

TRAVISIONS

TRA VISIONS 2022

Idea Number:

C2022 - 10

PILLAR / TRANSPORT MODE				
ROAD ☐	RAIL ☐	WATERBORNE ☒	AIRBORNE ☐	CROSS MODAL ☐
Project Related to:	☐ RA1: Smart Solutions and Society ☒ RA2: Green Mobility and Decarbonisation ☐ RA3: Innovative Infrastructure for Europe 2030 ☐ RA4: Policies and Economics for a Competitive Europe			

Project Title: Cold Ironing Implementation At The Port Of Piraeus

Group Leader: Nikolaos Kampolis
Group Secretary: Michail Besis
Group Member: Konstantinos Chouvardas
Group Member: Dimitrios Galanos
Group Member: Nikolaos Balanos
Group Member: Georgios Stratakis



This project has received funding from the European Union's Horizon 2020 Research and Innovation Programme under grant agreement n° 101006593



Table of Contents

1	<i>Introduction</i>	1
2	<i>Background</i>	1
2.1	Theory of Cold Ironing.....	1
2.2	Piraeus Containership Terminal.....	2
3	<i>Motivation</i>	2
3.1	Solar Energy.....	2
3.2	From a Concept to a Reality	3
4	<i>Methodology</i>	3
4.1	Traffic at the Port of Piraeus	3
4.2	Power demand.....	5
4.3	Emissions Savings Calculations.....	5
4.4	Fuel Consumption.....	7
5	<i>Technical Design</i>	8
5.1	System Configuration	8
5.1.1	Power Requirements in Port.....	8
5.1.2	System Layout	9
5.2	Software Design	9
5.2.1	Using HOMER.....	9
5.2.2	Required Infrastructure.....	11
6	<i>Renewable Station</i>	11
6.1	Solar Panel Characteristics.....	11
6.2	Solar Irradiance Estimations	12
6.3	PV panels installation analysis	13
6.4	Seasonal Variations in Energy Supply	14
7	<i>Investment Appraisal</i>	15
8	<i>Conclusion</i>	16
9.	<i>References</i>	17
9	<i>Appendices</i>	1
9.1	Appendix I.....	1

1 Introduction

Commercial Shipping at present constitutes a major emitter of greenhouse gases. It has been estimated that more than 840 mt of CO₂ were emitted by the world fleet in 2020 alone [1], representing about 2.5% of global CO₂ emissions. Emissions from commercial shipping however are not limited to CO₂ and include SO_x, NO_x, PM, and many more. It is well known that such emissions contribute to climate change air pollution. The effects of climate change are well known and wide reaching, and include global warming, extreme weather events, shifting wildlife populations, rising sea levels and many more [2].

In recent years, the maritime industry has been constantly attempting to reduce emissions, through the adoption of various new measures and regulations. Undoubtedly, without the measures already adopted, global emissions from shipping would have been significantly higher than what they already are [3]. Nevertheless, more needs to be done to tackle the industry's carbon footprint.

This project will concentrate on cold ironing, a measure that can yield substantial emissions savings of the global fleet. Cold ironing particularly tackles the problem of ship emissions at berth.

2 Background

The International Maritime Organization (IMO) has already adopted and implemented preliminary international greenhouse gas emissions reduction strategies. Almost 200 member states have agreed to limit their ship emissions by at least 50% with respect to the 2008 level by 2050 [4]. To this end, the new IMO2020 regulations mandate that from the 1st of January 2020, the global upper limit on the fuel oils' sulphur be reduced to 0.50% (from 3.5%). Such restriction will not only lead to a 77% drop in overall SO_x shipping emissions but also reduce tiny harmful particles formed during the burning of fuel known as particulate matter [4]. Following the intense efforts and changes to combat the global climate change, cold ironing is another option to reduce ship's emissions. The aforementioned system has already been implemented in several different ports around the world such as those at Los Angeles, Long beach, Seattle, Antwerp and Killini in Greece [5].

In general, when vessels are docked to port, they usually have one or two auxiliary generators operating to cater for auxiliary services such as lighting, pumping, ventilation, cooling, loading and unloading of cargo [6]. However, in the case of containerships the load needed for auxiliary services is much greater than that needed for other types of vessels, since the load needs to be large enough to cover the need for containerships' reefers refrigeration.

The containerships calling at the port of Piraeus produce a significant load by their diesel engines to cover their operational and refrigeration power needs. Containership's auxiliary diesel engines generate a number of hazardous gasses such as SO_x, NO_x and CO₂. Gasses not being enough, such engines also produce particle discharge along with noise and vibration, causing negative health and environmental impact on the surrounding communities.

Consequently, the combination of new regulations and the constant need for sustainable shipping, motivates the conduction of research on projects that reduce emissions of containerships, such as the one in this paper, the implementation of a cold ironing station at the containership terminal of Piraeus, Greece.

2.1 Theory of Cold Ironing

Cold ironing, also known as alternate maritime power (AMP) is the process whereby electrical power produced on shore, is provided via cables to ocean-going vessels, allowing them to shut down their diesel generators while they are docked [7]. Cold ironing covers a vessel's operational needs while at berth during loading or unloading activities.

The opportunity for ships at berth, to be connected to shore power instead of operating their diesel generators for their general power needs, allows them to limit fuel consumption, and subsequently emissions, reduce engine wear and running hours but also facilitates maintenance of the ship's diesel generators and main engine.

Three different individual subsystems including the shore side system, the ship-to-shore connection system and the vessel's interface equipment system form the main cold ironing station. For an efficient and safe operation all 3 subsystems must be fully compatible with one another. The electrical load supplied to vessels by shore can be sourced by 3 distinct ways: a separate power generation unit, a power plant supplying power to the port city or town or a renewable power generation unit. Cold Ironing is most potent if the shore power itself is generated from renewable energy sources. This process not only leads to the preservation of marine ecosystem but also contributes to the reduction in the usage of diesel and other oily power supply materials.

2.2 Piraeus Containership Terminal

Being the largest port in Greece, one of the largest ports in the Mediterranean and a central hub for access to Eastern Europe [8], Piraeus has a significant function both in international trade and the local and national economy. Although, Piraeus accommodates a diverse range of ships, ranging from ROROS, passenger ferries and cruise ships, this project will concentrate on the containership terminal of the port.

According to Port Economics, the containership terminal of Piraeus ranks as the 4th biggest container port in Europe with an annual handling throughput of 5.65 million TEU. It is worth mentioning that two out of three piers of the port are owned and operated by COSCO Shipping, offering advanced services in loading and unloading containers using technologically advanced cranes [9]. The container terminal generates an annual turnover of about €150 million [9]

3 Motivation

Considering the environmental and economic benefits that a cold ironing station offers, the research question regarding the existence of a cold ironing station in every maritime port is raised. In order to identify the primary factors that doesn't "allow" the concept of a cold ironing station to become a reality in every port, industry professionals were contacted for a more credible answer. The Client Relationship Manager of Marine and Offshore Lloyds Hellas, was contacted to have a discussion regarding the Cold Ironing station at the Port of Piraeus. After the meeting, four major problems were pinpointed that postpone the manufacturing of a Cold Ironing station at Piraeus.

These were the four problems that were indicated.

1. Lack of Regulations
2. Lack of Incentives
3. Lack of Infrastructure
4. Lack of Interest

First and foremost, the lack of regulations was discussed. As of 2021, the IMO does not require from any port authorities to provide shore power electricity to the vessels calling at port. Thus, as the implementation of a Cold Ironing station is not mandatory, a distinct incentive for investing in such system does not exist. This lack of incentive is the foundation of the second major problem that postpones the implementation of a cold ironing system. As neither the port authorities nor the ship owners of the vessels are required to retrofit the necessary equipment for shore power provision or reception, there is no clear inducement for the adoption of a cold ironing system. This lack of incentives signifies the importance of indicating the benefits of an alternative maritime power system. Subsequently, during the meeting the lack of infrastructure was discussed. As it is mentioned later on in Section 4 of the report, Piraeus is one of the busiest European Ports. In order to supply all these vessels with the required power that would substitute the energy produced from their diesel engines, a large investment on particular infrastructure is required. As of today, this infrastructure for the provision of electrical power is not available in most European Ports, which proves to be a significant barrier in the implementation of a cold ironing system. Lastly, the lack of interest that exists from both the shipowners and the port authorities, in implementing a cold ironing system due to the absence of a clear benefit for both sides, doesn't accelerate the implementation of such projects. Subsequently, all of these problems mentioned in this paragraph, signify the importance of indicating the benefits of cold ironing, an important section of this report.

3.1 Solar Energy

As it has been indicated in the introduction of this paper a cold ironing station is the most potent and sustainable if renewable energy is used to produce the electricity. A crucial design aspect of the cold ironing station at the port of Piraeus, is the production of the electricity using renewables.

