while all the other values stay the same as above. Thus, to calculate the total yearly cost for OPS facilities the Investment cost in terminal, the Investment cost for the ships, the Electricity costs and the Maintenance Savings are summarized.

The last equation has to do with how much it costs to use auxiliary engines from cruise ships in each terminal, and it is as follows:

$$OPc = +CON * Dis_p * 0{,}66 * NR_s * AvCalls_y * AvHB_y$$

Equation 4: Operational Cost (Source: World Ports Sustainability Program)

where, OP_c is the Operational Costs, CON refers to Consumption (ton/h) and Dis_p to Diesel (€/ton) while all the others stay the same as in the previous equations.

The next step is to estimate the difference between the total investment and operating costs, and this is done simply by subtracting the last from the first.

Finally, based on the following two equations, the carbon dioxide emissions were estimated both during the operation of a shore supply facility and when the ships are running auxiliary engines. We again consulted the report "European Commission Directorate-General Environment Service Contract on Ship Emissions: Assignment, Abatement and Market-based Instruments" about the different emitting factors depending on each energy source. We assumed, however, that the auxiliary engines for all ships run on diesel and that the source of energy for the shore supply facility was natural gas.

$$ELE = \frac{+EF_e * Con * NR_s * AvCalls_y * AvHB_y}{1000000}$$

Equation 5: Emissions from Shore Supply facilities (Source: World Ports Sustainability Program)

$$DISE = (EF_D * CON * NR_s * AvCalls_y * AvHB_y) * 1000/1000$$

Equation 6: Emissions from Auxiliary Engines (Source: World Ports Sustainability Program)

where EFe is the emission factor for the electricity with natural gas, and EFd is the emission factor for the diesel. Moreover, the difference between ELE and DISE is the reduction of the CO2 emissions in tons.

The main reason that the above had to be calculated is to be able to give a solution to the problem of the port with tangible data. The way to do this is with a scenario planning analysis presented in more detail in the fifth chapter of the research.

5. Results

In this part of the research, the results of the calculations will be presented. The final sample of cruise ships moored in the port of Piraeus consists of 166 ships, 1110 port calls and approximately 11317 hotel hours for the reported three years. These ships are not only a fleet of European companies, but many of them are also from international shipping companies that organize trips even to European waters in addition to transatlantic voyages. Furthermore, based on the results, the total carbon dioxide emissions for 2018, 2019 and 2020 are approximately 14,725, 16,612 and 2045 metric tons, respectively.

Before presenting and analyzing charts, let us focus on the table below. The following table contains general information for each year as well as the differences between them in the form of percentages. Based on this, we can observe relative changes in different variables over the years.

As it is evident, the year 2019 was the best from an economic point of view for the port of Piraeus but also for the entire capital of Greece. With at least 569 port calls, the number of passengers and consequently the number of customers in the food service as well as in cultural centers such as museums was high. Even in 2018, millions of visitors arrived in Greece and specifically in Piraeus, since the number of calls reached 476. However, the following year there was an increase of 20%, a percentage that was expected in 2020 as well. However, this did not happen, but a drop reached a rate of about 90% based on port calls.

	2020	**Percentage Difference**	**2019**	**Percentage Difference**	**2018**
Number of ships	18	-77%	79	14%	69
Port calls	65	-89%	569	20%	476
CO2 at MS ports	91824,95	-75%	363489,3	23%	295202,1
Hours at Piraeus	707	-88%	6002	30%	4608
CO2 at MS ports per hour	92,67818	-62%	245,8842	24%	197,668
CO2 At Piraeus	2045,954	-88%	16612,32	13%	14725,04

Table 3: Aggregated data and percentage differences.

Looking at the results from another perspective, that of the number of different cruise ships, are similar. This in percentages means an increase of 14% from 2018 to 2019 while a rapid decrease for 2020 compared to 2019 of 77%. All these vast differences in 2020 are due only to the pandemic. Shipping companies canceled numerous trips around mid-March and beyond to all countries because of measures to curb the virus's spread.

More information on the names of cruise ships, how many visits they have been made to the port and the total emission amounts in all ports of Member States can be found in detail for each year in Annexes I, II and III.

5.1. Sensitive Analysis

Under a set of given assumptions, the sensitive analysis evaluates how alternative values of an independent variable influence a particular dependent variable. In other words, it investigates how much the total uncertainty of the model is affected by the various sources of uncertainty in it. In the above graph, the dependent variable is the number of cruise ships docked at Piraeus port, while the independent variables are the months. Based on the above theory and the below graph for all the corresponding years used for the analysis, we can conclude the following.

It can be seen which months the arrivals of cruise ships in Piraeus are more remarkable. As it is understood, for the years 2018 and 2019, there is a gradual increase in the number from March onwards. The first peak for 2019 exists in May, while then there is a slight drop during the first month of summer and then an increase again until they reach the top in October. It follows almost the same pattern, and for 2018, there is a negligible drop in August and September, but again in October, they reach a zenith. Naturally, the cruise seems to thrive in Greece during the year's hottest months. Even in 2020, we notice that the sails had started in regular numbers compared to the previous years.

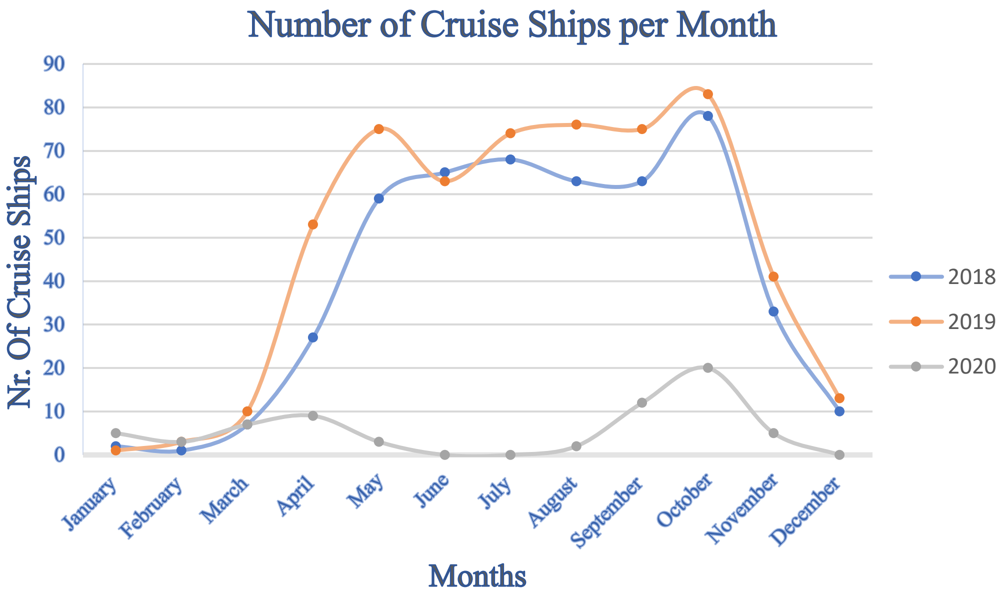


Figure 4:Number of cruise ships per month for each year

However, from mid-March, when the first quarantine began in Greece, the numbers started to fall significantly, with the result that during the summer, almost no cruises took place. Again, in September, we see a cowardly rise that peaks again in October. However, the percentages are much lower than in previous years due to the pandemic. Therefore, we can easily conclude that the arrivals fluctuate within a year due to other months. Moreover, the differences between the years can be interpreted due to uncertainty. For example, in 2020, we see huge differences from previous years that, before the pandemic, none could expect.

5.2. Scatter Plots

To continue and deepen our analysis, we created the following scatter diagrams, one for each year. Based on these, it is easy to extract information about how many or which of the ships it is necessary to immediately change their mode of operation to be able to reduce their pollutants. Scatter diagrams are designed to interpret the correlation between two transients. For this reason, we extracted these to examine whether each ship's total hours of stay in port (which is the independent variable) affect the total carbon dioxide emissions (which is the dependent variable). In addition, the diagrams show the linear trend line and the R-square. Based on the latter, we can assess how well the regression model fits into the observed data.

For 2018 and 2019, the R-square is at exceptionally elevated levels. More specifically, for 2018, we observe that 71% of the dependent variable is interpreted by the independent variable, while for 2019, almost 55%. However, for 2020 only 36% can be interpreted. Therefore, we can understand that the residuals interpret the remaining percentage of the dependent variable. Residues may be variables not included in the model but affect the dependent variable.

As understood from the following scatter plots, few ships have a moderately increased number of emissions during their stay in the port of Piraeus. On the contrary, there are some of them with carbon dioxide emissions at notably low levels, even close to zero. Several scenarios could explain these results.

Firstly, as the hours increase, the emissions also increase, which is logical since the ship needs energy for the proper operation of its facilities. Another explanation for this has to do with the engines of each ship. Smaller cruise ships, both in capacity and size, require smaller amounts of energy to operate and have engines with fewer kilowatts. Therefore, they will emit lower percentages of pollutants. Finally, a vital role is played by the fact that some ships run on electric/diesel engines, others only on diesel.

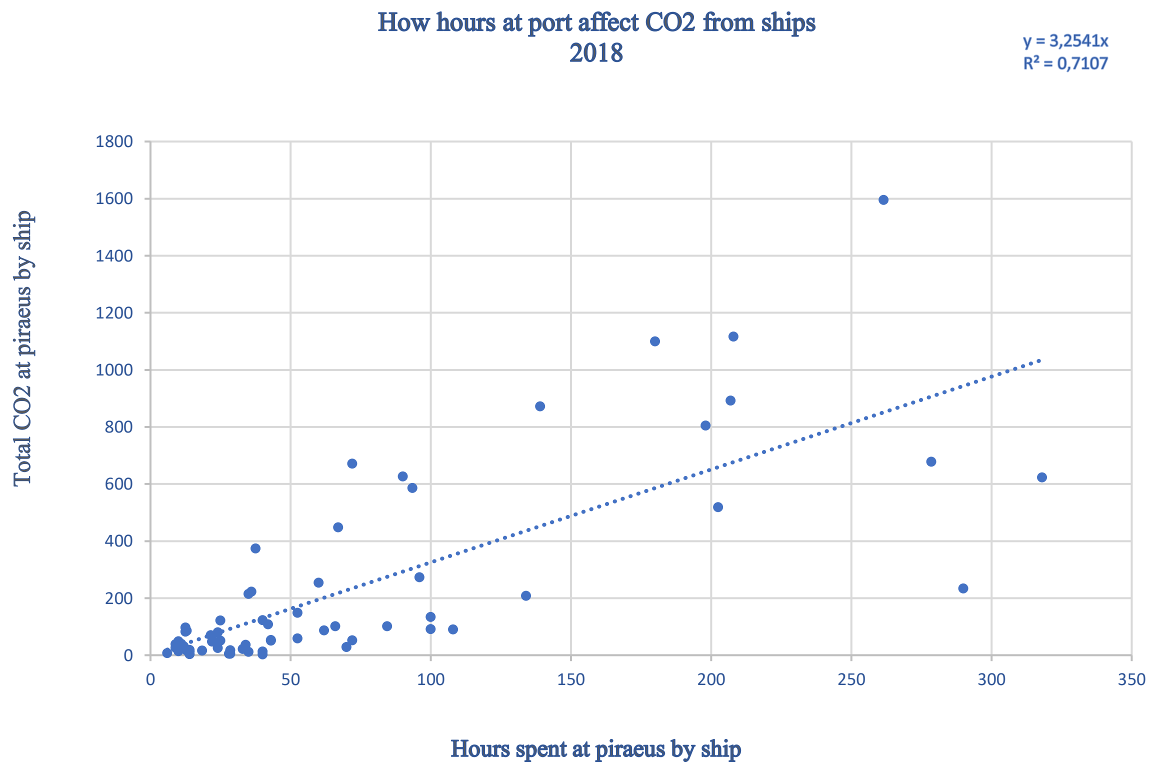


Figure 5: Scatter Plot 2018. How hours at port affect CO2 emissions from ships.

