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MSc Sustainability and Quality in the Marine Industry

THE IMPACT OF COLD IRONING IN MODERN PORTS: THE CASE OF PIRAEUS

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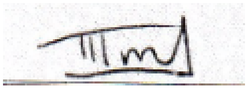
SIGN: 

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ABSTRACT

The transition toward sustainable and environmentally friendly practices in maritime operations has led to the widespread adoption of cold ironing, or shore power, in port facilities. Cold ironing refers to the practice of supplying electrical power from the shore to vessels while they are docked, allowing ships to shut down their auxiliary engines, thereby reducing air emissions, fuel consumption, and noise pollution. This thesis investigates the economic, and environmental implications of implementing cold ironing systems in ports,

Through a combination of case studies, data analysis, and modeling, the research examines the impact of cold ironing on port operations, vessel emissions, and energy consumption. It also explores whether onshore power supply or auxiliary engines is more environmental friendly and cost effective.

This thesis contributes to the understanding of cold ironing as a viable solution for improving port sustainability, optimizing its adoption and maximizing its environmental and economic benefits.

Contents

1.0 History Of Cold Ironing

Cold ironing, or shore-connected, shore-to-ship power (SSP) or alternative marine power (AMP), is the process of supplying shore power to a ship at berth while the main and auxiliary engines are turned off. Low temperature irons provide continuous power for emergency equipment, refrigeration, cooling, heating, lighting and other equipment while the vessel is loading and unloading cargo. Shore power is a general term for powering stationary ships, small craft, aircraft and road vehicles. Cold ironing is a shipping industry term first used when all ships were powered by coal-fired engines. When a ship is in port, there is no need to keep sending fire, and iron engines literally cool and eventually cool completely, hence the term cold iron. Turning off the main engine while in port remains the practice of the majority. However, auxiliary diesel generators that power cargo handling equipment and other vessel services while in port are a major source of air emissions from ships in ports today. This is because the auxiliary equipment operates on heavy oil and bunkers. Low temperature irons reduce harmful emissions from diesel engines by connecting vessel loads to greener land-based power sources. An alternative is to run the auxiliary diesel on gas (LNG or LPG) or ultra-low sulfur distillate fuels, but cold ironing is the only option when noise pollution is an issue. A vessel can be cold ironed by simply connecting it to another vessel's power supply. Navy ships have standardized processes and equipment for this procedure. However, this does not change the type of power supply, nor does it eliminate the source of air pollution. The source of onshore power can be grid power from the utility company, but can also be an external remote generator. These generators are powered by diesel or renewable energy sources such as wind, hydro and solar. Onshore power saves consumption of the fuel used to power the vessel while in port and eliminates the air pollution associated with that fuel consumption. The use of shore power makes it easier to maintain ships' engines and generators, and also reduces noise (Wikipedia)

2.0 Legislation

2.1 2006.339.EC

In the European Union (E.U.), since 2010 the Community ports demand a maximum limit of 0.1% sulphur by weight for marine fuels used by inland waterway vessels and ships at berth (Directive 2005/33/EC amending Directive 1999/32/EC). Despite this restriction, the Commission in 2006 recognized that the regulation established to date was insufficient to maintain port air quality. Consequently, it recommended Shore-Side Electricity (SSE) use by ships at berth in Community ports (Recommendation 2006/339/EC), since it provides additional benefits, such as noise reduction, especially for those ports situated near residential areas. The COM 2013(295) pointed out the need for stricter requirements on environmental performance in ports.

In a further step, Directive 2014/94/EU demands an adaptation of port facilities to be included in national policy frameworks, which will involve member states investing to ensure an SSE supply for vessels, especially in TEN-T Core Network ports, by 31 December 2025. In parallel, Regulation (EU) (2017/352) has stated the intention to define common criteria (among European Commission and member states) for voluntary environmental charging. However, this Regulation also gives freedom for ports to establish their own environmental charging system, and this has generated a multitude of solutions that have been adopted by ports (Sornn-Friese et al., 2021). European ports have based their business strategies on encouraging ship operators to use CI by making it more attractive: the national governments are supporting port infrastructure investments, and even operation costs. In order to coordinate implementation across ports the EU Commission's Directorate-General for Mobility and Transport (DG MOVE) conducted a study in 2017 about port infrastructure charges from sustainability criteria (European Commission, 2017). Among the conclusions, significant reductions in port dues (up to 50% applied as environmental charging for CI use) are necessary to maintain ship operators interest in CI use.