As of 2020, Renewable Energy accounts for a total of 29% of the total energy produced in Greece [10]. With Wind, Hydro and Solar energies being the three most common renewable sources, a particular source had to be selected for the cold ironing station. Keeping in mind the densely populated area of Piraeus that would not allow the installation of wind turbines, as well as the lack of infrastructure for the implementation of a hydroelectric energy system, photovoltaic energy was identified as the optimum renewable source. The available surface area next to the containership terminal, in combination with the familiarization that Greek authorities have with the harness of the solar energy [11], signify the differentiation between photovoltaic energy and other renewable energy sources. Above all though as it can be seen in Figure 1 [12], Piraeus is located in an area with high solar irradiance, meaning that the harness of solar energy in this location is feasible. More technical information regarding the photovoltaic renewable station is provided in Section 6 of this report.

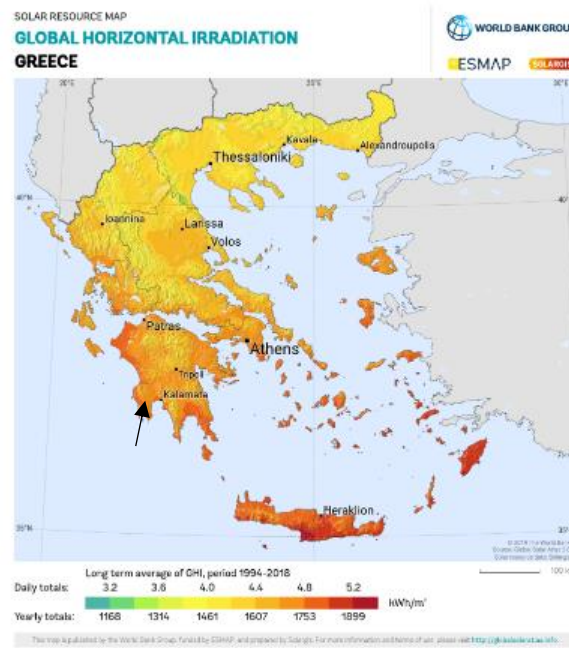


Figure 1: Greece's Solar Irradiance Map [12]

3.2 From a Concept to a Reality

Keeping in mind the four major problems that were mentioned earlier, regarding the implementation of a cold ironing station at the port of Piraeus, in the meeting with Mr. Kourbelis potential solutions for transforming this concept into a reality were discussed. These solutions include regulations and incentives that would accelerate the implementation of the cold ironing station.

First of all, as Mr. Kourbelis mentioned during the meeting, by 2027 [13] large commercial port will be required to supply some kind of shore side electricity to the vessels at berth. The provision of shore side electricity will assist with the IMO goal, regarding the reduction of Green House Gases by 40% before the year 2030 [14]. This legislation would expedite the implementation of Cold Ironing stations, as it would solve the problem regarding the lack of regulations. Furthermore, a solution to the second problem that delay the operation of a cold ironing station which is the lack of incentives, would be the selling of the kWh produced at a low price. This way, shipowners will be motivated to purchase the electricity from shore rather than use the vessels' diesel generators. Although, it is worth mentioning that the price in which the kWh will be sold needs to be profitable for the port authorities as well. Therefore, research and investigation regarding the optimum price for the energy produced, is crucial for the sound operation of a cold ironing system.

Lastly, in order to tackle the lack of infrastructure as well as the lack of interest that exists, the energy generated from the cold ironing station could be used for other projects as well. To elaborate on this, in the case of the cold ironing station at the containership terminal of Piraeus, the energy produced could also be used in the neighbouring Ro-Ro and Cruise Ship Terminals. In addition, the energy produced could be sold to the national grid for further usage. Furthermore, a more innovative idea would be to use this electricity produced for other "green" projects, such as an electrical vehicle charging station. These are some examples that would justify investing in the infrastructure required as well as capture the interest of various business sectors.

In the following section, the methodology regarding the estimation of the traffic at the port of Piraeus, power demand, electrical load as well as emissions savings, data crucial for the design of the cold ironing station, are analysed.

4 Methodology

4.1 Traffic at the Port of Piraeus

Traffic at the container terminal of the port of Piraeus has expanded rapidly over the past few years, rising to approximately 5.5 million TEUs handled in 2020 alone [15]. As the situation stands today, Piraeus is the largest port in terms of container throughput in the Mediterranean region and ranks fourth in Europe [16] altogether having recently overtaken the ports of Valencia and Algeciras. As shown from the data above, Piraeus is clearly a vibrant port, providing many benefits for the local community.

As the port expands however, emissions from ships have been a rising concern. Despite the fact that emissions at port, only constitute a small part of a ship's overall emissions, the fact that people live in the vicinity of the port, means that they must be reduced to preserve the health and quality of life of the local inhabitants.

As mentioned previously to tackle the problem of ship emissions at berth, a cold ironing installation fed by renewables should be installed. To appropriately size the cold ironing installation however and to calculate any emissions savings, it is critical to get an idea of the electrical load demanded from the vessels calling at the container terminal.

To estimate the load, a random sample of 100 vessels was taken from a database of port calls [17] and the TEU and Reefer TEU capacity of these vessels was found. The data regarding vessel particulars were found by using Clarkson's World Fleet Register [18]. From the sample, we saw that vessels sizes ranged from 700 TEU Feeders all the way to Super Post Panamax Vessels of more than 15000 TEU. For the sake of simplicity, it was decided to assign the vessels calling at port to 5 size classes. These groups can be seen in the table 1 below:

Table 1: Size Group Allocation

Group Name	TEUs
Group 1	700-1000
Group 2	1000-2000
Group 3	2000-5000
Group 4	5000-10000
Group 5	10000-22000

Following the formation of the five groups the average TEU and refrigerated TEUs were calculated for each group. The values obtained can be seen in Table 2 below. For each of the groups, a representative vessel with TEU and Reefer TEU close to the class average was selected, and this would form the basis of our analysis in our electrical load estimation.

Table 2: Case study vessel for each Group

Group Name	Case Study Vessel	Average Number of TEUs	Average Number of Refrigerated TEUs
Group 1	LIBERTAS-H	724	300
Group 2	VICTORIA L	1304	516
Group 3	NORDAUTUMN	3586	1000
Group 4	MAERSK KLEVEN	7403	1406
Group 5	AL MASHRAB	14993	2000

While the above data, tells us a lot about the size of vessels, calling at the port of Piraeus, it is of little use in estimating the energy demand for a given period, since it does not give us any information about the time each ship spends at berth nor the variety of size classes calling on a 'typical' day. To get an idea of the energy demanded (in kWh) by vessels in a day, a scheduling table was formed. This was done, by taking a schedule of vessels at berth for a 24 hour-period. Data was extracted from the Cosco Shipping Online Database [17] for ships berthed from 6:00 AM 18/3/2021 until 6:00 AM 19/3/2021. The scheduling table is presented below, in Figure 2. Each vessel during the 24-hour period was assigned to the corresponding group based on their TEU and Reefer TEU capacity.

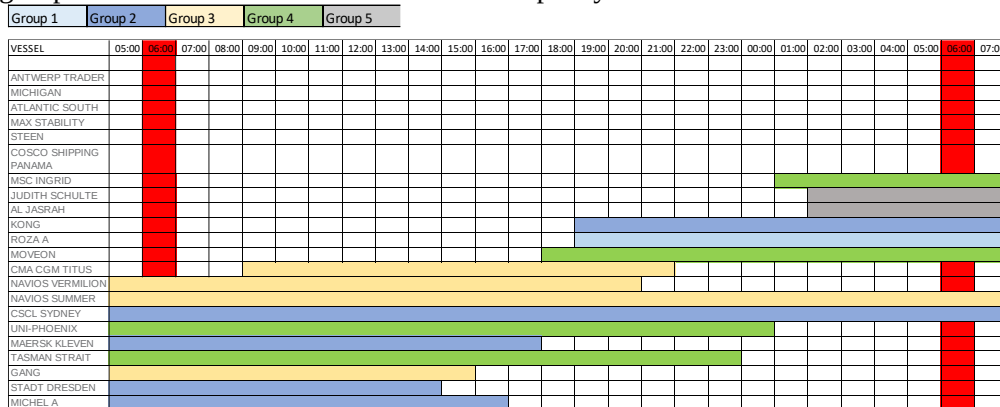


Figure 2: Containership terminal schedule table for 24-hours

4.2 Power demand.

Using the Table presented in Figure 2 the total number of ships berthed per category at the port over the 24-hour period were determined as well as an approximation of the total hours spent at berth per category.

From Clarkson's database [18] the auxiliary engines, onboard each sample vessel, were obtained as well as the power output of each generator. To determine the total power requirement for each vessel while at berth it was assumed that each vessel operates with one generator at 80% load. This generator would be supplying all electrical loads, less the reefer containers. To get the total electrical demand, we had to add on top of that the load of the reefer boxes.

For this calculation, we initially assumed that the vessels calling at the port, would be carrying 75% of their total reefer capacity on board. This is a reasonable approximation, since vessels are only rarely, in very strong markets, loaded to their full capacity. Next, we had to approximate the electrical load for each of the reefer containers. From the literature we found that on average each reefer box draws about 3kW of electricity [19], and this formed the basis of our further calculations. By multiplying the number of containers on board by the average electrical load, and adding on top of that the auxiliary loads, the total power demand for a single vessel could be found. This process was repeated for all the vessels categories.

Finally, in order to get a figure in kWh for a single day, the time spent at berth by vessels calling over a 24hr period, was multiplied by the electrical power for their respective categories and the total energy demand in kWh was found for a given day.