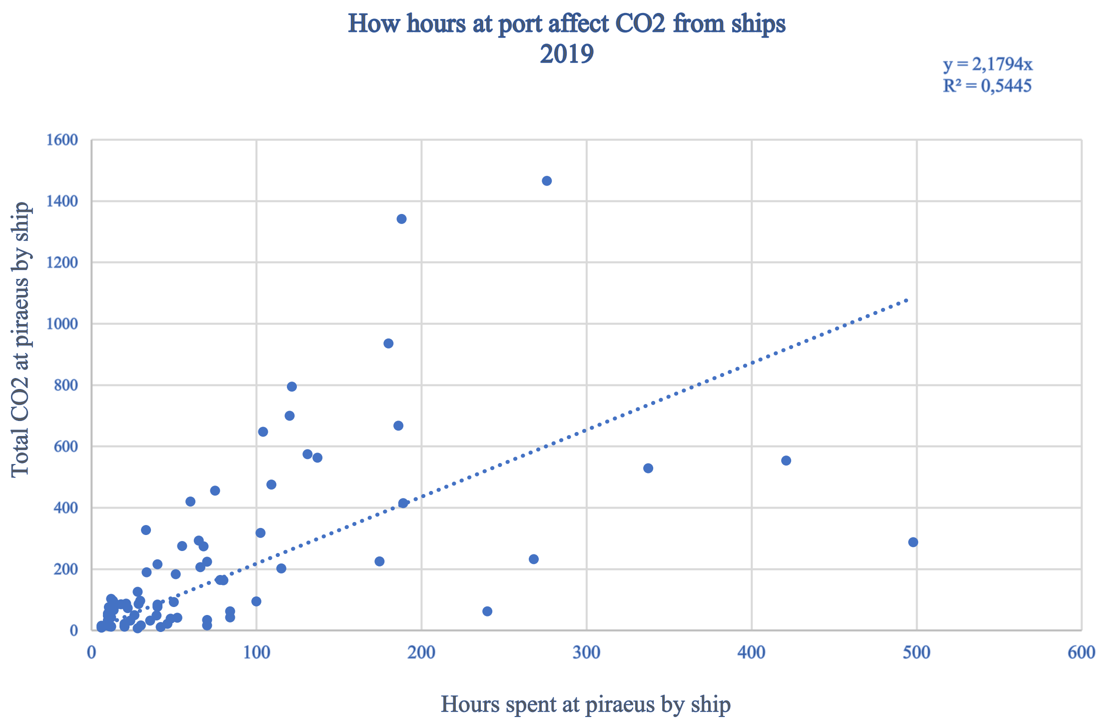


Figure 6: Scatter Plot 2019. How hours at port affect CO2 emission from ships.

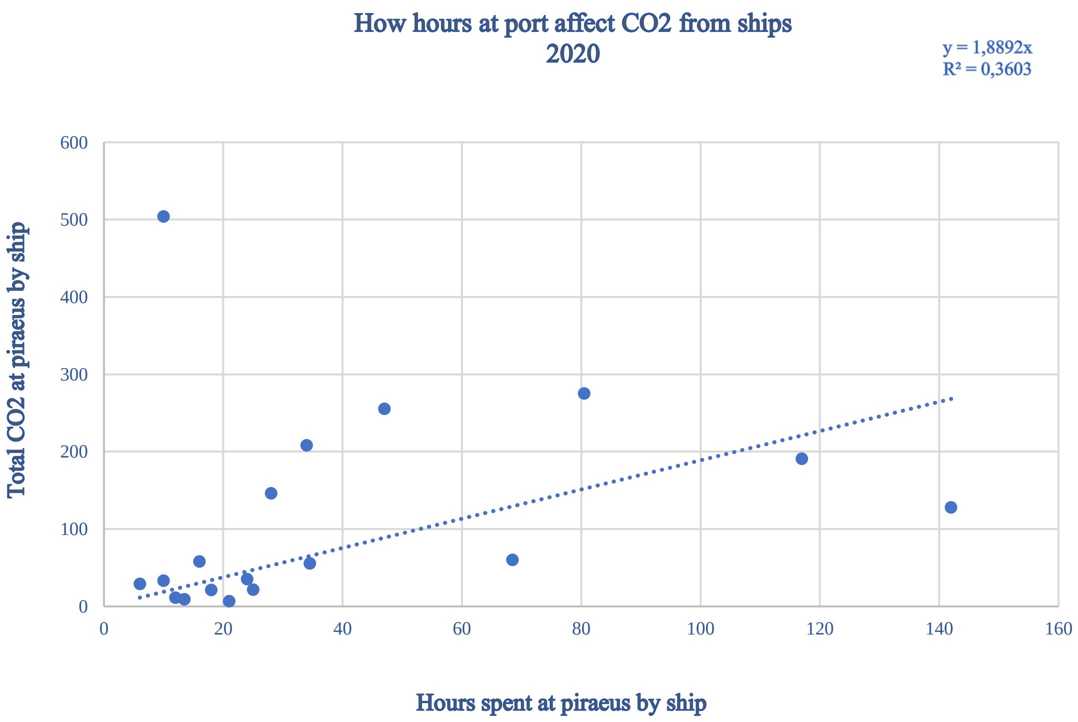
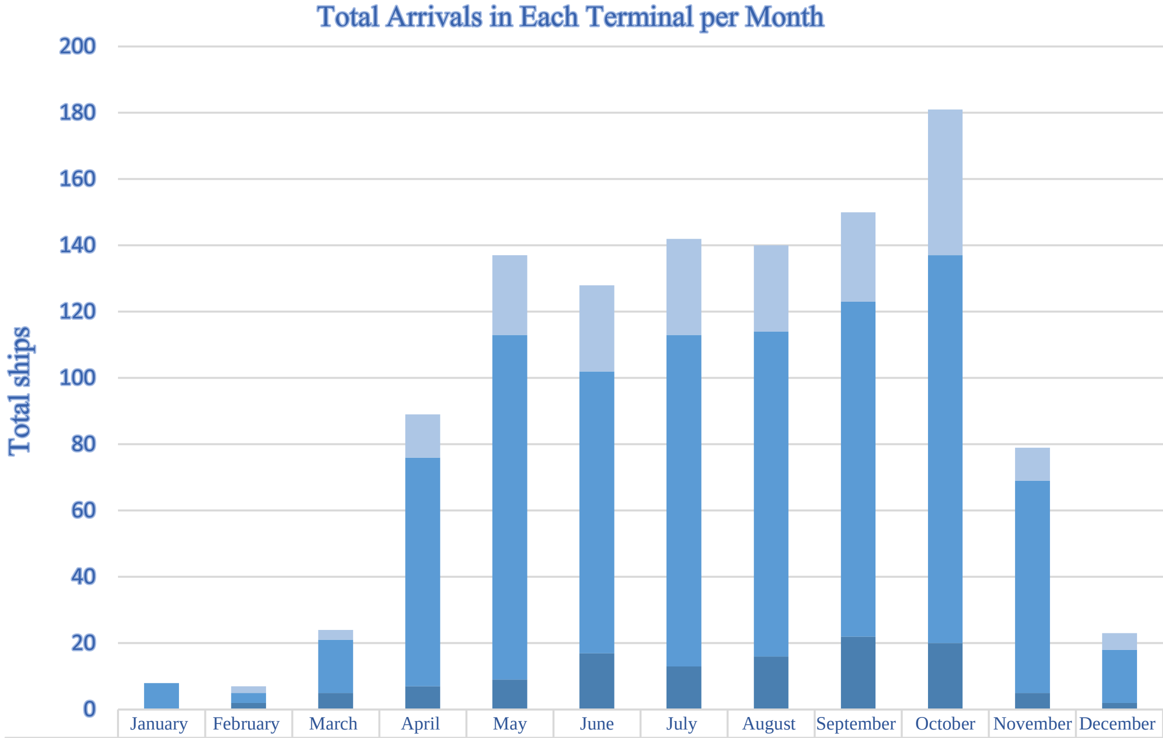


Figure 7: Scatter Plot 2020. How hours at port affect CO2 emissions from ships

5.3. Total Arrivals and CO2 emissions at each Terminal

At this point, four diagrams will be listed, one of which is a bar chart while the other three are pie charts. However, all four have one thing in common: the three docks that embody the cruise port of Piraeus. The following diagrams represent both the total arrivals at the different terminals and the corresponding carbon dioxide emissions. They will be meeting elements for the continuation of the research and specifically for the next stage in which possible scenarios for the port's future will be given.



	January	February	March	April	May	June	July	August	September	October	November	December
Terminal C	0	2	3	13	24	26	29	26	27	44	10	5
Terminal B	8	3	16	69	104	85	100	98	101	117	64	16
Terminal A	0	2	5	7	9	17	13	16	22	20	5	2

Figure 8: Total Arrivals in Each Terminal per Month.

We can draw information about different elements from the above bar chart. First, from the moment the total number of ships is erected each for the three years, and in combination with the first line chart, we can say with even greater confidence which months were the highest arrivals at the port. Then, based on the different colors on the bars, it is easy to see which dock most cruise ships anchor. Another element that can be extracted, always based on the information we have collected about the port, is that the ships that moor in Terminal B are also those that have a capacity of more than 2,000 passengers, as it can serve up to 4,500 people per hour. Finally, since most and the largest ships with the highest energy consumption anchor at this specific pier, it is expected that there will be the highest percentages of carbon dioxide emissions.

The following pie charts show the carbon dioxide emissions at each port pier for each year.

The comparison is necessary to be started on an annual basis. In 2018, there is a significant difference in emissions between terminal B and the other two. More specifically, there is a variation of 30% between terminals A and C. However, when we look at dockyard B, we see that the carbon dioxide emissions are 8,681.83 more metric tons than in C. While concerning terminal A, it is more than four times larger. The comparisons for 2019 are similar. Terminal B, in this case, also has the highest emission percentages, especially compared with C; the difference is approximately ten times larger. As for 2020, the numbers of all three are fairly low, and the contrasts between them range between 300 and 600 metric tons.

As expected in all three years, the pier with the most considerable amounts is Themistocles (Terminal B). Comparing 2018 with 2019, we see that their differences are relatively small. More specifically, during 2018, the emission amounts for docks A and B are slightly higher. This may mean a larger influx of ships with a smaller capacity since, as mentioned above, these terminals serve smaller ships. On the contrary, in 2019, there was an increase of about 25% in emissions in Terminal B. This is due either to increased ship arrivals, extended stays at the port, or even larger ships with more fuel consumption.