In the same line, the Green Guide (ESPO, 2012) and the ESPO Environmental Report (2019), which have both been published by the European Sea Ports Organization (ESPO), specifically encourage port authorities to be proactive in air quality management by including OPS facilities as ''soft infrastructures''(TEN-T policy) and it argued that bonuses or reductions in port dues should be considered for a short run in order to stimulate CI usage.

Most environmental schemes applied by European ports are based on environmental indexes or certifications (Energy Efficiency Design Index-EEDI-, Environmental Ship Index-ESI, Green Award- European Commission, 2017-), or even on the accomplishment of "Guidelines of good environmental practices" at national level, (such as Spain's Royal Legislative Decree 2011/2). In this way certificated vessels can obtain rebates on base port dues.

The implementation of environmental schemes in EU ports (mostly rebate schemes), is not conditioned by the port size. However, the large ports, due to their greater financial capacity, can more easily put in place an environmental charging scheme (European Commission, 2017).

2.2 2014.94

This Directive establishes a common framework of measures for the deployment of alternative fuels infrastructure in the Union in order to minimise dependence on oil and to mitigate the environmental impact of transport. This Directive sets out minimum requirements for the building-up of alternative fuels infrastructure, including recharging points for electric vehicles and refuelling points for natural gas (LNG and CNG) and hydrogen, to be implemented by means of Member States' national policy frameworks, as well as common technical specifications for such recharging and refuelling points, and user information requirements.

Member States shall ensure that the need for shore-side electricity supply for inland waterway vessels and seagoing ships in maritime and inland ports is assessed in their national policy frameworks. Such shore-side electricity supply shall be installed as a priority in ports of the TEN-T Core Network, and in other ports, by 31 December 2025, unless there is no demand and the costs are disproportionate to the benefits, including environmental benefits.

2.3 IEC/IEEE 8000

This part of IEC/IEEE 8000 describes high-voltage shore connection (HVSC) systems, onboard the ship and on shore, to supply the ship with electrical power from shore. This document is applicable to the design, installation and testing of HVSC systems and addresses:

- HV shore distribution systems,
- shore-to-ship connection and interface equipment,
- transformers/reactors, semiconductor/rotating frequency convertors,
- ship distribution systems, and control, monitoring, interlocking and
- power management systems.

It does not apply to the electrical power supply during docking periods, for example dry docking and other out of service maintenance and repair.

Additional and/or alternative requirements can be imposed by national administrations or the authorities within whose jurisdiction the ship is intended to operate and/or by the owners or authorities responsible for a shore supply or distribution system. It is expected that HVSC systems will have practicable applications for ships requiring 1 MVA or more or ships with HV main supply. Low-voltage shore connection systems are not covered by this document.

2.4 FuelEU Maritime

FuelEU Maritime is a recently adopted regulation which requires that from January 1, 2030 container passenger and cruise ships greater than or equal to 5000 GRT (Gross Weight Tonnage) must connect to shore power in main EU ports and replace their electricity needs. The reason FuelEU Maritime is applied only in these type of ships is because these are the ones with the highest emissions while berthed. The FuelEU Maritime regulation also includes provisions for taking into account ships with wind-assisted propulsion. (DNV)

The GHG intensity requirement applies to 100% of energy used on voyages and port calls within the EU or European Economic Area (EEA), and 50% of energy used on voyages into or out of the EU or EEA.

To avoid evasive behavior, container ships stopping in transhipment ports outside the EU or EEA, but less than 300 nautical miles from an EU or EEA port, need to include 50% of the energy for the voyage to that port as well, rather than only the short leg from the transhipment port. The EU will provide a list of transhipment ports (DNV). https://www.dnv.com/maritime/insights/topics/fuel-eu-maritime/index.html

2.5 Alternative Fuel Infrastructure Regulation (AFIR)

The AFIR, Article 9, regulates shore power supply by incentivizing sufficient infrastructure development with a standardized shore-side electricity supply chain in TEN-T network ports. Its sets targets for the development of adequate alternative fuel infrastructure in the European Union (Péter Gullai, 2023).