Table 3: Auxiliary Engines onboard each Sample Vessel

Group Number	Vessel Name	A/E Type
1	LIBERTAS-H	2x MaK 6M20 1,920ekW total, (2,400kVA total).
2	VICTORIA L	3x MAN Energy Solutions 7L23/30H Mk.1 3000 ekW total
3	NORDAUTUMN	4x MAN Energy Solutions 9L28/32H 7,200ekW total, (9,000kVA total)
4	MAERSK KLEVEN	4x MAN Energy Solutions 7L32/40 12,000ekW total, (15,000kVA total)
5	AL MASHRAB	4x HHI-EMD (HiMSEN) 9H35DF at 16,676ekW total, (20,845kVA total)

Table 4: Total Energy Demanded per category over a 24-hour period.

Group Number	No. of Ships Per Category	Hours per category	Power per generator at 80% (kW)	75% of Reefers (kW)	Total Load (KW) per ship	Total load 24hrs (kWh)
1	1	12	768	675	781	11520
2	5	68	800	1161	1267	68000
3	4	62	1440	2250	2356	111600
4	4	56	2400	3164	3270	168000
5	2	10	3335.2	4500	4606	41690

4.3 Emissions Savings Calculations

As mentioned before, the main driver of constructing a cold ironing installation, is to reduce emissions at port and as a result, estimating the greenhouse gas emissions savings from this installation was an important part of our project. To quantify the emissions savings, the following process was performed:

Initially, the specific fuel oil consumption (SFOC) was found from the auxiliary engine manuals for each of the model vessels. The SFOC was found to be roughly constant for all the vessels at about 185g/kWh [20]. Next to calculate the mass of fuel consumed, the SFOC was multiplied by the energy demanded per day for each of the vessels in the category. This

process was carried out for all the ship classes and the mass of fuel consumed per day was found. Calculations for this process can be seen in equation (1), where EL is electrical load in %, P is rated power output, and t is time over which the activity takes place.

$$FC = 10^{-3} \times t \times EL \times SFOC \times P \quad (1)$$

To convert the fuel mass into emissions of pollutant x, the mass of fuel consumed (FC) was multiplied with the respective emission factor (EF_x) for the pollutant x.

$$\varepsilon_x = FC \times EF_x \quad (2)$$

In our report, the focus is CO₂ emissions however, SO_x and NO_x emissions were also calculated. Fuel emission factors have been the topic of research of various papers in the literature, however in our calculations, standard emission factors prescribed by the EU were used [21]. Since Piraeus is in an emissions-controlled area, the assumed fuel for the diesel generators was distillate marine gas oil.

Table 5: Emissions factors for bottom-up emissions due the combustion of fuels [21]

Emissions species	Marine HFO emissions factor (g/g fuel)	Marine MDO emissions factor (g/g fuel)	Marine LNG emissions factor (g/g fuel)
CO ₂	3.11400	3.20600	2.75000
CH ₄	0.00006	0.00006	0.05120
N ₂ O	0.00016	0.00015	0.00011
NO _x Tier 0 SSD	0.09282	0.08725	0.00783
NO _x Tier 1 SSD	0.08718	0.08195	0.00783
NO _x Tier 2 SSD	0.07846	0.07375	0.00783
NO _x Tier 0 MSD	0.06512	0.06121	0.00783
NO _x Tier 1 MSD	0.06047	0.05684	0.00783
NO _x Tier 2 MSD	0.05209	0.04896	0.00783
CO	0.00277	0.00277	0.00783
NM VOC	0.00308	0.00308	0.00301

The total emissions savings for a given day were computed, if all the vessels calling at the terminal were to be supplied by shore power. This was done using equation 1 and 2, the SO_x NO_x and CO₂ emissions savings for a 24hr period can be seen below.

Table 6: Total Emissions over a 24-hour period

NO _x		CO ₂		SO _x	
Group 1	0.17 tonnes	Group 1	6.83 tonnes	Group 1	4.26 kg
Group 2	1.07 tonnes	Group 2	41.86 tonnes	Group 2	26.1 kg
Group 3	1.76 tonnes	Group 3	68.70 tonnes	Group 3	42.8 kg
Group 4	2.63 tonnes	Group 4	102.71 tonnes	Group 4	64.1 kg
Group 5	0.62 tonnes	Group 5	24.19 tonnes	Group 5	15.1 kg
Sum	6.24 tonnes	Sum	244.29 tonnes	Sum	152.4 kg

It is reasonable to assume however that not all vessels calling at the port would be plugging into the shore power. Many shipowners may not have the requisite installation on board to connect to shore and some vessels may only be calling at the port for a very short period thus not being suitable for cold ironing.

To avoid oversizing the installation we assumed that 60% of the vessels calling at port would use the installation and 3 out of 5 berths would be supplied with electricity. Of course, this would mean that CO₂, SO_x and NO_x would be reduced by 40% when compared to the above figures, since these tables display emission savings if all the ships were using shore power. The realised emission savings can be seen in Table 7 below:

Table 7: Realised Emission Savings for 60% of the demand

Emission Species	Emission Savings (tonnes/day)
CO ₂	146.57
SO _x	3.744
NO _x	0.09144

4.4 Fuel Consumption

Part of the emission-controlled areas (ECAs), Piraeus requires that vessels calling at its port to use low sulphur bunker (0.1%) according to “ECA and Ports List” [22]. That can be achieved through three main methods: by using low sulphur fuel such as low sulphur, MGO (Marine Gas Oil), converting to LNG (Liquified Natural Gas) or to be equipped with exhaust gas cleaning technologies. Specifically, needing electrical power to cover the hotel and deck loads as well as to comply with regulations, the containerhips calling at the container terminal of Piraeus were found from Clarkson’s data not to use scrubbers or LNGs but instead to burn MGO. It’s worth mentioning that this report will also determine the most appropriate selling price for the power generated from the renewable energy sources so that an incentive to the shipping companies can be given in order to utilize that power. Therefore, the daily fuel consumptions required by the vessels to operate their auxiliary generators must be determined so that the daily fuel expenses bared by the shipping companies can be eventually calculated. Being the major running cost for shipowners, fuel consumption was calculated by using equation (1) as mentioned in section 4.3.

By dividing the total fuel consumed with the number of vessels included in each category, the average total fuel consumed per ship in tonnes during the 24-hour period was determined. The average behaviour of MGO’s price per metric ton during the last 6 months for 20 global ports is illustrated below in Fig.3 [23].



Figure 3: Global 20 Ports Average – MGO [23]

According to the graph displayed in Fig.3 above, the average MGO’s price for the 6-month period is estimated at \$502/metric ton. Therefore, by using the average amount of fuel consumed per ship and the MGO’s price per tonne, the average fuel costs endured per vessel at berth were determined and presented in Table 8 below.

Table 8: Average fuel cost per vessel for the 24-hour period.

Power per generator at 80% (kW)	Approx. Hours per category (hours)	Power produced per generator per category (kWh)	Fuel consumed per category (MT)	Number of Vessels per category	Average Fuel consumed per vessel for the 24hour period (MT)	Average Fuel costs per vessel for the 24hour period (\$)
768	12	9216	1.70496	1	1.70	855.89
800	68	54400	10.064	5	2.01	1010.43
1440	62	89280	16.5168	4	4.13	2072.86
2400	56	134400	24.864	4	6.22	3120.43
3335.2	10	33352	6.17012	2	3.09	1548.70

Since 185 grams of fuel are needed to produce 1 kWh and the MGO's price is \$502 per metric ton, the amount of money spent by each ship at berth to produce 1 kWh comes at about \$0.0924 which is equivalent to 0.077 €/kWh according to an exchange rate of. ($1\$=0.83\text{€}$) [24].

5 Technical Design

5.1 System Configuration

In 2006 the Institute of Electrical and Electric Engineers (IEEE 2006) introduced an international standard which proposed the most efficient High Voltage Shore Connection system design (HVSC), a standard that has been widely adopted ever since [25]. The aim of this publication is to determine requirements that support the efficiency and safety of connections of compliant ships to compliant high voltage shore power supplies through a compatible shore-to-ship connection. Adequate planning, thorough cooperation between ship and terminal facilities and suitable operating while complying with the requirements of the publication enable the vast majority of vessels to connect to HVSC at different berths. Implementation of this practice provides the benefits of standard and straightforward connection without the need for adaptation at different ports.

5.1.1 Power Requirements in Port

To determine the power requirements of the different container vessels arriving at berth, data from a study at the Port of Rotterdam were used [26]. The study focused on 53 arriving container ships and identified their electrical system characteristics, power requirements, fuel consumption while at berth and whether any equipment to receive shore-side electricity had already been installed.

The voltages used on board ranged from 380 to 6600 volts, with 440 volts being used for most of the larger vessels. A small number of ships constructed after 2001 were found to have a voltage of 6600 volts. The graphs in figure (4) below present the findings in more detail.