Based on these diagrams, it is obvious which of the three terminals in the cruise port of Piraeus has the most remarkable environmental problem. Even if it is the most remote from the residential area of Piraeus, such large percentages of gaseous pollutants negatively affect both the environment and the lives of people living near it.

This is the most fundamental element for the continuation of the work since the next part will be based on it. This section will present scenarios for optimizing the situation at this dock regarding DO2 emissions. In addition, the scenarios will list solutions for how the port can move in the future and become more environmentally friendly, both to the environment and to humans.

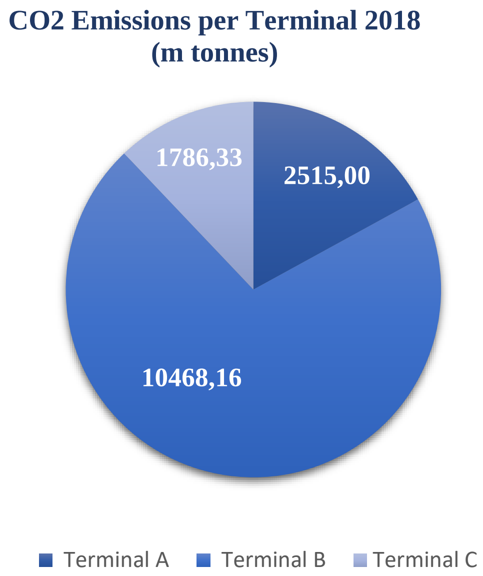


Figure 9: Pie chart 2018. CO2 emissions per terminal.

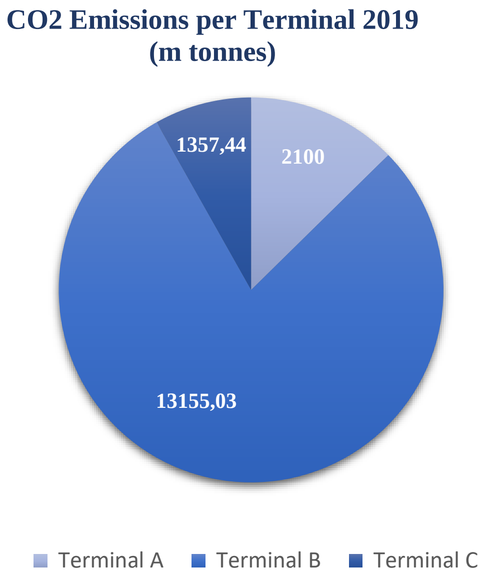


Figure 10 : Pie chart 2019. CO2 emissions per terminal.

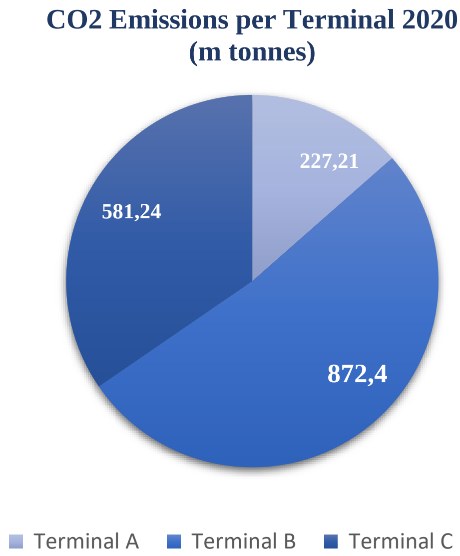


Figure 11: Pie chart 2020. CO2 emissions per terminal

6. Discussion

To continue the research and arrive at some solutions to the problem, we will create a scenario analysis.

Many factors drive the cruise industry, and it would be reasonable to consult them before proceeding with the scenario analysis. According to Peručić, during the second half of the 20th century, marketing played an essential role in cruise development. Through his research, we conclude that with the implementation of call marketing strategies regarding the new market trends, the fulfilment of the needs and the requirements of the passengers, there is a greater demand for cruising. In addition, the same research notes that cruise companies have managed to make this industry accessible to the average consumer once they have taken into account the global economic restructuring, the growing economies of scale, the increasing workforce and capital, and the deregulation. Apart from the above, technology is one of the most fundamental factors that have greatly influenced the demand for cruising (and not only this industry). Through it, people from all over the world can search and choose the right cruise for them. In addition, the development of technology has helped the development of ships in terms of comfort, capacity and safety. Finally, understanding the passengers' motivations is vital to creating the appropriate onboard experiences. This is another marketing strategy which is understood to play a significant role in the development and competition of cruise companies (Perucic & Greblick, 2022).

The first step is to describe the focal question to be solved. In the above sections, we have already analyzed in detail what exactly the problem is, so here we will formulate a question to build the potential scenarios for the future of the port and especially for the Terminal B that is the one with the most annual visits, and consequently with the most emissions.

Focal question: "*In the coming years, should the port of Piraeus change its facilities to become more sustainable and comply with the laws of the European Union and the International Maritime Organization?*"

The steps below must be followed to answer this question. First of all, the external forces will be explored, and this will be done with the help of SEEPT analysis (Social, Economic, Environmental, Political, Technological). In order to derive two critical uncertainties, a Wilson Matrix and a Cross impact analysis will be implemented based on the external forces.

Moreover, after we end up with the two most critical uncertainties, the four scenarios will be created.

6.1. External Forces

The first thing to do is make a list of forces that affect the critical question. As mentioned above, these forces will draw on five key areas: society, the economy, the environment, politics, and technology. We can not list all the forces; however, the following table presents some of the most important and below are briefly described.

Social Forces	Economic Forces	Environmental Forces	Political Forces	Technological Forces
• Citizens Health and Safety • Training • Employment • Population Growth	• Sustainable investments • Additional Funds • Port operation efficiency • Facilities cost	• Climate Change • Environmental Agreements • Environmental Management • Air pollution	• The European Union • The International Maritime Organization • The Greek National Government	• Shore supply Infastructure • Digitalization • Energy efficiency with IoT

Figure 12: External Forces Summary

- Social Forces

The health and safety of citizens, especially in cities such as Piraeus, are of the utmost importance and directly and indirectly influence the decisions of competent organizations. Research has shown that emissions harm the environment and affect people's physical health. In addition, employment and unemployment rates also affect our core question. It is indispensable to have a workforce for the development and change of the port of Piraeus for the better. Therefore, this is related to the following external social force, training. The existence of dynamic staff with the necessary knowledge about the supply of land makes the transition of Piraeus to "Green Port" even more manageable. Finally, the world's ever-increasing population affects emissions as they will continue to have an upward trend.

- Economic Forces

For the port of Piraeus to change to alternative energy sources and specially to shore supply, large-scale investments must be made. For this reason, sustainable investments have been chosen as an external economic force. These investments can be made either by stakeholders or by Additional Funds from the government or even the EU. Apart from investments, another critical factor influencing port change is the construction costs of the necessary facilities. Finally, the term port operating efficiency has to do with the amount of money that the port earns from the annual attendance of passengers and goods in it, which affects the focal question that has been asked.

- Environmental Forces

The external environmental forces may be the ones that will influence the question the most and are the foundations for creating the scenarios for the future. Climate change has profoundly affected the world, especially in recent decades. In recent years, agreements have been signed throughout the world and will continue in the coming years to reduce pollution. Environmental agreements and environmental management that include ways of monitoring different elements (such as air and water quality in ports) directly affect whether the port of Piraeus will change for the better or not. Finally, the external environmental forces could not miss the air pollution, which is the main topic of this research.

- Political Forces

As far as external political forces are concerned, they can all influence the future decisions of Piraeus. Since Greece is an EU country, it is also affected by its laws and regulations and is obliged to obey them. In addition, since Europe is in constant communication and agreement with the International Maritime Organization on environmental issues, it is necessary to select it as an external factor. Finally, the National Government of Greece and the Municipality of Piraeus are the policies of power that have the most direct contact with the Piraeus Port Authority. They are also the ones who will decide, primarily, how to implement the legislations and regulations of the EU and the International Maritime Organization.

- Technological Forces

After the environmental, the technological ones are considered as the most important regarding the focal question. Initially, no action can be taken to improve the situation in the port without the necessary onshore supply facilities. In addition, Digitization brings new opportunities and challenges to the shipping sector. A typical example is cameras or drones that can collect information about pollutant emissions and monitor and evaluate air quality. The energy efficiency of the Internet of Things is in line with Digitization, and it can also help in the better control of the ports in the port and the control of the ships' energy consumption.

6.2. Wilson Matrix and Critical Uncertainties

Having described in the above section all the possible external forces that may affect the question, it was necessary to recognize the critical uncertainties for the port of Piraeus. To do this, a cross-impact analysis was created and then the Wilson Matrix (both are in Appendix).

From the Cross-sectional analysis matrix, we concluded that the variables that affect the rest the most are the environmental ones since they were the ones that collected the highest score. With the help of the Wilson Matrix, the main uncertainties were found. In other words, which of the external forces has the most meaningful impact but also the highest uncertainty on the main question. These forces that were judged to be quite uncertain and have a high impact are the following: Shore-supply Infrastructure, Environmental Agreements, Air Pollution, and Facilities Cost.

To proceed to the following step of the scenario planning analysis, we must select two of the above critical uncertainties to form the script matrix. These two uncertainties were deemed necessary: the onshore supply infrastructure and air pollution.

6.3. Scenario Matrix

Based on the above uncertainties, we will build the script matrix in this section. To do this, we will correctly configure the two critical uncertainties so that they can stand in a scenario matrix.

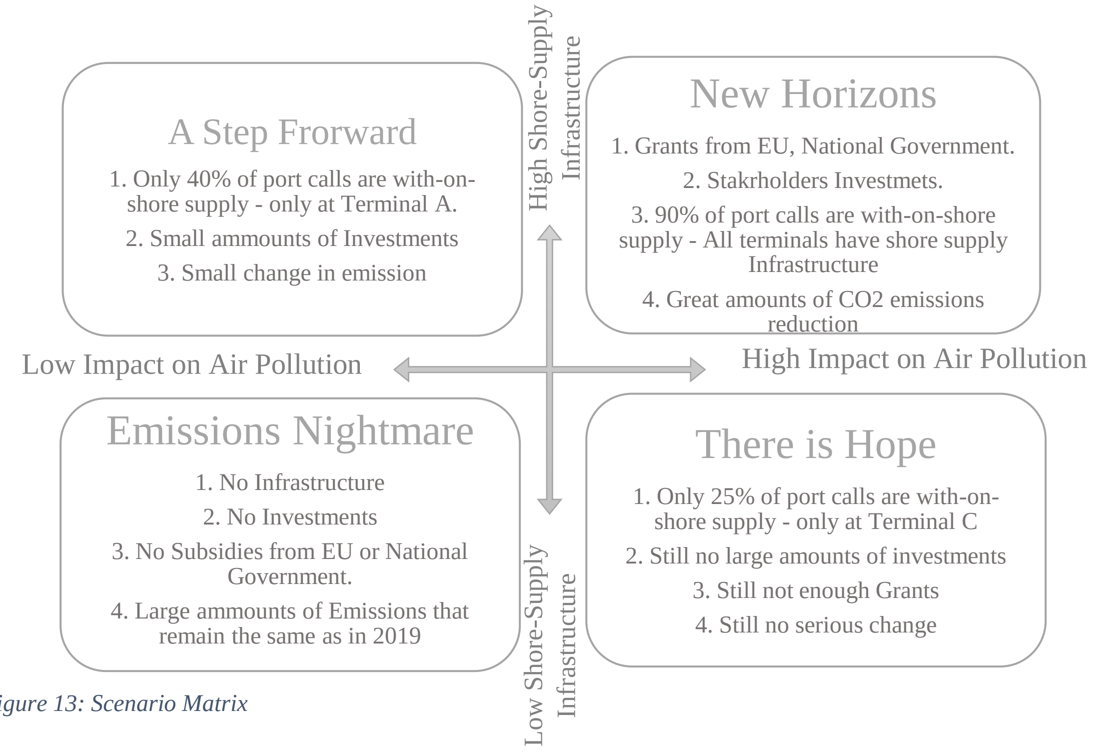


Figure 13: Scenario Matrix

This means that we will use: low and high impact on air pollution and low and high shore supply infrastructure.