Main obligation of Member States is to, at the end of each year starting from 2024, ensure that specific power output targets are provided through publicly accessible recharging stations.

Sets mandatory deployment targets for electric recharging and hydrogen refuelling infrastructure for the road sector, for shore-side electricity supply in maritime and inland waterway ports, and for electricity supply to stationary aircraft. By making a minimum of recharging and refuelling infrastructure available across the EU the regulation will end consumer concerns about the difficulty to recharge or refuel a vehicle. AFIR also paves the way for a user-friendly recharging and refuelling experience, with full price transparency, common minimum payment options and coherent customer information across the EU. (Jahnz, 2023)

Table 1. FuelEU Maritime regulation and AFIR requirements. (source Liudmila Osipova and Camilla Carraro, 10/2023)

	FuelEU Maritime (Article 6)	AFIR (Article 9)
Electricity/ Power supply	Ships should connect and use shore power supply for all their electrical demand while at-berth.	Ports shall be equipped to provide a minimum of 90% of the demand for shore-side electricity supply (sufficient shore-side power output), depending on the volume of port calls (see Main Exemptions below).
Ship type, size, mode	Container and passenger ships (including cruise ships) greater than or equal to 5,000 GT while moored at the quayside.	Seagoing container and passenger ships (including cruise ships), other than ro-ro and high-speed passenger craft, greater than or equal to 5,000 GT while moored at the quayside.
Ports included	Port of call[2] as covered by AFIR Article 9. After 2035, extension to other EU ports with installed shore power, and extension to any ports by a unilateral decision of a Member State after consulting relevant stakeholders.	TEN-T core and comprehensive network ports, excluding remote islands not connected directly to the electricity grid.
Implementation Timeline	January 1, 2030. Some changes in policy exemptions starting in 2035 (see below).	January 1, 2030
Main exemptions	• Port calls for ships moored at the quayside for less than 2 hours. Unscheduled, non-systematic, and temporal port calls; emergency port calls. • Port calls for ships using zero-emission technologies such as on-board fuel cells, on-board electrical energy storage, and on-board power generation from wind and solar energy listed in Annex III of the regulation, including future updates. • Port calls for ships that are unable to connect to shore power due to unavailable connection, incompatible points, or insufficient or unstable shore power availability. After 2035 this exemption can be applied only to a maximum 10% of the ship's total number of port calls, or to a maximum 10 port calls during relevant reporting period.	• Port calls exempt from the FuelEU Article 6. • Ports with average number of annual port calls over the last 3 years below 100 for seagoing containerships, or below 40 for seagoing ro-ro passenger ships and high speed passenger craft; below 25 for seagoing passenger ships other than ro-ro passenger and craft. • Ports on islands in outermost regions, Ceuta, and Melilla not connected to the electricity grid. In-force until the connection has been completed or there is sufficient locally generated electricity capacity from non-fossil energy sources.