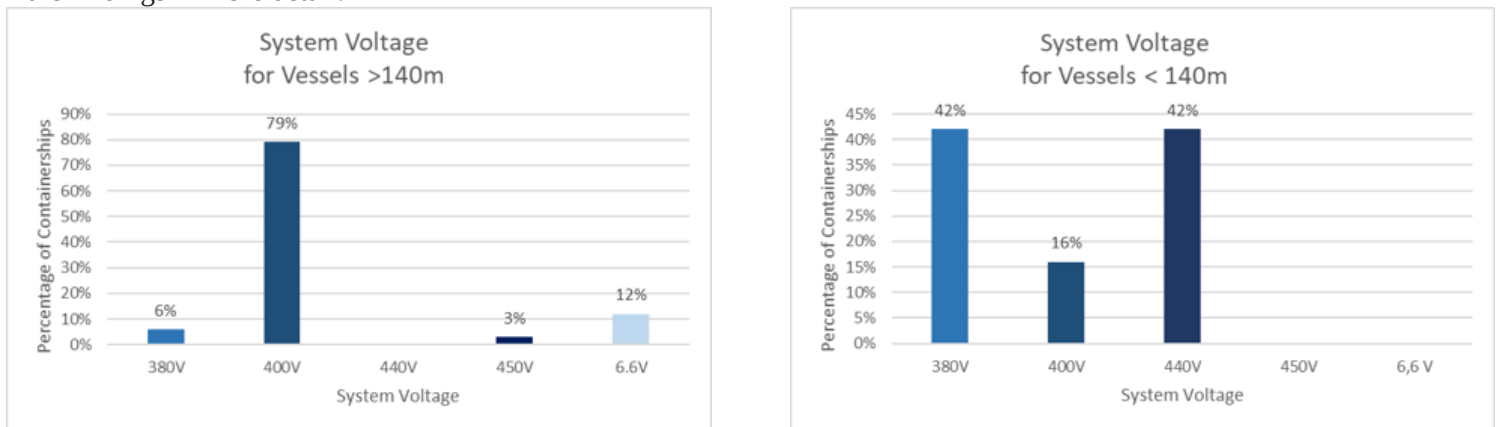
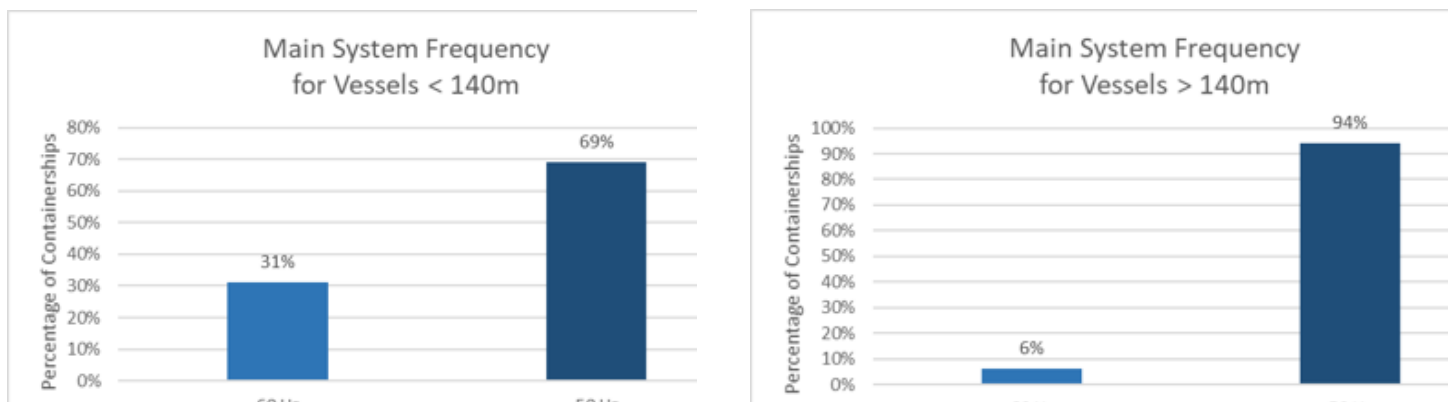


Figure 4: System voltage variation for vessels less than 140m and over 140m

The frequencies reported by the study were found to be either 50 or, as the majority was, 60Hertz. Among all the vessels involved in the report, only two were equipped with an operating system of 50 Hertz. The graphs in figure (5) bellow illustrate the findings.



The conversion of the provided voltage to match the electrical system specifications onboard with the use of a transformer is a straightforward process that can be achieved in the limited space available. However, pairing the frequency of the current received from shore is more difficult, requires more space and is costly [26]. Thus, it is more efficient to install a power converter at the port site that would provide the vessels with the corresponding frequency.

5.1.2 System Layout

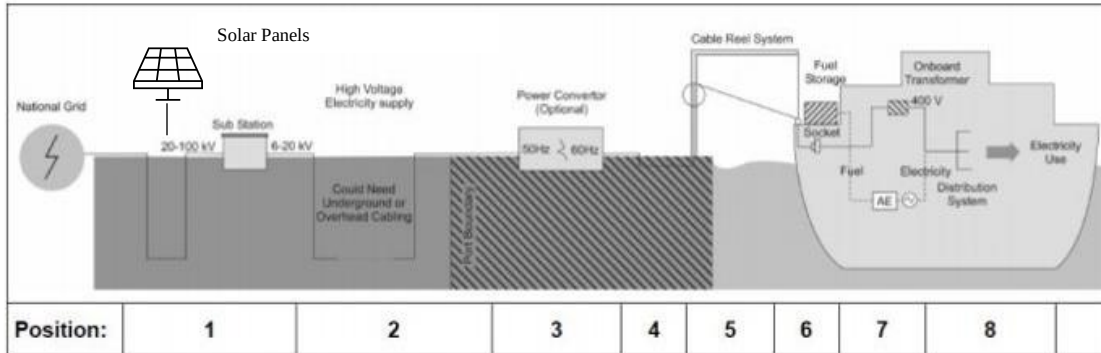


Figure 5: Typical Cold Ironing configuration presented by the recommendation 2006/339/EC

The figure above illustrates a typical cold ironing configuration as presented in the recommendation 2006/339/EC of the EU [25]. The main components of the system are illustrated bellow. Each number is attributed to the exact position the number is located in Figure 8.

1. A connection to the solar panel site and to the national grid carrying 20-100 kV electricity from a local sub-station where it is transformed to 6-20 kV.
2. Cables to deliver the 6-20 kV power from the sub-station to the port terminal.
3. Power (frequency) convertor.
4. Cables to distribute electricity to the terminal. These might be installed underground within existing or new conduits.
5. A cable reel system to avoid handling high voltage cables. This might be built on the berth supporting a cable reel, davit and frame which could be used to raise and lower the cables to the vessel. The cable reel and frame could be electro-mechanically powered and controlled.
6. A socket onboard the vessel for the connecting cable.
7. A transformer onboard the vessel to transform the high voltage electricity to 400 V.
8. Consequently, the electricity is distributed around the ship and the auxiliary engines are switched off

5.2 Software Design

Predictive software for the design of community microgrids is a handy tool that has experienced wide acknowledgment the last decade due to its relative ease of use and ability to adapt to different scenarios. The use of software allows for the multidimensional design of microgrids with increased energy requirements, examining the urban form to explore its impact on the performance of the system's distributed energy resources and loads. HOMER (Hybrid Optimization of Multiple Electric Renewables) is software that simplifies the task of evaluating power system designs using sensitivity and optimization algorithms to determine the most suitable type, size and number of components [27].

5.2.1 Using HOMER

Generating a model requires the identification of inputs that the program will use to evaluate the systems technical and economic feasibility. Power source selection is a necessary prerequisite so power from the grid and solar panels were selected. Pricing for buying and selling power to the grid were obtained from Greek government publications for industrial applications while the price of the solar panels was decided as seen in Section 6 of this paper [28]. The load applied on the system is another essential input for the generation of the model. The software offers various types of electric loads, such as for home usage or powering a parking lot, with each having different characteristics, such as the distribution of power demand throughout the day. Although cold ironing is not specified in the system's default applications, it was found that by using the industrial load default, the effects of vessel power supply were simulated.

The load had a constant rating throughout the day and the year, i.e. no peak months were selected. The required amount of power required for the project was also inserted as calculated in Section 4.2 of this paper. The geographic coordinates of the installation were also selected as HOMER uses solar data from the area of interest to estimate the solar exposure of the panels selected and thus the energy output throughout the year.

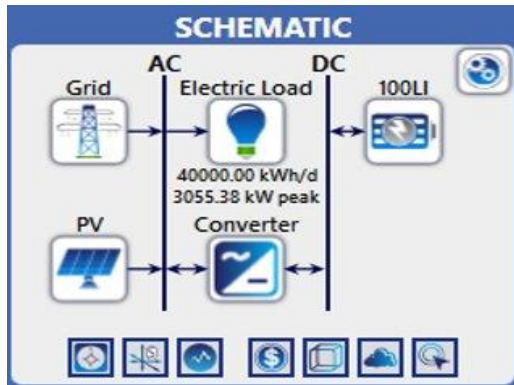


Figure 6: Schematic of proposed configuration by HOMER

the sources to DC for storage.

Considering the differences between the schematic produced by HOMER and the requirements of this project, the system can be modified to serve the needs of this design. The battery is removed and thus the converter is no longer needed, as all the components of the distribution system now require only AC. This simplification reduces the initial capital required to set up the facility, reduces the maintenance costs, requires less installation area and overall simplifies the design and operation of the process.