6.4. Scenario Logics

One is the scenario we will focus on the most, the one that has to do with the port's future. However, below is a brief analysis of the other scenarios.

- Emissions Nightmare

Based on this scenario, the situation at the port will not change at all in the near future. There is still a significant lack of intervention by all the competent members. Neither the shareholders, the national government, nor the EU invests in helping make the port more sustainable. It is impossible to carry out activities of this scope without even a small amount of grants. Also, the use and installation of the necessary technology is essential. If there are no investments and adequately trained staff, installing and using the specified equipment will be difficult. Emissions will remain high, almost at the same levels of 2019, that is, 24,204.43 metric tons, or even higher depending on the number of ships. This means that the environment will continue to be damaged, and the life around the port will be of inferior quality. With polluted air, people's health problems will become more serious. Finally, the port will have to face sanctions from both the EU and the International Maritime Organization.

- There is Hope

After some years and realizing that the situation is critical, there will be a slight change in the port. We are in the phase where small investments are being made. The difference is not big enough; however, the effort to move from a cruise port with huge emission rates to a greener port is starting. An initial amount of about 25% of the port calls that enter the port is using shore supply facilities. Moreover, investments for the smallest terminal, terminal C, reach the amount of 1,272,553.28 euros to build appropriate shore supply infrastructure. On the other hand, if all the ships that dock at this terminal continue to use their auxiliary engines it will cost the port around 1,519,024 euros yearly. The new equipment involves an annual cost reduction of 246,471 euros. Furthermore, due to the usage of natural gas as a source of power production, the decrease in CO_2 emissions is significant for this specific terminal. More specifically from 4538.21 tons when the ships are using their auxiliary engines to 2591.42 tons with shore supply facilities. However, the belief of a drop in pollutants is not possible with only such a small percentage of ships that can use these infrastructures and with only one terminal ready. With the help of all interested members, the environmental situation and the life quality around the port are slightly improved. Finally, the port, unfortunately, will not realize some of the sanctions yet and will be forced to find other investments or other solutions.

- Small Step Forward

Another scenario for the port's future is "one step ahead". After seven to ten years, the port is in better condition in terms of reducing gas emissions. Forty per cent of the port calls are using onshore supply since also terminal A has these facilities. For the creation of facilities and in this dock, investments of 1,488,847 euros were needed. On the contrary, looking at the cost situation from another point of view, when the ships used auxiliary engines, they cost about 1.8 million euros. This means that there is a significant reduction in costs that reaches about 250 thousand euros per year. Also, if arrivals remain at about the same levels as in 2019, there is a reduction in carbon dioxide emissions of 2,216 tons, only for Terminal A. But even in this case, the emission rates are high as the largest terminal and the one with the biggest environmental problem remains unexploited. Both the Piraeus Port Authority, Greek Government, the EU and the International Maritime Organization evaluate it as necessary to re-finance the expansion of this network facility at Terminal B as well. In this way, they hope for the better operation of the port and beyond to achieve reduction or even elimination of carbon dioxide emissions.

- New Horizons

After about fifteen years and with several negotiations for the financing for the completion of the B terminal, the cruise port of Piraeus can be characterized as "green".

Studies were needed on how the necessary equipment could be installed at this terminal to be able to connect the cruise ships of varied sizes and energy consumption to the shore supply system. More research was needed because the number of ships anchored on it is quite large, and the engines often differ considerably. The main element was that the cruise ships, during their stay at the anchorage, have a maximum energy consumption of 16/20 MVA and that to be able to connect, they need four plus one plugs/cables. In addition, for the process to occur correctly and in the best feasible way, those in charge had to mark that the transformer would have to be on land, so choosing the right installation location is essential. Finally, specially trained personnel were hired for the construction and continuous operation of the onshore supply facilities.

The transition process took several years until its completion, as many facilities had to be built. In more detail, since it was difficult to connect the facilities with wind energy since the port is located near a residential area, they resorted to the solution of thermal power plants. An onshore power plant building has been set up with all the necessary facilities such as an entry transformer, a frequency converter, an on-board frequency transformer and output switch gear. Cables connect these to the shore connection and the cable management wagon that joins the ship and provides it with the necessary energy. As it is understood, to realize all the above, relatively enormous amounts of investments and financing were needed. More specifically, the facility's construction required the funding of eleven million euros. Despite these huge sums of money, the operation of auxiliary machines was even more unprofitable for the port, as it cost about twenty million euros annually.

Nevertheless, in addition to the costs of the facilities, the benefits are various. The first and most important is the significant reduction of pollutants. Concerning the consumption of heavy fuels, the shore supply reduces its carbon dioxide emissions and other air pollutants such as NOx and SOx. The reduction of carbon dioxide emissions at this terminal also reached 25651.79 tons (from about sixty thousand to thirty-four thousand tons). This results in the best air and water quality and the best quality of life for the inhabitants of the wider area. In addition, the noise caused by the ships during their stay at the dock was reduced since the auxiliary engines were no longer in operation.

Finally, the port of Piraeus is exempted to some extent from sanctions. It is ready for the next step, which includes upgrading the other terminals, especially the container port.

7. Conclusions

Based on all the research conducted, diverse conclusions were drawn. Through its review, bibliographies described and analyzed the legislation of the International Maritime Organization, which is an essential element for the analysis of this work. Then, we saw how extensive the port is, the port of Piraeus and especially the cruise port since it consists of three terminals that can serve 3000 passengers per hour in total. In addition, we noticed that there are no onshore refueling facilities.

As for the data, their collection was quite challenging as it had to be collected from diverse sources. Thetis MRV CO2 emissions public report was the primary source for the data set, as it was necessary to use carbon dioxide emissions for research. Further data were the cruise ship itineraries, the arrival and departure times from the port, and the number of passengers used to complete which terminal each ship moors.

After the necessary calculations, we concluded that the arrivals at the port and consequently the increased emission rates depend directly on the months. In addition, pollution and port calls depend on subversive scenarios such as the pandemic that rocked the globe in 2020. It was vital to see which terminal most ships entered to continue the research. Furthermore, after it was observed that Terminal B holds the first place in terms of arrivals, it was expected to have the most emissions in all three years mentioned (2018, 2019, 2020).

The above conclusions made it possible to create four scenarios regarding the port's future. An OPS system at the port is important for reducing both the costs and emissions. As we saw in the fifth chapter of the work and through the four scenarios, creating an OPS system is extremely important. In the latest and most desirable scenario for the port, called New Horizons, it is observed that 90% of the ships anchored in the port now use the facilities. In this way, and since all three cruise ship terminals are ready, the reductions as far as the costs are concerned reach € 9,803,361.04. Moreover, and even more importantly, carbon dioxide emissions from about seventy tons per year fell by thirty thousand tons. An extremely significant reduction that has a positive impact on both the environment and the lives of people around the port. Finally, in this way, the port will be free from any sanctions and comply with the rules and legislation of the International Maritime Organization and the European Union.

References

Abbasov, F. (2018, Ms). *Initial IMO GHG Strategy .* Brussels: Transport and Environment . Retrieved from IMO.

Abbasov, F. (2019). *One Corporation to Pollute Them All.* Brussels: Transport and Environment .

Bernacchi, R. (2017). *Shore-to-ship power & Smart Ports.* Zurich: ASEA Brown Boveri (ABB).

Brooks , C., & Adler , K. (2021, July 6). *IMO has a new plan to reduce shipping's carbon emissions; will it be enough?* Retrieved from IHS Markit: https://cleanenergynews.ihsmarkit.com/research-analysis/imo-has-a-new-plan-to-reduce-shippings-carbon-emissions-will-i.html

Chang, C. C., & Jhang, C. W. (2016). Reducing speed and fuel transfer of the Green Flag Incentive Program in Kaohsiung Port Taiwan. *Transport and Environment*, 1-10.

CREW CENTER. (2017, October 17). *CREW CENTER*. Retrieved from Piraeus, Greece Cruise Port Schedule January - June 2018: https://crew-center.com/piraeus-greece-cruise-port-schedule-july-december-2018

CREW CENTER. (2017, October 17). *CREW CENTER*. Retrieved from Piraeus, Greece Cruise Port Schedule July - December 2018: https://crew-center.com/piraeus-greece-cruise-port-schedule-august-december-2019

CREW CENTER. (2018, October 11). *CREW CENTER*. Retrieved from Piraeus, Greece Cruise Port Schedule August-December 2019: https://crew-center.com/piraeus-greece-cruise-port-schedule-august-december-2019

CREW CENTER. (2018, October 11). *CREW CENTER*. Retrieved from Piraeus, Greece Cruise Port Schedule January - June 2019: https://crew-center.com/piraeus-greece-cruise-port-schedule-january-june-2019

Cruise Lines International Association. (2022). *State Of The Cruise Industry Outlook.* London: CLIA.

CruiseMapper. (2022, February 28). *Piraeus-Athens (Greece)*. Retrieved from CruiseMapper: https://www.cruisemapper.com/ports/piraeus-athens-port-80

Cruises, D. (2022, March 10). *Deluxe Cruises*. Retrieved from Deluxe Cruises: https://deluxecruises.com/index.html

CRUISES, E. (2022, FEBRUARY 20). *5 HUGE Differences Between a Ferry and a Cruise Ship (Real Examples)*. Retrieved from EMMA CRUISES: https://emmacruises.com/differences-ferry-cruise-ship/#:~:text=Ferries%20are%20small%20ships%20designed,more%20onboard%20amenities%20than%20ferries.

Cruisett, S. (2022, March 11). *Ships Cruisett*. Retrieved from Ships Cruisett: https://http://ships.cruisett.com/index.html

De Jonge, E., Hugi, C., & Coper, D. (2005). *European Commission Directorate General Environment Service Contract on Ship Emissions: Assignment, Abatement and Market-based Instruments.* Northwich: Entec UK Limited.

De Melo Rodríguez, G., Alcalde, E. M., González, M., & Saurí, S. (2017). Evaluating air emission inventories and indicators from cruise vessels at ports. *World Maritime University* , 405-420.