3.0 Onshore equipment

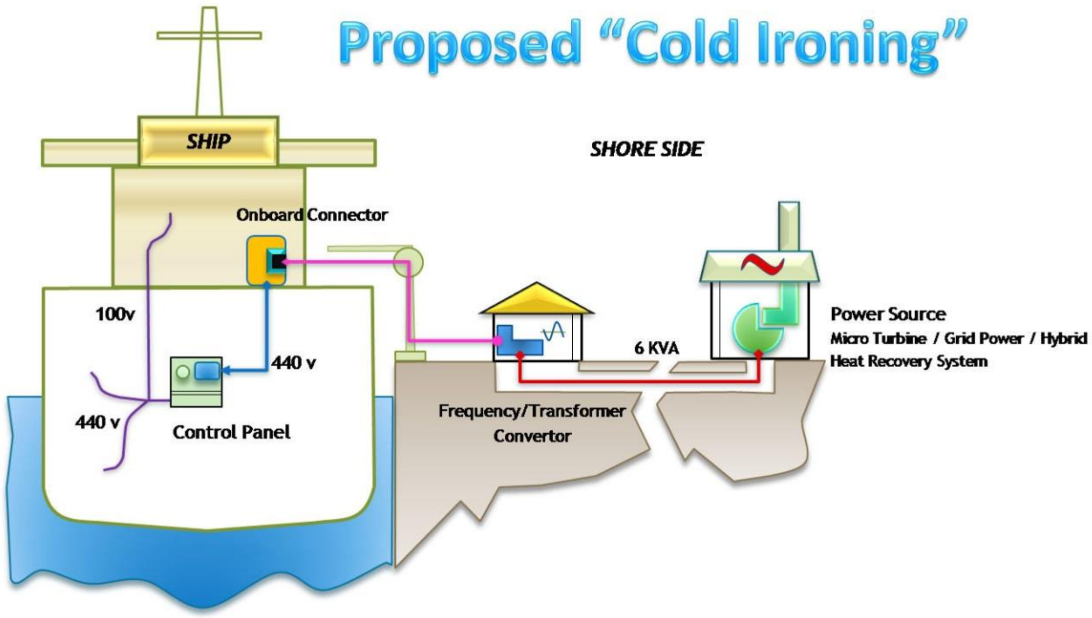
In essence, a shore power system consists of four parts;

1. The shoreside energy supply,
2. the shore power connection point,
3. the cable management system,
4. the shipside connection point

(Ballini and Bozzo 2015; Gamette et al. 2010; Røed 2018; Sciberras et al. 2015; Tarnapowicz and German-Galkin 2018; Trellevik 2018).

Therefore, in this section, the system function and alternative implementations will be discussed for each system part and followed by the knowledge gap.

Picture 1. Cold Ironing Schematic (Source: Wikipedia)



1. Shoreside energy supply

The shoreside energy supply is the substation in which the high-voltage grid power is converted to the correct voltage and frequency. Electricity supply in the Community generally has a frequency of 50 Hz. A ship designed for 60 Hz electricity might be able to use 50 Hz electricity for some equipment, such as domestic lighting and heating, but not for motor driven equipment such as pumps, winches and cranes. Therefore, a ship using 60 Hz electricity would require 50 Hz electricity to be converted to 60 Hz.

2. Shore power connection point

Furthermore, the shore to ship power connection is standardised by IEC 80,005 and consists of multiple cables with a voltage of either 11 or 6.6 kV. The number of cables is dependent on the total power consumption while connected (Røed 2018).

3. Cable management system

The cable management system (CMS) placement on the terminal side has been seen in the long beach implementation and the normative guidelines from the International Electrotechnical Commission (IEC) (Gamette et al. 2010; Røed 2018) There are several examples of terminal design; the slender jetty is found predominantly. Besides these, for loading (dirty) tankers, a buoy is not uncommon as well. In many cases, the jetties are already quite full, possibly requiring additional jetties to be constructed, impacting the investments significantly. Furthermore, the location of the CMS concerning the ship is important because that will define the distance from which the cable must be transported to the ship's receiving point.

Reel on top

This is an elevated container with a reel inside. The connection is made midships, requiring extensive ATEX compliance measures. The hose handling crane also has to be present on the vessel, besides connections on the portside and starboard, including a galvanised cable tray to run the cable to the aft part of the ship to the shipside system. This system currently only exists as a design and has not yet been operational. Alternatively, the connection could be made to the aft-ship, using the provision crane instead of the hose handling crane. This would reduce the amount of cabling on the ship and place the connection outside of the ATEX zone. Furthermore, it is assumed that only one connection point is required due to the limited range of the provision crane.

Loading arm

The key difference between a loading arm and the reel on top is that the crane is located on the terminal. The cables could be run through pipes to comply with the ATEX requirements, similar to the vapour return lines. The same cable and connection requirements for the reel on top are required.

Floater

A self-propelled floater could connect the cable to the aft side of the vessel. Then, if available, the provision crane could get the cable from the floater to the vessel, if available. A key advantage is that the aft side of the vessel is usually not an ATEX zone, requiring less strict measures concerning the connection. Also, the shipside energy system is located aft, resulting in a much shorter connection distance. Finally, in this situation, only one connection point would be required. Due to the floater, this concept is quite flexible, though it currently only exists as a concept and has not been developed or used.