5.2.2 Port Side Configuration

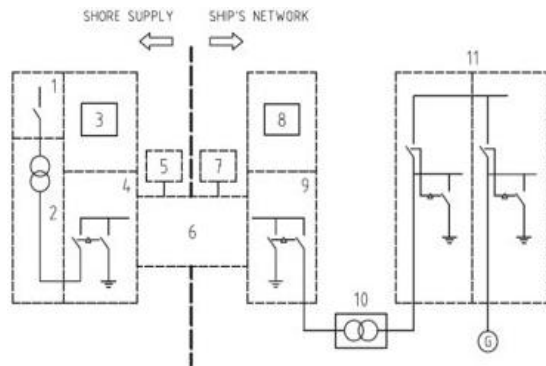


Figure 7: Port and Shore supply for HVSC system

The international standard IEC/ISO/IEEE 80005-1 [29] sets out the requirements for HVSC and is applicable to ships requiring 1 MW or more or ships with high voltage main supply, while IEC/ISO/IEEE 80005-3 (pre-standard) [30] deals with Low Voltage Shore Connections (LVSC). The aim of these two standards is to establish the requirements to ensure compatibility between ship and shore connection equipment, establish appropriate operating procedures and encourage compliance with the standard so that a maximum number of ships can use shore connection equipment at as many ports as possible.

The figure above illustrates the port side configuration for a HVSC system presented in IEC/ISO/IEEE 80005-1. The main components of this configuration are [29]:

1. High Voltage shore supply system
2. Shore side transformer
3. Shore side protection relaying
4. Shore side circuit breaker and earthing switch
5. Control
6. Shore to ship connection and interface equipment
7. Control
8. Ship protection relaying
9. Shore connection switchboard
10. On-board transformer
11. On-board receiving switchboard

The HVSC system uses a dedicated isolated transformer as the last power component before the interconnection between the ship and the port. The term dedicated transformer means only one ship connection to a transformer to satisfy the galvanic isolation requirements in order to protect the ship power system from abnormalities in the shore power system.

Many power system grounding problems and stray currents associated with other port facilities can affect the ship power supply ground fault protection, unless the shore power system has its own grounding zone provided by a dedicated transformer with a neutral grounding resistor. The isolation transformer should be of dynamic configuration, with the star winding connected to the ship side.

The neutral point of the isolation transformer feeding the shore to ship power receptacles shall be earthed through a neutral earthing resistor. The continuity of the neutral earthing resistor shall be continuously monitored and in the event of loss of continuity the shore side circuit breaker shall be tripped. Equipment earthing conductors terminated at the shore power outlet box receptacles shall be connected to the ship and continued to the ship to create an equipotential bond between the shore and the ship. This may require bonding to the ship switchgear earthing bus or bonding to the ship hull [29].

5.2.3 Required Infrastructure

The requirements of this project imply that a High Voltage / Medium Voltage substation is going to be deployed within the port to supply the vessels with the necessary power, containing all the frequency converters and the necessary transformers. The shore side installation includes:

1. A main substation building to store the main equipment such as transformers, frequency converters and personnel rooms
2. One Shore substation supplying power to berth connection boxes
3. Three berth connection boxes fitted with shore socket outlets for interconnection with the ships
4. Three cable management systems for each berth connection box
5. The earthing system
6. Protection control and monitoring system



Figure 8: Shore Side Installation Design at the Containership Terminal

6 Renewable Station

A crucial aspect of the cold ironing design is the construction of the renewable station using photovoltaic panels. As it was mentioned in the introduction of this report, the cold ironing station is most sustainable when the electricity provided is from renewables. As it has been mentioned in Section 3.1, considering the high solar irradiance of Greece, as well as the surface area available next to the containership terminal, solar panels were selected as the equipment for the renewable station. In the following subsections, the technical characteristics of the photovoltaic station and the energy produced from the renewable station are analysed.

6.1 Solar Panel Characteristics

For the identification of the most suitable solar panel, research was conducted. After evaluating, several solar panels that are used for commercial use, Luxor's Eco Line Half Cell Bifacial [28] was selected. Each of the selected Luxor's Solar Panel can produce a certain amount of voltage, amperage, and wattage. With the individual price of 359 € per unit, the selected solar panels can operate at extensive temperature conditions, ranging from $-40\text{ }^{\circ}\text{C}$ to $85\text{ }^{\circ}\text{C}$. Keeping in mind the typical solar panel efficiency of 17% [31] and also after examining the specification of the selected solar panel [32],

approximately, the panel produces a total power output of 525 Watts while operating at 20% efficiency. Below, in Table 9 all the significant characteristics of the selected solar panel are shown.

Table 9 : LUXOR's Eco Line Half Cell Bifacial Characteristics [32]

Characteristics	
Price	359 Euros
Power output at 20% efficiency	525 Watts
Rated Voltage Vamp	40.66 Volts
Dimensions (L x W x H)	1134 mm x 35mm x 2279 mm
Max. System Voltage	1500 Volts
Number of Cells	144 Monocrystal Hive Cells
Operating Temperature	-40 C° to 85 C°

6.2 Solar Irradiance Estimations

To perform the technical analysis of the renewable station, and calculate the total energy produced from the PV panels, several calculations were needed. With the calculation of the daily produced energy as the main goal, equation (3) was established:

$$\text{Avg Total Daily Energy Produced} = (\text{Avg energy produced / panel / day}) \times (\text{Num. of Solar Panels}) \quad (3)$$

where, Avg Total Daily Energy & Avg energy produced/ panel / day are measured in KWh.

Subsequently, the Average Energy Produced / panel / day and the Num. of Solar Panels needed to be identified. To begin with, in order to establish the Avg Total Daily Energy Produced, the following procedure was adopted. The average daily energy produced per panel per day was obtained using eq (4)

$$\text{Avg energy produced / panel / day} = \frac{(\text{Solar Panel Power Output}) \times (\text{Avg Solar Irradiance})}{(\text{Area of One Panel})} \quad (4)$$

Where, the Average solar irradiance was acquired from an online database specifically for the Containership terminal. Furthermore, for each month the number of solar panels required to provide 60% of the Total energy demand, was computed using eq. (5).

$$\text{No of Solar Panles} = \frac{60\% \text{ of Energy Demand}}{\text{Avg energy prduced per panel per day}} \quad (5)$$

The number of solar panels calculated previously was determined to continue with the calculations average

$$\text{Average Number of solar panels} = 41836$$

Consequently, since the required variables in equation (3) were calculated, the Average total Daily Energy can be calculated. Table 10 presents the monthly aforementioned variables.

Table 10: Daily Energy Produced by Solar Panels

Month	Average Solar Irradiance (kWh/m ² /day)	Average daily energy kWh/panel/day	Number of Solar Panels Required	Average energy produced KWh/day
Jan	3.11	4.2197	56992	176534.9
Feb	3.54	4.8031	50069	200943.3
Mar	4.42	5.9971	40101	250895.3
Apr	5.21	7.0689	34020	295738.6

May	5.61	7.6117	31594	318444.1
Jun	6.17	8.3715	28727	350231.7
Jul	6.22	8.4393	28496	353069.9
Aug	6.18	8.3850	28680	350799.4
Sep	5.59	7.5845	31707	317308.8
Oct	4.27	5.7935	41509	242380.8
Nov	2.95	4.0026	60083	167452.8
Dec	2.53	3.4327	70057	143612.0

An estimation of the total energy produced by the solar panels can be obtained, using equation (6) displayed below.

$$Total\ Energy\ Produced\ per\ annum = \sum_{i=1}^{12} [(Avg\ Energy\ Produced\ per\ day)_i \times 30] \quad (6)$$

where i , represents each month on the calendar and $(Avg\ Energy\ Produced/day)_i$ the corresponding average energy produced per day of each month.

Finally, the total energy produced annually was estimated, as seen in equation (7).

$$Total\ Energy\ Produced\ per\ annum = 95,022,349\ kWh. \quad (7)$$

6.3 PV panels installation analysis

Furthermore, Google Earth was used to aid with the analysis regarding the accurate installation of the photovoltaic panels on the cliff next to the containership terminal. The hill that was selected for the installation of the panels measured 128 meters in height and 276 meters in width.

For the identification of the angle of installation for the PV panels, the hill was modelled as a right triangle, and subsequently, its slope was identified. Consequently, the Pythagorean Theorem was used on the right triangle seen in Figure 4, and its hypotenuse was calculated as it can be seen from equation (8) below.

$$BC^2 = AB^2 + AC^2 \quad (8)$$

where $AB = 128$ meters and $AC = 275.51$ meters

Consequently, solving for the hypotenuse, BC is computed to be 303.42 meters.

At next, angle b can be calculated using the arccosine of the angle as seen in equation (9)

$$b = \cos^{-1}\left(\frac{AB}{BC}\right) \quad (9)$$

Thus, the angle of the hill is computed to be 24.9° degrees



Figure 9: Slope calculation of hill

The slope of the hill was calculated to assist with the calculation of the angle of installation of the solar panels.