Demopoulos , N. (2019). *Presentation of Financial Results 2019.* Athens, Greece: Piraeus Port Authority S.A.

DNV. (2021, June 17). *IMO update: Marine Environment Protection Committee – MEPC 76.* Retrieved from DNV: https://www.dnv.com/news/imo-update-marine-environment-protection-committee-mepc-76-203128

Donnelly, J. (2021, May 20). *Port Technology* . Retrieved from What is a Green Port?: https://www.porttechnology.org/news/what-is-a-green-port/

EC. (2011). *WHITE PAPER Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system.* Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:52011DC0144&from=en

EC. (2020b). *REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL: establishing the framework for achieving climate neutrality and amending Regulation (EU) 2018/1999 (European Climate Law).* Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:52020PC0080&from=EN

EC. (2020c). *REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL: establishing the framework for achieving climate neutrality and amending Regulation (EU) 2018/1999 (European Climate Law).* Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:52020PC0080&from=EN

EC. (2020d). *REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL: establishing the framework for achieving climate neutrality and amending Regulation (EU) 2018/1999 (European Climate Law).* Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:52020PC0080&from=EN

ELIME. (2021). *CRUISE DATA 2015 - 2020 TOTAL COUNTRY.* Athens: Hellenic Ports Association. Retrieved from https://www.elime.gr/index.php/krouaziera

EMSA. (2019). *CO2 emission report.* EMSA/Thetis EU, European Maritime. Retrieved from https://portal.emsa.europa.eu/web/thetis-eu/

EMSA. (2022, February 22). *EMSA THETIS MRV*. Retrieved from Public Emission Report: https://mrv.emsa.europa.eu/#public/emission-report

EMSA: European Maritime Safety Agency. (2021). *European Maritime Transport Environmental Report 2021.* Luxembourg: Publications Office of the European Union, 2021.

ESPO. (2020). *Environmental Report 2020. EcoPortsinSights 2020.* ESPO.

EU. (2014). *DIRECTIVE 2014/94/EU Of The European Parliament And Of The Council, On The Development Of Alternative Fuels Infrastructure.* Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:32014L0094&from=EN

EU. (2016). *DIRECTIVE (EU) 2016/2284 Of The European Parliament And Of The Council, On The Reduction Of Certain Atmospheric Pollutants.* Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:32016L2284&from=EN

GL Reynolds. (2019). *The multi-issue mitigation potential of reducing ship speeds.* GL Reynolds Environmental Sustainability Consultants.

Greek Cruises. (2022, January 20). *Cruise Schedule*. Retrieved from Greek Cruises: http://www.greekcruise.gr/index.php/routes

Hellenic Port Association. (2019, January 10). *Cruise Data 2018*. Retrieved from ELIME: https://www.elime.gr/deltia-typou/item/1270-elime-04012019

IMO. (2018). *INITIAL IMO STRATEGY ON REDUCTION OF GHG EMISSIONS FROM SHIPS.* Retrieved from https://wwwcdn.imo.org/localresources/en/OurWork/Environment/Documents/Resolution%20MEPC.304%2872%29_E.pdf

IMO. (2021, June 17). *Marine Environment Protection Committee (MEPC 76), 10 to 17 June 2021 (remote session)*. Retrieved from IMO: https://www.imo.org/en/MediaCentre/MeetingSummaries/Pages/MEPC76meetingsummary.aspx

IMO. (2021). *Safety and environmental standards on passenger ships*. Retrieved from IMO: https://www.imo.org/en/MediaCentre/HotTopics/Pages/passengership-default.aspx

IMO. (2022, March 15). *Marine Environment Protection Committee (MEPC).* Retrieved from IMO : https://www.imo.org/en/MediaCentre/MeetingSummaries/Pages/MEPC-default.aspx

IMO. (2022). *Passenger ships*. Retrieved from International Maritime Organization: https://www.imo.org/en/OurWork/Safety/Pages/PassengerShips.aspx

International Maritime Organization. (2022, 19 3). *International Convention for the Prevention of Pollution from Ships (MARPOL).* Retrieved from IMO: https://www.imo.org/en/About/Conventions/Pages/International-Convention-for-the-Prevention-of-Pollution-from-Ships-(MARPOL).aspx#:~:text=The%20International%20Convention%20for%20the,2%20November%201973%20at%20IMO.

Jamshidi, H. (2015, April 11). *Maritime Tourism*. Retrieved from Financial Tribune: https://financialtribune.com/articles/travel/14294/maritime-tourism

Kiel, P. o. (2022, March 30). *ON-SHORE POWER*. Retrieved from Port of Kiel: https://www.portofkiel.com/blue-port-en/shore-power-facilities.html

Lind, M., Becha, H., Simha, A., Larsen, S. E., Ben-Amram, E., & Gnass, M. (2021, February 24). *The Maritime Executive*. Retrieved from Port Call Optimization: Two Sides of the Same Coin: https://www.maritime-executive.com/editorials/port-call-optimization-two-sides-of-the-same-coin

Lloret, J., Carreno , A., Caric, H., San, J., & Fleming, L. E. (2021). Environmental and human health impacts of cruise tourism: A review . *Elsevier*, 1-13.

Maragkogianni , A., & Papaefthimiou, S. (2015). Evaluating the social cost of cruise ships air emissions in major. *Transportation Research*.

MEPC. (2021). *Marine Environment Protection Committee (MEPC 76).* Retrieved from https://www.imo.org/en/MediaCentre/MeetingSummaries/Pages/MEPC76meetingsummary.aspx

Merico , E. (2017). Atmospheric impact of ship traffic in four Adriatic-Ionian port-cities: Comparison and harmonization of different approaches. *Transport and Environment*, 431-445.

Miola , Ciuffo, Giovine, & Marra. (2010). *Regulating Air Emissions from Ships: The State of the Art on Methodologies,Technologies and Policy Options.* Luxembourg: European Commission. Joint Research Center. Institute for Environment and Sustainability. JRS Reference Reports 60732.

MRV. (2015). *EUROPEAN UNION MRV REGULATION: Guidance for ships over 5000GT which carry passengers or cargo to, from or between EU/EEA ports, regardless of Flag.* International Chamber of Shipping. Retrieved from https://www.ics-shipping.org/wp-content/uploads/2020/08/ics-guidance-on-eu-mrv.pdf

Murena, F., Mocerino , L., Quaranta, F., & Toscano, D. (2018). Impact on air quality of cruise ship emissions in Naples, Italy. *Atmospheric Environment*, 70-83.

Nedcruise. (2022, February 20). *Nedcruise*. Retrieved from Nedcruise,info: https://nedcruise.info/

OECD. (2020). Greece. In *OECD TOURISM TRENDS AND POLICIES 2020* (pp. 181-185). OECD Library.

Ogilvy, J. (2015, January 8). *Scenario Planning and Strategic Forecasting.* Retrieved from Forbes: https://www.forbes.com/sites/stratfor/2015/01/08/scenario-planning-and-strategic-forecasting/?sh=60958f12411a

OLP Piraeus Port Authority S.A. (2017). *Piraeus Cruise Port.* Athens: OLP. Retrieved from https://www.olp.gr/images/pdffiles/Cruise/Presentation_Cruise_Terminal_-2017-v2-en_ppt.pdf

Perucic, D., & Greblick, M. (2022). *Key Factors Driving the Demand for Cruising and Challenges Facing the Cruise Industry in the Future.* Zagreb: Tourism. An International Interdisciplinary Journal.

Pinterits, M., Bernhard , U., Bartmann, T., & Gage, M. (2021). *European Union emission inventory report 1990-2019 under the UNECE Convention on Long-range Transboundary Air Pollution (Air Convention).* Copenhagen: Luxembourg: Publications Office of the European Union, 2021.

Piraeus Port Authority S.A. (2022, February 19). *Environmental Protection. EU-Projects-Active*. Retrieved from OLP: https://www.olp.gr/en/environmental-protection/eu-projects/active

Piraeus Port Authority S.A. (2022, February 19). *Environmental Protection. EU-Projects-Inactive*. Retrieved from OLP: https://www.olp.gr/en/environmental-protection/eu-projects/active-2

Prevljak, N. H. (2021, September 1). *EU maritime transport to increase in coming years. So will GHG emissions.* Retrieved from OFFSHORE ENERGY: https://www.offshore-energy.biz/eu-maritime-transport-to-increase-in-coming-years-so-will-ghg-emissions/#:~:text=Air%20pollution%3A%20In%202019%2C%20sulphur,marine%20species%20in%20different%20ways.

Program, W. P. (2022, 4 9). *Cost Calculation*. Retrieved from World Ports Sustainability Program : https://sustainableworldports.org/ops/costs/cost-calculation/

Psarras, P. (2020, December 25). *2020: Which cruise ships visited Piraeus during the year of the pandemic [videos].* Retrieved from Piraeus Piraeus: https://www.pireaspiraeus.com/cruisepiraeus2020/

Scheepvaartwest. (2022, February 22). *Scheepvaartwest*. Retrieved from Scheepvaartwest.be: https://www.scheepvaartwest.be/CMS/index.php

Tichavska, M., & Tovar, B. (2015). Environmental cost and eco-efficiency from vessel emissions. *Transportation Research Part E: 83*, 126-140.

Toscano, D., & Murena, F. (2019). Atmospheric ship emissions in ports: A review. Correlation with data of ship traffic. *Atmospheric Environment: X*.

Tzannatos, E. (2010). Ship emissions and their externalities for the port of Piraeus – Greece. *Atmospheric Environment*, 400-407.

Tzannatos, E., & Kilic, A. (2014). Ship Emissions and Their Externalities at the Container Terminal of Piraeus - Greece. *International Journal of Environmental Research*, 1329-1340.

UNFCCC. (2015). *The Paris Agreement.* Denmark: Phoenix Design Aid.

UNWTO. (2019). *INTERNATIONAL TOURISM GROWTH CONTINUES TO OUTPACE THE GLOBAL ECONOMY.* Madrid: World Tourism Organization (UNWTO. Retrieved from https://www.unwto.org/international-tourism-growth-continues-to-outpace-the-economy)

Van Lieshout, A. (2019). *Viability Study of Sustainable Shore Side Electricity for Container Vessels in the Port of Rotterdam.* Delft: Technical University of Delft.

Verifavia Shipping. (2017). *EU MRV Regulation: Overview, Update & Guidance.* Goteborg: Verifavia.

Wan, Z., Ji, S., Liu, Y., Zhang, Q., Chen, J., & Wang, Q. (2020). Shipping emission inventories in China's Bohai Bay, Yangtze River Delta, and Pearl River Delta in 2018. *Marine Pollution Bulletin*, 1-10.

Wikipedia. (2022, March 2). *Cruise ship*. Retrieved from Wikipedia the Free Encyclopedia: https://en.wikipedia.org/wiki/Cruise_ship

Wikipedia. (2022, January 25). *Cruise ship pollution in Europe*. Retrieved from WIKIPEDIA the Free Encyclopedia: https://en.wikipedia.org/wiki/Cruise_ship_pollution_in_Europe

Wikipedia. (2022, March 15). *Environmental effects of shipping*. Retrieved from Wikipedia The Free Encyclopedia: https://en.wikipedia.org/wiki/Environmental_effects_of_shipping#Ballast_water

Wikipedia. (2022, March 2). *Ferry*. Retrieved from Wikipedia the Free Encyclopedia: https://en.wikipedia.org/wiki/Ferry

Yau, P. S., Lee, S. C., Corbett, J. J., Wang, C., & Ho, K. F. (2012). Estimation of exhaust emission from ocean-going vessels in Hong Kong. *Science of The Total Environment* , 299 - 306.