The solar panel tilt angle plays a significant role in maximising the produced energy of the panels. The estimation of the solar panel tilt angle was based on a study presented in the Mediterranean green energy forum in 2013 [33].

The focus of the study was a latitude-based model for tilt angle optimization for solar collectors in the Mediterranean region. The quadratic regression model that allows the determination of the annual optimal tilt angle for maximum solar energy based on site's latitude in the Mediterranean region is given by the following mathematical model in eq. (10),

$$\phi = (1.25351 \times l) - (0.00728944 \times l^2) \quad (10)$$

Where, ϕ is the annual optimum solar panel tilt angle and l is the site's latitude.

The hill that was selected as the optimum location has a latitude of 37.966° N. Therefore, applying eq. (7), the optimum annual angle to maximise the solar energy was determined.

$$\text{Optimum angle} = 37^\circ \quad (11)$$

As a result, the solar panels relative to the hill slope will be placed on a 12° angle.

6.4 Seasonal Variations in Energy Supply

It is reasonable to assume that there will be seasonal and daily variation in terms of the solar irradiance at the Port of Piraeus. Inevitably, this means that there will be times when more energy is produced by the installation than is demanded from the ships, and there will also be times when less energy is produced than needed. This is shown in Figure (14) below.

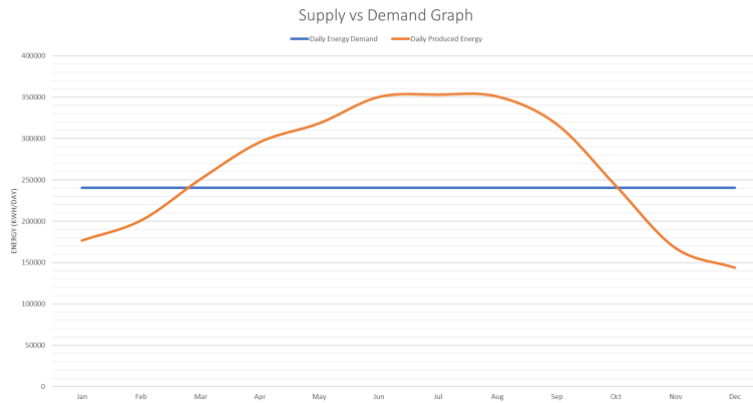


Figure 10: Seasonal Variation of solar panel production against demand

The blue line in the figure above shows energy demand per day, whilst the orange line shows energy produced. Between March and mid-September, there is excess electrical energy produced from the installation, this is shown by the orange line which lies above the blue line. On the other hand, during the winter months there is a shortage of electrical energy at the port, as shown by the blue line which lies above the orange line.

To tackle this imbalance, one alternative would be to have some means of energy storage, to store the excess energy produced. This would however add a further unnecessary degree of complexity and cost to the design. Alternatively, excess energy could be sold to the electrical grid during the summer months and bought back when there is a shortage in the winter.

For the sake of simplicity, this has been the chosen alternative for our design. Of course, the installation is correctly sized, so that over a 12-month period as much energy is produced from the solar panels, as is demanded from the ships calling at port.

7 Investment Appraisal

As shown previously, the environmental benefits are clear for implementing a cold ironing installation at the Port of Piraeus. However, as with any large investment, often the obstacles to its implementation are not technical but rather financial. Consequently, it would be prudent to carry out an investment appraisal for the project to assess its feasibility. It is worth noting that the total cost of the project consists of the cost of the shore side equipment needed to plug in the ships when at berth, but also the cost of constructing the Photovoltaic installation itself to produce the electrical power.

To establish the selling price of the KWh produced from the cold ironing station, the fuel savings, were evaluated. To elaborate further on this, the price of the KWh was set at a price lower than what it would cost the owner to operate the diesel engines of the ship while at berth. This pricing strategy aims to provide an incentive for owners to use shore power, and to purchase electrical energy from the renewable station thus reducing emissions at berth. Finally, a payback period regarding the investment for the implementation of the cold ironing station was computed.

To establish the payback period, the overall cost of the investment needed to be found.

Starting with the renewable station, as mentioned in Section 7, a total of 41836 PV panels will be installed. Although, each panel costs 359 Euros according to the manufacturer [32], in this scenario for the calculation of the total cost regarding the solar panels, volume discount pricing [34] was taken into consideration. By utilizing economies of scale [35], meaning that by increasing the total output of production the total cost per unit is decreased, the seller can provide volume discount pricing. In this scenario a volume discount of only 10% will be assumed, although in reality this figure may be much bigger. This conservative discount has been applied, to include the possibility of a worst-case scenario. Including the 10 percent discount, the price per panel will be 323 Euros. Consequently, the total cost of the solar panels will be 13,513,028 Euros including the price of installation.

Regarding the modification and the installation of the main components of a cold ironing station in the containership terminal of Piraeus, a cost of 4.000.000 Euros per terminal was assumed, with the most expensive equipment being the frequency converters [36]. This assumption was based on CARB's estimation [37] for the retrofit of the electrical equipment required for shore power provision in containership terminals. Consequently, since the cold ironing station will facilitate three of the five berths at the port of Piraeus, a total of 12.000.000 Euros was assumed as the capital investment for the implementation of the project. Thus, the total capital investment for the implementation of the cold ironing station including the solar panels will cost approximately, 25,513,028 Euros. Lastly, an annual operational and maintenance cost of 1.5% was assumed for the PV station [38] as well as a 15% running expenses for the terminal including the maintenance, contract and electricity transport cost [39].

Subsequently, to calculate the payback period of the investment, the revenues obtained from the selling of the energy produced needs to be estimated. As mentioned in Section 5.3, The average cost for the vessels calling at Piraeus, while burning MGO was estimated to be 0.077 Euros per kWh. Thus, in order to provide an incentive to the shipowners to purchase the power from the grid, the selling price of the energy was set at 0.06 €/kWh. The total annual revenues were estimated by multiplying the selling price of the kWh with the total annual energy produced.

Bellow in Table 11, the Cumulative Cash Flow statement of the Cold Ironing Station is presented.

Table 12: Cumulative Cash Flow Statement Per Year

Annual Fees	
O&M Fees PV	1.5%
Running Expenses	15%
Inflows	
Selling Price Per KWh	€ 0.06
KWh produced per year	95022349.09
Total Inflows	€ 5,701,340.95
Outflows	
O&M Panels	€ (202,695.42)
Running Expenses	€ (1,800,000.00)
Total Outflows	€ (2,002,695.42)
Net Inflow	€ 3,698,645.53

Table 11: Payback Period for Cold Ironing Station

Cumulative Cash Flow	
Year 1	€ (25,513,028.00)
Year 2	€ (21,814,382.47)
Year 3	€ (18,115,736.95)
Year 4	€ (14,417,091.42)
Year 5	€ (10,718,445.90)
Year 6	€ (7,019,800.37)
Year 7	€ (3,321,154.85)
Year 8	€ 377,490.68
Payback Period (years)	6.90

The payback period of the investment has been calculated above, in Table 12 to assess the financial viability of the solar panel installation. To encourage the use of shore power the price of a kWh of electricity has been set at a price somewhat lower than what it would cost the shipowner to produce the energy onboard. The lower price compensates to some extent for the cost of the onboard installation and the hassle of plugging in to shore power. Surprisingly, the payback period comes out to a very reasonable 6.9 years, when accounting for the cost of the solar panels, installation, and annual maintenance. The annual yield of the investment, also comes out to 14%, making the cold ironing installation a very attractive investment proposition. Of course, the above figures are based on our assumption that 60% of the vessels calling at the port would be capable and willing to plug into shore power. At present however, only a minority of vessels have the appropriate retrofits to use cold ironing, something that would impact our yield and payback period calculation.

Improvements on the report

Although, the analysis in this report successfully investigates the implementation of a cold ironing station at the containership terminal of Piraeus, improvements could be made to increase the accuracy of the computed values. To elaborate on the statement, an improvement could be made regarding the estimation on the number of containers that call at the port of Piraeus. For a more accurate appraisal, the data regarding the annual traffic of vessels that call at the port of Piraeus, could be obtained directly from Cosco, rather than using the model that was computed in this report.

Furthermore, the estimated power consumption for the containership vessels was based on a significant assumption by splitting the vessel sample list into 5 groups. For a more accurate estimation of the power needs of the vessels calling at the terminal, data should be extracted directly from the managing company of each vessel over a certain period, resulting on a more accurate power demand.

Lastly, to enhance the efficiency of the photovoltaic station, an improvement could be made on the technology of the solar panels. Future research could include solar panels that would track the direction of the sun throughout the day and alter their tilt angle. By optimizing the efficiency of the PV station, an increase in the renewable power produced could be achieved. Such increase in the power produced could lead to a surge in profits, since more power would be available for sale to the grid. The recommendations if implemented on future studies on this topic, could increase the accuracy of the analysed project and ensure the precision of the evaluation.

8 Conclusion

The adoption of cold ironing at various ports around the world has given clear insight on the environmental and economic benefits of its application. Providing shore power to arriving vessels diminishes the need for use of onboard diesel generators to cover the electric demands while at berth. As a result, the emission of greenhouse gases related to on site power generation is eliminated, while fuel savings are increased.