APPENDIX I

Ship name	Port calls	Hours spend at ports	CO2 at MS ports	Hours at Piraeus	CO2 at MS ports per hour	CO2 at Piraeus	Engine total power (kW)	Nr. Of Engines	Total Fuel consumption	Terminal	Capacity
Aegean Odyssey	8	2400	2171,74	100	0,90	90,49	10300	2	4246,5	Terminal C - Alkimos	386
AIDAbella	3	1459,5	4841,50	24	3,32	79,61	36000	4	12597,12	Terminal B - Themistocles	2500
AIDAcara	2	1707,5	5504,33	21,5	3,22	69,31	21720	4	11449,09	Terminal A - Miaoulis	1186
AIDAstella	1	1904	9143,02	10	4,80	48,02	10300	4	12033,04	Terminal B - Themistocles	2700
AIDAvita	1	2190	4323,41	10	1,97	19,74	36000	4	8566,47	Terminal C - Alkimos	1266
Aurora	1	1132	8706,60	12,5	7,69	96,14	58800	4	33554,4	Terminal B - Themistocles	1878
Azamara Journey	1	1913,5	492,76	14	0,26	3,61	13500	4	5391,49	Terminal C - Alkimos	694
Azamara Pursuit	3	1583	484,26	40	0,31	12,24	18240	4	3981,07	Terminal C - Alkimos	777
Azamara Quest	2	2220,5	411,57	28	0,19	5,19	18240	4	5110,35	Terminal C - Alkimos	686
Black Watch	1	949	2883,23	10	3,04	30,38	13240	4	8994,7	Terminal C - Alkimos	539
Celebrity Constellation	6	1073	430,28	70	0,40	28,07	50000	4	4774,71	Terminal B - Themistocles	2170
Celebrity Eclipse	2	1263	1326,23	24	1,05	25,20	67200	4	23310,1	Terminal B - Themistocles	2850
Celebrity Reflection	9	1359,5	1127,55	108	0,83	89,57	62400	4	17296,99	Terminal B - Themistocles	3046
Celestyal Crystal	29	2487,5	4868,51	318	1,96	622,39	19200	4	6912,69	Terminal B - Themistocles	1409
Celestyal Olympia	56	2621	6371,93	278,5	2,43	677,06	17060	4	10011,95	Terminal B - Themistocles	1575
Club Med 2	1	1011	264,88	14	0,26	3,67	5890	4	4658,23	Terminal C - Alkimos	214
Columbus	1	1290	4586,95	11	3,56	39,11	38800	4	14446,99	Terminal B - Themistocles	1400
Costa Deliziosa	15	1479	9269,57	139	6,27	871,18	64000	6	25536,48	Terminal B - Themistocles	2260
Costa Luminosa	18	1573,5	8446,16	208	5,37	1116,49	64000	6	22264,37	Terminal B - Themistocles	2260
Costa Mediterranea	1	1646	7041,59	9	4,28	38,50	62370	6	15186,25	Terminal B - Themistocles	2680
Costa neoRiviera	22	1854,5	7528,55	198	4,06	803,80	31680	4	12289,13	Terminal C - Alkimos	670
Crown Princes	6	1451	10094,20	90	6,96	626,10	12604	6	24723,27	Terminal B - Themistocles	4800
Europa	1	1225	2506,00	12	2,05	24,55	13300	2	4980,21	Terminal C - Alkimos	275
Gemini	17	852	1323,51	134	1,55	208,16	8400	4	3555,77	Terminal A - Miaoulis	1074
Horizon	24	1398	1124,66	290	0,80	233,30	19980	4	13236,59	Terminal B - Themistocles	1828
Jewel Of the Seas	15	1253	1103,24	18,5	0,88	16,29	59000	3	19169,68	Terminal B - Themistocles	2501
Koningsdam	3	1100	3368,82	40	3,06	122,50	50400	4	18158,76	Terminal B - Themistocles	2650
La belle des oceans	1	452	531,70	6	1,18	7,06	5350	2	5220,20	Terminal C - Alkimos	128
Le Laperouse	4	462,5	1304,00	52,5	2,82	148,02	8000	4	1780,46	Terminal C - Alkimos	264
Le Lyrial	6	1126,5	1719,00	66	1,53	100,71	7200	4	2416,51	Terminal C - Alkimos	264
Marella Celebration	4	1260	3228,02	42	2,56	107,60	22600	2	9197,48	Terminal A - Miaoulis	1254
Marella Discovery 2	7	1414	9456,99	67	6,69	448,10	58500	5	13537,01	Terminal B - Themistocles	1836
Mein Schiff 1	1	1358	1763,40	14	1,30	18,18	37130	4	10843,46	Terminal B - Themistocles	2900
Mein Schiff 2	6	1657	1990,51	84,5	1,20	101,51	37130	6	13825,72	Terminal B - Themistocles	1912
Mein Schiff 3	2	1300,5	759,3	28,5	0,58	16,64	45200	4	12996,38	Terminal B - Themistocles	2506
Mein Schiff 4	3	1449	1720,90	43	1,19	51,07	44000	4	18024,05	Terminal B - Themistocles	2507
Mein Schiff 5	1	1291	1042,08	14	0,81	11,30	50400	4	14579,89	Terminal B - Themistocles	2534

MSC Lirica	1	1272	3715,00	9	2,92	26,29	30600	4	13627	Terminal B - Themistocles	1984
MSC Magnifica	4	1855	11453,00	36	6,17	222,27	58000	5	27244	Terminal B - Themistocles	2518
MSC Musica	29	990	6040,00	261,5	6,10	1595,41	58000	5	25299	Terminal B - Themistocles	2550
MSC Orchestra	4	1187	11814,00	37,5	9,95	373,23	58000	5	31479	Terminal B - Themistocles	2550
MSC Poesia	23	1309	5642,00	207	4,31	892,20	58000	5	22563	Terminal B - Themistocles	2550
Norwegian Spirit	8	2329	15283,93	13	6,56	85,31	58800	4	57575,36	Terminal B - Themistocles	2018
Norwegian Star	9	970,5	9049,23	72	9,32	671,35	58800	4	21665,3	Terminal B - Themistocles	2348
Oceana	13	1935	12123,90	93,5	6,27	585,83	46080	4	28264,3	Terminal A - Miaoulis	889
Nautica	1	1512,5	3875,33	202,5	2,56	518,85	13500	4	6422,87	Terminal C - Alkimos	688
Riviera	4	2054	8687,18	60	4,23	253,76	42000	4	15409,66	Terminal C - Alkimos	1250
Oosterdam	4	1763	3819,51	22	2,17	47,66	51940	5	13798,83	Terminal B - Themistocles	1964
Pacific Princess	2	1377	1727,30	13	1,25	16,31	13500	4	7072,13	Terminal C - Alkimos	688
Queen Elizabeth	1	1362	8320,60	180	6,11	1099,64	64000	6	33197,77	Terminal B - Themistocles	2092
Rhapsody of the Seas	15	1362	85,06	40	0,06	2,50	52800	4	3887,55	Terminal B - Themistocles	1998
Salamis Filoxenia	5	659,5	736,25	52,5	1,12	58,61	13240	2	3229,51	Terminal A - Miaoulis	1009
Sapphire Princess	2	1190,5	5783,94	25	4,86	121,46	37500	4	26056,88	Terminal B - Themistocles	2670
Seabourn Encore	3	1386	1709,62	43	1,23	53,04	23040	4	4953,34	Terminal C - Alkimos	604
Seabourn Odyssey	10	1919	2571,10	100	1,34	133,98	23040	4	7360,54	Terminal C - Alkimos	450
Seabourn Ovation	1	1868	2454,38	10	1,31	13,14	23040	4	5973,53	Terminal C - Alkimos	604
Seven Seas Voyager	2	1598,5	4941,81	22	3,09	68,01	23040	4	8373,19	Terminal A - Miaoulis	706
Silver Muse	2	1701	3435,04	25	2,02	50,49	26100	4	5543,96	Terminal C - Alkimos	596
Silver Spirit	1	1863,5	1855,30	14	1,00	13,94	26100	4	5936,27	Terminal C - Alkimos	608
Silver Whisper	5	1834	2574,04	62	1,40	87,02	15700	2	6117,83	Terminal C - Alkimos	382
Silver Wind	3	2159	1370,58	33	0,63	20,95	10600	2	4712,34	Terminal C - Alkimos	294
Sirena	1	622	1584,24	12	2,55	30,56	18240	4	3812,22	Terminal C - Alkimos	688
Ventura	1	1815,5	11941,50	12,5	6,58	82,22	67200	4	37598,13	Terminal B - Themistocles	3192
Viking Orion	2	706	737,98	34	1,05	35,54	23520	4	2057,89	Terminal A - Miaoulis	930
Viking Sky	2	1809	11069,44	35	6,12	214,17	23520	4	10889,3	Terminal A - Miaoulis	930
Viking Star	5	2038	5777,62	96	2,83	272,15	23520	4	10579,32	Terminal A - Miaoulis	930
Viking Sun	2	1775	598,68	35	0,34	11,80	23520	4	7879,85	Terminal A - Miaoulis	930
Vision of the Seas	6	1237	883,22	72	0,71	51,41	52800	4	15115,91	Terminal B - Themistocles	2050
Wind Star	21	1578	280,36	28,5	0,18	5,06	2964	3	1256,5	Terminal C - Alkimos	142