A fundamental aspect of this project is the generation of power through solar panels, a renewable energy source that does not operate in the expense of the environment. This major modification to the typical cold ironing design provides a sensible reduction of the air pollutants associated with the production of power, as many projects that solely rely on grid power relocate the pollution from the port to the power plant.

Adequate research has been done related to the application of high voltage shore connection systems, providing a solid framework for further development and application. The existence of official documents outlining the requirements and potential pitfalls of the system facilitate the design stage and make the process easier to be adapted to different scenarios. Although the implementation of cold ironing poses a straightforward solution to reduce air and noise pollution at a local scale, it is evident that much remains to be done for a full-scale adoption of this practice by every port. Lack of regulations paired with a hefty initial capital cost for both ship operators and port authorities act as a deterring agent against possible future investors. However, as pressure is acted upon governments to hinder global warming, endorsement of ecologically responsible projects as so is of increased interest.

9. References

- [1] M. L. Andersen, "Formal Safety Assessment of an Open Loop System," MS Thesis NTNU, 2015.
- [2] C. Nunez, "Causes and effects of climate change," Nartional Geographic, 2019.
- [3] B. O. t. P. a. E. D. F. (EDF), "Green Shipping: Urgent move to fight climate change," 29 September 2020. [Online]. Available: <https://www.climateweeknyc.org/event/green-shipping-urgent-move-fight-climate-change>.
- [4] IMO, "Global limit on sulphur in ships' fuel oil reduced from 01 January," 20 12 2019. [Online].
- [5] J. a. Prousalidis, "The ports as micro-grids: development perspectives," Proceedings of HAEE 12-16, 2017.
- [6] A. a. E. T. Kilic, "Ship emissions and their externalities at the container terminal of Piraeus-Greece," International Journal of Environmental Research 8.4 1329-1340, 2014.
- [7] M. Dower, "DI004- Prociding Electric Power to Ships (Cold Ironing) at the Ports," Workgroup Recommendations and Other Potential Control Measures Diesel Initiatives Workgroup, 2007.
- [8] PPA, "Sustainable and Low carbon Port Action Plan," INterreg Adrion, 2019.
- [9] B. Maundrill, "Port technology- Piraeus becomes top Mediterranean port," 21 May 2020. [Online]. Available: <https://www.porttechnology.org/news/piraeus-becomes-top-mediterranean-port/>.
- [10] WorldData, "Energy consumption Greece," [Online]. Available: <https://www.worlddata.info/europe/greece/energy-consumption.php>.
- [11] BP, "Statistical Review of World Energy," 2020. [Online]. Available: <https://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy.html>.
- [12] Solargis, "Solar Resource maps of Greece," [Online]. Available: <https://solargis.com/maps-and-gis-data/download/greece>.
- [13] B. Wire, "Global Shore Power Market Outlook Report 2018-2027 by Connection, INstallation, Component, Geography, Competitive Landscape," ResearchAndMarkets.com, [Online]. Available: <https://www.businesswire.com/news/home/20190926005568/en/Global-Shore-Power-Market-Outlook-Report-2018-2027>.
- [14] IMO, "Reducing greenhouse gas emissions from ships," IMO, 2020. [Online]. Available: <https://www.imo.org/en/MediaCentre/HotTopics/Pages/Reducing-greenhouse-gas-emissions-from-ships.aspx>.
- [15] D. Glass, "Piraeus Largest european Med port in 2020," 15 March 2021. [Online]. Available: <https://www.seatrade-maritime.com/ports-logistics/piraeus-largest-european-med-port-2020>.
- [16] T. Notteboom, "Top 15 Containers ports in Europe in 2020," [Online]. Available: <https://www.porteconomics.eu/top-15-containers-ports-in-europe-in-2020/>.
- [17] C. Shipping, "Scheduled Vessels," 2021. [Online]. Available: <http://www.pct.com.gr/db-data.php?id=32>.
- [18] "Clarkson's Shipping Intelligence Network," [Online]. Available: <https://sin.clarksons.net/>. [Accessed 2021].
- [19] W. B. e. a. Fitzgerald, "Energy use of integral refrigerated containers in maritime Transportation," *Energy Policy*, vol. 39.4, pp. 1885-1896, 2011.
- [20] Caterpillar, "VM 32 E Technical Data," [Online]. Available: <https://s7d2.scene7.com/is/content/Caterpillar/C10865660>.
- [21] IMO, "Third IMO GHG Study 2014," 2014. [Online]. Available: <https://www.imo.org/en/OurWork/Environment/Pages/Greenhouse-Gas-Studies-2014.aspx>.
- [22] NETPAS, "ECA and Ports List," 2020. [Online]. Available: http://netpas.net/extension/common/seca_list.php.
- [23] Ship&Bunker, "World Bunker Prices," [Online]. Available: <https://shipandbunker.com/prices>.
- [24] xe, "USD to EUR," [Online]. Available: <https://www.xe.com/currencyconverter/convert/?Amount=1&From=USD&To=EUR>.
- [25] C. Recommendation, "on the promotion of shore-side electricity for use by shipsat berth in community ports," (2006/339/EC), 2008.
- [26] S. Doves, "Alternative Maritime Power in the Power in the Port of Rotterdam," Rotterdam, The Netherlands, 2006.
- [27] H. Pro, "HOMER-Pro-Microgrid Software for Designing Optimized Hybrid Microgrids," [Online]. Available: www.homerenergy.com/products/pro/index.html.
- [28] "ΤΙΜΕΣ ΠΩΛΗΣΕΩΣ ΗΛΕΚΤΡΙΚΗΣ ΕΝΕΡΓΕΙΑΣ ΥΠΟ ΧΑΜΗΛΗ ΤΑΣΗ (XT)," ΔΗΜΟΣΙΑ ΕΠΙΧΕΙΡΗΣΗ ΗΛΕΚΤΡΙΣΜΟΥ Α.Ε.
- [29] I. 8005-1, "Utility connections in port-Part 1: High voltage shore connection (HVSC) systems - General Requirements," ISO, 2006.
- [30] I. D. 80005-3, "Utility connections in port — Part 3: Low Voltage Shore Connection (LVSC) Systems — General requirements," ISO.
- [31] energysage, "Most efficient solar panels: solar panel efficiency explained," [Online]. Available: <https://news.energysage.com/what-are-the-most-efficient-solar-panels-on-the-market/>.
- [32] L. Solar, "Eco line Half-cell- Solar Modules," [Online]. Available: www.luxor.solar/en/solar-modules/eco-line/eco-line-half-cell.html.
- [33] H. a. D. L. Darhmaoui, "Latitude based model for tilt angle optimization for solar collectors in the Mediterranean region," *Energy Procedia*, vol. 42, pp. 426-435, 2013.
- [34] Corporate Finance Institute, "Volume discount- Overview, How it works, examples," 2020.

- [35] W. Kenton, “Economies of Scale,” Investopedia, 4 March 2021. [Online]. Available: www.investopedia.com/terms/e/economiesofscale.asp. .
- [36] W. P. S. Program, “Shore Power Supply,” [Online]. Available: sustainableworldports.org/ops/library/. .
- [37] H. Wang, “Cost and Benefits shore power port Shenzhen,” The International Council on Clean Energy, [Online]. Available: theicct.org/publications/costs-and-benefits-shore-power-port-shenzhen. .
- [38] e. a. Scottyc2112, “What are the operational costs of a solar panel system?,” Power from sunlight, 20 June 2017. [Online]. Available: www.powerfromsunlight.com/operational-costs-solar-panel-system/. .
- [39] T. G. Papoutsoglou, “A cold ironing study on modern ports, implementation and benefits thriving for worldwide ports,” BS thesis, 2018.