Table 4: Data for the year 2018

APPENDIX II

Ship name	Port calls	Hours spend at ports	CO2 at MS ports	Hours at Piraeus	CO2 at MS ports per hour	CO2 at Piraeus	Engine total power (kW)	Nr. Of Engines	Total Fuel consumption	Terminal	Capacity
Aegean Odyssey	7	1136,5	835,16	84	0,73	61,73	10300	2	1285,8	Terminal C - Alkimos	386
AIDAbella	1	1520	4949,18	10	3,26	32,56	36000	4	9375,63	Terminal B - Themistocles	2500
AIDAblu	1	2384	11525,92	10	4,83	48,35	36000	4	15012,53	Terminal B - Themistocles	2192
AIDAcara	3	1680	5491,74	29,5	3,27	96,43	10300	4	10968,11	Terminal A - Miaoulis	1186
AIDAprima	1	949	5204,1	10	5,48	54,84	46800	3	14702,37	Terminal C - Alkimos	1266
AIDAvita	3	1685	2073,78	39,5	1,23	48,61	36000	4	4267,66	Terminal B - Themistocles	1266
Amera	1	1652	5085,14	10	3,08	30,78	21120	4	10816,95	Terminal A - Miaoulis	835
Azamara Journey	2	2228	493,07	28	0,22	6,20	13500	4	5929,15	Terminal C - Alkimos	694
Azamara Pursuit	5	2286,5	517,73	70	0,23	15,85	18240	4	6781,49	Terminal C - Alkimos	777
Azura	1	1525,5	7425,7	13,5	4,87	65,71	67200	6	22734,8	Terminal A - Miaoulis	1226
Berlin	1	985	1113,73	11	1,13	12,44	7060	2	3836,21	Terminal C - Alkimos	420
Celebrity Constellation	6	1825,5	862,7	70	0,47	33,08	50000	2	17162,15	Terminal B - Themistocles	2170
Celebrity Infinity	2	1301,5	1170,09	35,5	0,90	31,92	50000	2	18541,78	Terminal B - Themistocles	2170
Celebrity Reflection	1	1301,5	1404,87	12	1,08	12,95	62400	4	19430,03	Terminal B - Themistocles	3046
Celestyal Crystal	38	3067,5	4028,65	421	1,31	552,91	19200	4	7453,84	Terminal B - Themistocles	1409
Celestyal Olympia	72	2887,5	4513,59	337,5	1,56	527,56	17060	4	9719,4	Terminal B - Themistocles	1575
Club Med 2	3	1043	264,88	42	0,25	10,67	5890	2	4658,23	Terminal C - Alkimos	214
Costa Deliziosa	17	1578,5	6919,49	131	4,38	574,25	64000	6	27324,27	Terminal B - Themistocles	2260
Costa Diadema	1	2872	13719,13	10	4,78	47,77	75600	6	23330,37	Terminal B - Themistocles	1253
Costa Luminosa	8	1340	8139,13	75	6,07	455,55	64000	6	22186,41	Terminal B - Themistocles	2260
Costa Victoria	18	1875,5	7698,81	137	4,10	562,38	50700	6	11520,79	Terminal B - Themistocles	1928
Crown Iris	4	1125,5	6339,84	33,5	5,63	188,70	21120	4	12857,53	Terminal A - Miaoulis	1056
Crystal Serenity	4	2208,5	7925,25	51	3,59	183,01	52198	6	12844,98	Terminal A - Miaoulis	1040
Emerald Princes	8	1554	9061,37	120	5,83	699,72	67220	6	22611,78	Terminal B - Themistocles	3114
Europa	2	1300	2484,4	26	1,91	49,69	13300	2	5754,37	Terminal C - Alkimos	275
Explorer of the Seas	1	1110	1067,6	12	0,96	11,54	75600	6	26605,45	Terminal B - Themistocles	3114
Gemini	12	743	1301,73	115	1,75	201,48	8400	4	2886,43	Terminal A - Miaoulis	1074
Horizon	33	1757	1012,07	498	0,58	286,86	19980	4	11583,21	Terminal B - Themistocles	1828
Jewel Of the Seas	23	1993,5	1722,15	268	0,86	231,52	59000	3	27775,44	Terminal B - Themistocles	2501
Koningsdam	10	1747	6263,22	186	3,59	666,83	50400	4	15991,55	Terminal B - Themistocles	2650
La belle des oceans	1	486	1215	6	2,50	15,00	5350	2	10935	Terminal C - Alkimos	128
Le Bougainville	15	1021,5	1312	174,5	1,28	224,13	8000	4	2546,14	Terminal C - Alkimos	184
Le Lyrial	8	488,5	1513,4	102,5	3,10	317,55	7200	4	2544	Terminal C - Alkimos	264
Marella Celebration	4	1389	2892,12	40	2,08	83,29	22600	2	8449,44	Terminal A - Miaoulis	1254
Marella Discovery	5	1232	6158,6	55	5,00	274,94	58500	5	17601,39	Terminal B - Themistocles	1830
Marella Dream	2	2105	6863,58	22	3,26	71,73	23830	5	19891,39	Terminal B - Themistocles	1506
Marella Explorer 2	4	1563	8387,11	40	5,37	214,64	37130	6	15709,28	Terminal B - Themistocles	1814

Mein Schiff	14	1674	3668,14	189	2,19	414,14	37130	4	23555,1	Terminal B - Themistocles	1912
Mein Schiff 3	4	1776	1384,33	48	0,78	37,41	45200	4	15709,28	Terminal B - Themistocles	2506
Mein Schiff 4	4	1710	1332	52	0,78	40,51	44000	6	18890,13	Terminal B - Themistocles	2507
Mein Schiff 5	3	1230,5	568,21	46	0,46	21,24	50400	6	12328,8	Terminal B - Themistocles	2534
Mein Schiff 6	7	1630,5	1529,91	100	0,94	93,83	44000	6	13495,36	Terminal B - Themistocles	2534
MSC Lirica	8	1704,5	6866	68	4,03	273,91	30600	4	17758	Terminal B - Themistocles	1984
MSC Magnifica	29	1762	9357	276	5,31	1465,68	58000	5	29042	Terminal B - Themistocles	2518
MSC Musica	20	1150	5974	180	5,19	935,06	58000	5	20542	Terminal B - Themistocles	2550
MSC Sinfonia	2	2270	9368	21	4,13	86,66	31680	4	24772	Terminal B - Themistocles	2163
MSC Poesia	3	1608,5	7599	18	4,72	85,04	58000	5	25658	Terminal B - Themistocles	2550
Nieuw Statendam	2	1258	5631,89	28	4,48	125,35	51200	4	16112,56	Terminal B - Themistocles	2666
Norwegian Epic	1	2001	14422,71	10,5	7,21	75,68	80400	6	29709,58	Terminal B - Themistocles	4200
Norwegian Jade	16	1521,5	10856,05	188	7,14	1341,40	72000	5	20387,95	Terminal B - Themistocles	2402
Norwegian Pearl	3	994	9844,56	33	9,90	326,83	72000	5	18620,39	Terminal B - Themistocles	2394
Norwegian Spirit	9	2398	14928,64	104	6,23	647,45	58800	4	34584,47	Terminal B - Themistocles	2018
Norwegian Star	5	1539,5	10766,39	60	6,99	419,61	58800	4	24984,56	Terminal B - Themistocles	2348
Oceana	9	1619,5	10581,8	121,5	6,53	793,88	46080	4	23458,8	Terminal A - Miaoulis	889
Oceania Insignia	1	230	803,64	12	3,49	41,93	18596	4	1769,39	Terminal A - Miaoulis	824
Oceania Marina	4	1747	7865,59	65	4,50	292,65	42000	4	13752,5	Terminal B - Themistocles	1250
Oceania Riviera	1	1349	6650,14	12	4,93	59,16	67200	4	9278,1	Terminal C - Alkimos	1250
Pacific Princess	2	1279	1727,3	23,5	1,35	31,74	13500	4	7072,13	Terminal C - Alkimos	688
Queen Mary 2	1	442,5	3271	13	7,39	96,10	15700	4	48449,6	Terminal B - Themistocles	2695
Rhapsody of the Seas	12	1294,5	5639,93	109	4,36	474,90	52800	4	6104,42	Terminal B - Themistocles	1998
Salamis Filoxenia	1	679	985	6	1,45	8,70	13240	2	3385,82	Terminal A - Miaoulis	1009
Sapphire Princess	1	1237,5	6933,57	15	5,60	84,04	37500	6	30207,6	Terminal B - Themistocles	2670
Seabourn Encore	4	1275	2423,85	40	1,90	76,04	23040	6	4864,91	Terminal C - Alkimos	604
Seabourn Odyssey	8	1758	3580,26	80	2,04	162,92	23040	6	6655	Terminal C - Alkimos	450
Seabourn Ovation	2	1902	2043,7	20	1,07	21,49	23040	6	10548,21	Terminal C - Alkimos	604
Seven Seas Voyager	6	1971	6156,03	66	3,12	206,14	23040	6	9763,65	Terminal A - Miaoulis	706
Silver Shadow	5	1739,5	3195,7	50	1,84	91,86	62400	2	6727,99	Terminal C - Alkimos	388
Silver Spirit	1	1893,5	3357,34	9	1,77	15,96	26100	4	7010,52	Terminal C - Alkimos	608
Silver Whisper	1	1465	2344,79	10	1,60	16,01	15700	2	4895,83	Terminal C - Alkimos	382
Sky Princess	1	171	1459,15	12	8,53	102,40	62400	4	5328,5	Terminal B - Themistocles	3660
Spectrum of the Seas	1	49,5	123,43	10	2,49	24,94	67200	6	2767,3	Terminal B - Themistocles	4246
Star Pride	2	1075	764,59	20	0,71	14,22	7280	4	2499,78	Terminal C - Alkimos	208
Veendam	2	1058	545,97	30	0,52	15,48	34560	5	8118,35	Terminal B - Themistocles	1350
Viking Jupiter	4	2001	6403,25	70	3,20	224,00	23520	4	12019,9	Terminal A - Miaoulis	930
Viking Sky	2	2430,5	7289,72	28,5	3,00	85,48	23520	4	14767,06	Terminal A - Miaoulis	930
Viking Star	7	1948	4099,96	78	2,10	164,17	23520	4	14225,2	Terminal A - Miaoulis	930
Vision of the Seas	7	1161,5	577,8	84	0,50	41,79	52800	4	12751,33	Terminal B - Themistocles	2050
Wind Star	24	1796	460,7	240	0,26	61,56	2964	3	1308,67	Terminal C - Alkimos	142
Wind Surf	2	1954	1152,19	20	0,59	11,79	9120	4	2946,38	Terminal C - Alkimos	386

Table 5:Data for the year 2019

APPENDIX III

Ship name	Port calls	Hours spend at MS ports	CO2 at MS ports	Hours at Piraeus	CO2 at MS ports per hour	CO2 at Piraeus	Engine total power (kW)	Nr. Of Engines	Total Fuel consumption	Terminal	Capacity
Aegean Majesty	1	600,00	545,97	12	0,91	10,92	10300	5	8118,35	Terminal B - Themistocles	1350
AIDAbella	1	3563,00	11722,59	10	3,29	32,90	36000	4	4842,93	Terminal B - Themistocles	2500
AIDAblu	2	2947,00	14146,59	6	4,80	28,80	36000	4	9884	Terminal B - Themistocles	2192
Boudica	1	53,00	2671,16	10	50,40	503,99	14000	4	6988,3	Terminal A - Miaoulis	900
Celebrity Infinity	2	1868,00	1587,94	25	0,85	21,25	50000	2	5247,07	Terminal B - Themistocles	2170
Celestyal Crystal	8	439,00	715,61	117	1,63	190,72	19200	4	764,53	Terminal B - Themistocles	1409
Costa Deliziosa	5	2450,00	13307,85	47	5,43	255,29	64000	6	11378,33	Terminal B - Themistocles	2260
Costa Diadema	2	2500,00	15308,87	34	6,12	208,20	75600	6	7175,4	Terminal A - Miaoulis	1253
Costa Fortuna	2	2960,00	15441,96	28	5,22	146,07	63360	6	5457,73	Terminal B - Themistocles	3470
Jewel Of the Seas	4	21,00	6,70	21	0,32	6,70	59000	3	793,12	Terminal B - Themistocles	2501
La belle des oceans	2	73,00	84,64	18	1,16	20,87	5350	2	520,2	Terminal C - Alkimos	128
Le Champlain	7	518,00	1769,00	81	3,42	274,91	8000	4	1890	Terminal C - Alkimos	264
Mein Schiff 3	1	976,00	663,74	14	0,68	9,18	45200	4	2869,24	Terminal B - Themistocles	2506
Mein Schiff 6	5	820,00	718,22	69	0,88	60,00	44000	6	2631,8	Terminal B - Themistocles	2534
MSC Opera	2	2757,00	9953,00	16	3,61	57,76	30600	4	8154	Terminal B - Themistocles	2679
Ocean Majesty	3	580,00	844,98	24	1,46	34,96	12016	2	951,37	Terminal C - Alkimos	621
Seabourn Ovation	13	182	163,93	142	0,90	127,90	23040	4	628,60	Terminal C - Alkimos	604
World Explorer	4	1350,00	2172,20	35	1,61	55,51	9000	2	966,85	Terminal C - Alkimos	200