9 Appendices

9.1 Appendix I

100-sample vessel calling at the Containership Terminal divided into 5 groups

	Vessel Name	ata	atd	TEUs	of which reefers	Average TEUS	Average Reefer				
700-1000 TEUs	WEC MAJORELLE	13/02/2021 15:40	14/02/2021 13:35	700	200						
	ALASA	13/02/2021 12:00	14/02/2021 07:50	700	288						
	CONTSHIP ECO	09/02/2021 10:00	10/02/2021 19:05	700	120						
	WEC MAJORELLE	07/02/2021 01:35	08/02/2021 06:40	700	200						
	ATLANTIC SOUTH	19/02/2021 21:40	20/02/2021 14:30	706	236						
	MAX STABILITY	19/02/2021 22:00	20/02/2021 14:15	724	300						
	ATLANTIC PIONEER	15/02/2021 13:35	17/02/2021 09:20	724	300						
	LIBERTAS-H	13/02/2021 11:50	14/02/2021 08:00	724	300						
	ATLANTIC PIONEER	09/02/2021 23:55	09/02/2021 08:25	724	300						
	DANCE	10/02/2021 08:25	11/02/2021 18:55	822	400						
	MOVEON	18/02/2021 19:00	19/02/2021 23:00	868	300						
	MOVEON	07/02/2021 18:10	08/02/2021 06:40	868	300						
	STEEN	19/02/2021 17:35	20/02/2021 23:30	907	400						
	STEEN	12/02/2021 19:30	14/02/2021 08:15	907	400						
	STEEN	06/02/2021 00:50	07/02/2021 10:30	907	400						
2000-5000 TEUs	MAERSK NEWPORT	10/02/2021 09:00	10/02/2021 23:05	2478	704						
	GULBENIZ A	06/02/2021 08:20	06/02/2021 22:40	2478	612						
	ANTWERP TRADER	20/02/2021 05:40	20/02/2021 19:00	2480	1132						
	STADT DRESDEN	17/02/2021 08:15	18/02/2021 15:20	2742	800						
	GH BRICKFIELDER	12/02/2021 13:10	14/02/2021 07:00	2758	998						
	ETE N	12/02/2021 15:25	13/02/2021 18:55	2790	1012						
	FLEUR N	08/02/2021 10:40	10/02/2021 11:20	2790	1012						
	SATIE	13/02/2021 20:05	15/02/2021 02:35	2824	1172						
	IRENES RAINBOW	04/02/2021 18:20	06/02/2021 06:50	2824	1172						
	AS CARELIA	05/02/2021 16:25	06/02/2021 14:45	2826	1172						
	EVER BONNY	15/02/2021 18:00	18/02/2021 03:00	2926	688						
	NAVIOS SUMMER	18/02/2021 05:35	18/02/2021 20:15	3450	1100						
	GERHARD SCHULTE	15/02/2021 05:55	15/02/2021 23:25	3534	1000						
	BACH	13/02/2021 11:45	14/02/2021 07:10	3534	1000						
	NORDAUTUMN	10/02/2021 09:15	11/02/2021 06:40	3586	1000						
1000-2000 TEUs	CSCL SYDNEY	18/02/2021 04:35	19/02/2021 07:25	4250	800						
	ZIM VANCOUVER	16/02/2021 01:20	17/02/2021 23:10	4250	800						
	ZIM YOKOHAMA	09/02/2021 09:30	10/02/2021 07:35	4250	800						
	NAVIOS VERMILION	18/02/2021 08:45	18/02/2021 21:10	4253	920						
	SEASPAR JAKARTA	14/02/2021 04:55	15/02/2021 03:50	4253	800						
	SYNERGY BUSAN	12/02/2021 10:30	13/02/2021 14:00	4253	800						
	LICA MAERSK	15/02/2021 03:05	15/02/2021 16:40	4258	2200						
	LAURA MAERSK	09/02/2021 11:30	09/02/2021 02:00	4258	2200						
	MSC INGRID	19/02/2021 08:50	19/02/2021 20:25	4392	600						
	MSC SARAH	09/02/2021 10:15	07/02/2021 00:20	4395	600						
	OOCL KOBE	09/02/2021 09:10	10/02/2021 07:00	4578	800						
	YM EXPRESS	11/02/2021 08:15	12/02/2021 07:40	4662	800						
5000-10000 TEUs	MP THE EDELMAN	13/02/2021 13:15	14/02/2021 03:10	5060	908						
	MSC MADRID	08/02/2021 09:30	10/02/2021 06:55	5500	1200						
	XIN LIAN YUN GANG	17/02/2021 08:40	18/02/2021 23:25	5618	1220						
	AL MANAMAH	08/02/2021 09:50	09/02/2021 08:45	5921	972						
	NINERIO EXPRESS	18/02/2021 15:50	19/02/2021 08:40	7179	1400						
	MAERSK KLEVEN	18/02/2021 05:40	18/02/2021 23:30	7803	1404						
	APL ANTERWIP	05/02/2021 08:15	06/02/2021 08:50	8100	1000						
	CMA CGM TITUS	18/02/2021 17:50	18/02/2021 10:15	8495	1400						
	JUDITH SCHULTE	18/02/2021 01:30	20/02/2021 03:45	8948	2000						
	JOHANNA SCHULTE	07/02/2021 17:05	08/02/2021 18:25	8948	2000						
	COSCO SHIPPING PANAMA	18/02/2021 12:40	20/02/2021 07:25	9443	2800						
	CMA CGM MEKONG	13/02/2021 12:15	13/02/2021 13:50	9962	2900						
10000-20000 TEUs	CMA CGM COLUMBIA	12/02/2021 11:10	13/02/2021 11:45	11888	1600						
	COSCO HARMONY	13/02/2021 15:50	14/02/2021 23:55	12092	1600						
	THALASSA ELPIDA	15/02/2021 02:00	17/02/2021 07:10	13806	1600						
	CSCL URANUS	14/02/2021 11:20	17/02/2021 08:45	14074	2000						
	TAURUS	07/02/2021 15:45	08/02/2021 10:25	14424	2000						
	COSCO SHIPPING ALPS	05/02/2021 23:15	07/02/2021 06:40	14500	1400						
	ZEPHYR LUMOS	12/02/2021 11:00	13/02/2021 10:30	14952	2200						
	ZENITH LUMOS	08/02/2021 10:20	10/02/2021 17:35	14952	2000						
	AL JASRAH	18/02/2021 02:25	20/02/2021 06:40	14993	2000						
	AL MASHRAH	08/02/2021 19:40	08/02/2021 08:45	14993	2000						
	MSC AMSTERDAM	08/02/2021 09:00	10/02/2021 03:00	15908	2800						
	MSC ANNA	17/02/2021 03:50	18/02/2021 03:50	19200	3000						
	MSC ANNA	09/02/2021 01:05	09/02/2021 17:55	19200	3000						
	MSC CLARA	10/02/2021 05:55	10/02/2021 21:30	19224	3600						
	COSCO SHIPPING TAURUS	14/02/2021 10:00	17/02/2021 01:45	20000	1988						
	OOCL HONG KONG	18/02/2021 23:25	20/02/2021 20:45	21413	2000						
1000-2000 TEUs	EGY FUTURE	12/02/2021 11:40	14/02/2021 07:25	1129	304						
	PACORA	14/02/2021 09:25	15/02/2021 12:20	1150	464						
	PACORA	08/02/2021 15:45	07/02/2021 15:25	1150	464						
	UNI-ASSENT	10/02/2021 22:40	12/02/2021 07:35	1164	400						
	UNI-ASSURE	10/02/2021 12:20	11/02/2021 06:30	1164	400						
	AURETTE A	14/02/2021 03:20	15/02/2021 01:25	1199	356						
	PAN GS	14/02/2021 16:10	17/02/2021 17:00	1200	464						
	DANIEL A	07/02/2021 17:10	08/02/2021 07:05	1208	356						
	KARLA A	05/02/2021 08:05	06/02/2021 14:00	1221	356						
	MICHIGAN	20/02/2021 00:45	20/02/2021 20:20	1296	780						
	VICTORIA L	07/02/2021 13:30	09/02/2021 02:00	1304	516						
	ROZA A	18/02/2021 19:00	20/02/2021 20:25	1445	240						
	CORELLI	13/02/2021 15:45	14/02/2021 03:15	1445	240						
	ROZA A	09/02/2021 15:40	07/02/2021 15:00	1445	240						
	AS ROSALIA	16/02/2021 14:40	18/02/2021 17:15	1496	552						
	CONTSHIP RUN	07/02/2021 03:20	08/02/2021 03:45	1574	310						
1000-2000 TEUs	MICHEL A	17/02/2021 08:10	18/02/2021 15:30	1604	612						
	UNI-PHOENIX	17/02/2021 22:45	19/02/2021 15:10	1638	340						
	EF EMIRA	07/02/2021 15:10	08/02/2021 02:20	1706	600						
	TASMAN STRAIT	17/02/2021 10:40	18/02/2021 17:30	1713	754						
	PIRAEUS TRADER	10/02/2021 22:55	12/02/2021 07:40	1740	740						
	CHIEF CUNG	10/02/2021 08:20	11/02/2021 18:10	1740	600						
	CHIEF ALICIA	08/02/2021 10:25	10/02/2021 13:10	1740	600						
	HANSA LIMBURG	04/02/2021 21:05	09/02/2021 21:30	1740	600						
	APOSTOLOS II	10/02/2021 14:30	12/02/2021 07:40	1878	700						
	SONGA BONN	08/02/2021 16:00	07/02/2021 07:05	1970	884						

Appendix II

Determining of Supply vs Demand curve

Month	Average Solar Irradiance (kWh/m ² /day)	Average daily amount kWh/panel/day	Number of Solar Panels Required	Average daily power produced KWh/day	Daily demand/month	Supply vs Demand
Jan	3.11	4.2197	56992	176534.9	240486	-63951.1
Feb	3.54	4.8031	50069	200943.3	240486	-39542.7
Mar	4.42	5.9971	40101	250895.3	240486	10409.3
Apr	5.21	7.0689	34020	295738.6	240486	55252.6
May	5.61	7.6117	31594	318444.1	240486	77958.1
Jun	6.17	8.3715	28727	350231.7	240486	109745.7
Jul	6.22	8.4393	28496	353069.9	240486	112583.9
Aug	6.18	8.3850	28680	350799.4	240486	110313.4
Sep	5.59	7.5845	31707	317308.8	240486	76822.8
Oct	4.27	5.7935	41509	242380.8	240486	1894.8
Nov	2.95	4.0026	60083	167452.8	240486	-73033.2
Dec	2.53	3.4327	70057	143612.0	240486	-96874.0