Table 6: Data for the year 2020

APPENDIX IV

Cross Impact Analysis Matrix

	S1	S2	S3	S4	EC1	EC2	EC3	EC4	EN1	EN2	EN3	EN4	P1	P2	P3	T1	T2	T3	Score
S1		2	2	2	1	1	1	0	1	1	0	1	2	2	2	1	1	1	21
S2	0		3	0	1	2	0	0	0	0	0	0	0	0	1	2	2	2	13
S3	0	1		2	0	0	3	0	3	0	0	3	1	1	2	1	1	1	19
S4	1	1	2		0	0	1	0	3	0	0	3	0	0	2	0	0	0	13
EC1	0	0	2	0		1	3	3	1	0	1	2	0	0	0	3	2	2	20
EC2	0	2	2	0	1		2	1	1	0	0	2	1	1	1	2	2	2	20
EC3	2	1	2	0	1	2		0	3	2	2	3	1	1	1	1	1	1	24
EC4	0	0	1	0	2	2	2		0	0	2	1	1	1	1	3	3	2	21
EN1	2	0	0	3	3	2	2	2		3	3	3	2	2	2	2	2	2	35
EN2	1	0	0	0	3	3	3	1	3		2	3	2	2	2	2	2	2	31
EN3	2	0	0	2	3	3	3	2	2	2		2	2	2	2	2	2	2	33
EN4	3	0	1	3	3	3	3	2	3	3	3		2	2	2	2	2	2	39
P1	1	1	1	1	2	2	2	1	3	3	3	3		2	2	1	1	1	30
P2	1	0	0	0	2	2	2	1	3	3	3	3	2		2	1	1	1	27
P3	2	1	2	0	2	2	2	2	2	2	2	1	1	1		1	1	1	25
T1	2	2	2	1	2	2	2	3	2	1	2	2	1	1	1		1	2	29
T2	1	2	2	1	2	1	2	1	1	1	1	1	1	1	1	2		3	24
T3	1	2	2	1	2	2	2	1	2	1	2	2	1	1	1	1	2		26

Figure 14: Cross Impact Analysis Matrix

The cells with the darkest color are the variables that collected the highest score and are some of the most critical uncertainties that could affect the focal question.

APPENDIX V

Wilson Matrix

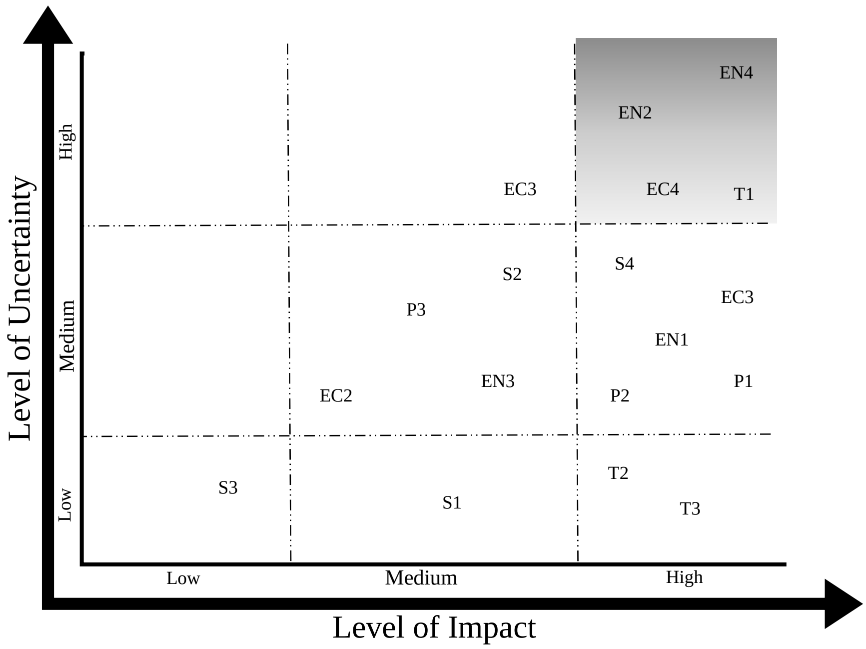


Figure 15: Wilson Matrix

The above graph documents all the external forces analyzed in section five, and as it is evident, they influence the decisions of the port of Piraeus differently. The following list contains each power, as well as its symbol, used in the graph.

- Citizens Health and Safety (S1)
- Training (S2)
- Employment (S3)
- Population Growth (S4)
- Sustainable investments (EC1)
- Additional Funds (EC2)
- Port operation efficiency (EC3)
- Facilities cost (EC4)
- Climate Change (EN1)
- Environmental Agreements (EN2)
- Environmental Management (EN3)
- Air pollution (EN4)
- The European Union (P1)
- The International Maritime Organization (P2)
- The Greek National Government (P3)
- Shore supply Infrastructure (T1)
- Digitalization (T2)
- Energy efficiency with IoT (T3)

APPENDIX VI

Terminal C				
Ships	21			
Average Calls per year	5			
Average Hours at berth	10,5			
Investment cost				
Input				**Yearly cost**
OPS				
INVESTMENT COSTS				
General Information Investmet				
Interest rate		6%		
depreciation (years)		20		
Investment costs terminal				
high voltage connection from grid (including transformer) (€)		1500000		
Cable installation (€)		225000		409.143,36 €
Total investments (€)		1725000		
Maintenance, contract and electricity transport costs (15%) (€)		258750		
Investment costs ships				
Transformer (€)		44600		
Main swithboard, control panel (€)		10000		
Cabling (€)		3900		162.032,50 €
Cable reel system (€)		30000		
Total investments (€)		88500		
OPERATIONAL COSTS				
Electricity costs				
Electricity price (€/ kWh)		0,11		
tax (€/ kWh)				709.094,93 €
Consumption (kW)		5847		
Saved maintenance				
Maintainance per engine (€/ h)		-2		-7.717,50 €
number of engines		3,5		
				1.272.553,28 €
Auxiliary engines				
Input terminal		0		
General info investement costs		0		
no investments		0		
Investment costs terminal				
no investments		0		
Investment costs ships				
no investments		0		
OPERATIONAL COSTS				
Fuel costs				
Diesel (€/ton)		1623		
Consumption (ton/h)		1,28634		1.519.024,28 €
ETS costs				
ETS CO2 price		0		
			Totall yearly cost reduction	-246.471,00 €
			Totall monthly cost reduction	-20.539,25 €
	Emissions (ton)			
Electricity source - Natural Gas	2591,42			
Fuel - Diesel	4538,21			
	-1946,79			

Figure 16: Costs Calculation - Terminal C

- Investment Cost Terminal = -PMT [interest rate; depreciation; SUM (High voltage conn. From grid: Cable installation);0) + Maintenance, contract, and electricity transport cost]
- Investment Cost Ship = -PMT [[interest rate; depreciation; SUM (Transformer: Cable reel system)] * Ships

Terminal A				
Ships	14			
Average Calls per year	4			
Average Hours at berth	11,4			
Investment cost				
Input				**Yearly cost**
OPS				
INVESTMENT COSTS				
General Information Investmet				
Interest rate	6%			
depreciation (years)	20			
Investment costs terminal				
high voltage connection from grid (including transformer) (€)	2000000			
Cable installation (€)	255000			534.851,18 €
Total investments (€)	2255000			
Maintenance, contract and electricity transport costs (15%) (€)	338250			
Investment costs ships				
Transformer (€)	65416			
Main swithboard, control panel (€)	15000			
Cabling (€)	3900			151.738,10 €
Cable reel system (€)	40000			
Total investments (€)	124316			
OPERATIONAL COSTS				
Electricity costs				
Electricity price (€/ kWh)	0,11			
tax (€/ kWh)				807.365,33 €
Consumption (kW)	11497			
Saved maintenance				
Maintainance per engine (€/ h)	-2			-5.107,20 €
number of engines	4			
				1.488.847,40 €
Auxiliary engines				
Input terminal	0			
General info investement costs	0			
no investments	0			
Investment costs terminal				
no investments	0			
Investment costs ships				
no investments	0			
OPERATIONAL COSTS				
Fuel costs				
Diesel (€/ton)		1623		
Consumption (ton/h)		2,529		1.729.539,30 €
ETS costs				
ETS CO2 price		0		
			Totall yearly cost reduction	-240.691,90 €
			Totall monthly cost reduction	-20.057,66 €
	Emissions (ton)			
Electricity source - Natural Gas	2950,55			
Fuel - Diesel	5167,14			
	-2216,58			

Figure 17: Costs Calculation - Terminal A

Terminal B				
Ships	44			
Average Calls per year	13			
Average Hours at berth	8			
Investment cost				
Input				**Yearly cost**
OPS				
INVESTMENT COSTS				
General Information Investmet				
Interest rate	6%			
depreciation (years)	20			
Investment costs terminal				
high voltage connection from grid (including transformer) (€)	2500000			
Cable installation (€)	255000			653.443,45 €
Total investments (€)	2755000			
Maintenance, contract and electricity transport costs (15%) (€)	413250			
Investment costs ships				
Transformer (€)	116508			
Main swithboard, control panel (€)	25000			
Cabling (€)	3900			749.608,64 €
Cable reel system (€)	50000			
Total investments (€)	195408			
OPERATIONAL COSTS				
Electricity costs				
Electricity price (€/ kWh)	0,11			
tax (€/ kWh)				9.343.368,32 €
Consumption (kW)	18562			
Saved maintenance				
Maintainance per engine (€/ h)	-2			-45.760,00 €
number of engines	5			
				10.700.660,41 €
Auxiliary engines				
Input terminal	0			
General info investement costs	0			
no investments	0			
Investment costs terminal				
no investments	0			
Investment costs ships				
no investments	0			
OPERATIONAL COSTS				
Fuel costs				
Diesel (€/ton)		1623		
Consumption (ton/h)		4,08364		20.016.858,55 €
ETS costs				
ETS CO2 price		0		
			Totall yearly cost reduction	-9.316.198,14 €
			Totall monthly cost reduction	-776.349,85 €
	Emissions (ton)			
Electricity source - Natural Gas	34145,76			
Fuel - Diesel	59797,56			
	-25651,79			

Figure 18: Costs Calculation - Terminal B

Diesel emissions Factor	CO2 (g/kWh)	3,2
Electricity - Natural Gas	CO2 (g/kWh)	402
	Source: Rotterdam Euromax study (see library)	

Figure 19: Emissions Factors (De Jonge, Hugi, & Coper, 2005)