Crane and cable reel

This is the system of choice for most ferries and cruise ships already receiving shore power. The system consists of a shore-based crane and cable reel connecting to the aft side of the vessel. As these ships predominantly dock at quaysides, this system is quite flexible. Placed on a jetty, however, the range of the system is limited due to the immobility of the crane. As the connection is aft, the benefit of one connection point, a short distance to the shipside system and no ATEX requirements remain.

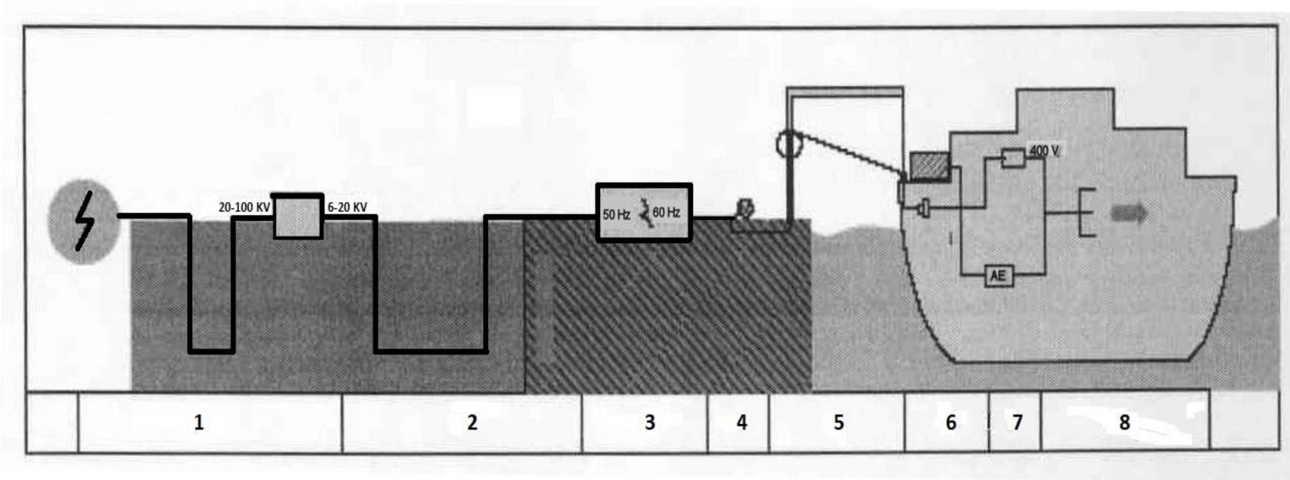
4.Shipside connection point

As mentioned in the previous sub-section, there are two connection points for the ship: midships and aft. Considering that most ports have jetties for loading/unloading, the midship connection is more flexible when considering significant variation in ship sizes, as it remains in the same position. On the other hand, the aft connection requires more flexibility from the system as due to the midship connection, the location will vary with the size of the ship; see also the leftmost. Considering the impact of the ATEX zone (EU 2014), the aft ship connection is outside of that and could be a more standard connection.

4.0 Technical requirements

The diagram below illustrates typical requirements for a shore-side electricity connection. Other configurations are possible, depending on the ship and berth. The International Electrical Commission and International Association of Classification Societies are currently working on industry standards, which can, in the future, be considered by the IMO.

Picture 2. Typical requirements for a Shore-side Electricity Connection. (Source: Technical-Economical Analysis Of Cold-Ironing: Case Study Of Venice Cruise Terminal)



1.A connection to the national grid carrying 20-100 kV electricity from a local substation, 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 conversion, where necessary. (Electricity supply in the Community generally has a frequency of 50 Hz. A ship designed for 60 Hz electricity might be able to use 50 Hz electricity for some equipment, such as domestic lighting and heating, but not for motor driven equipment such as pumps, winches and cranes. Therefore, a ship using 60 Hz electricity would require 50 Hz electricity to be converted to 60 Hz).

4.Cables to distribute electricity to the terminal. These might be installed underground within existing or new conduits.

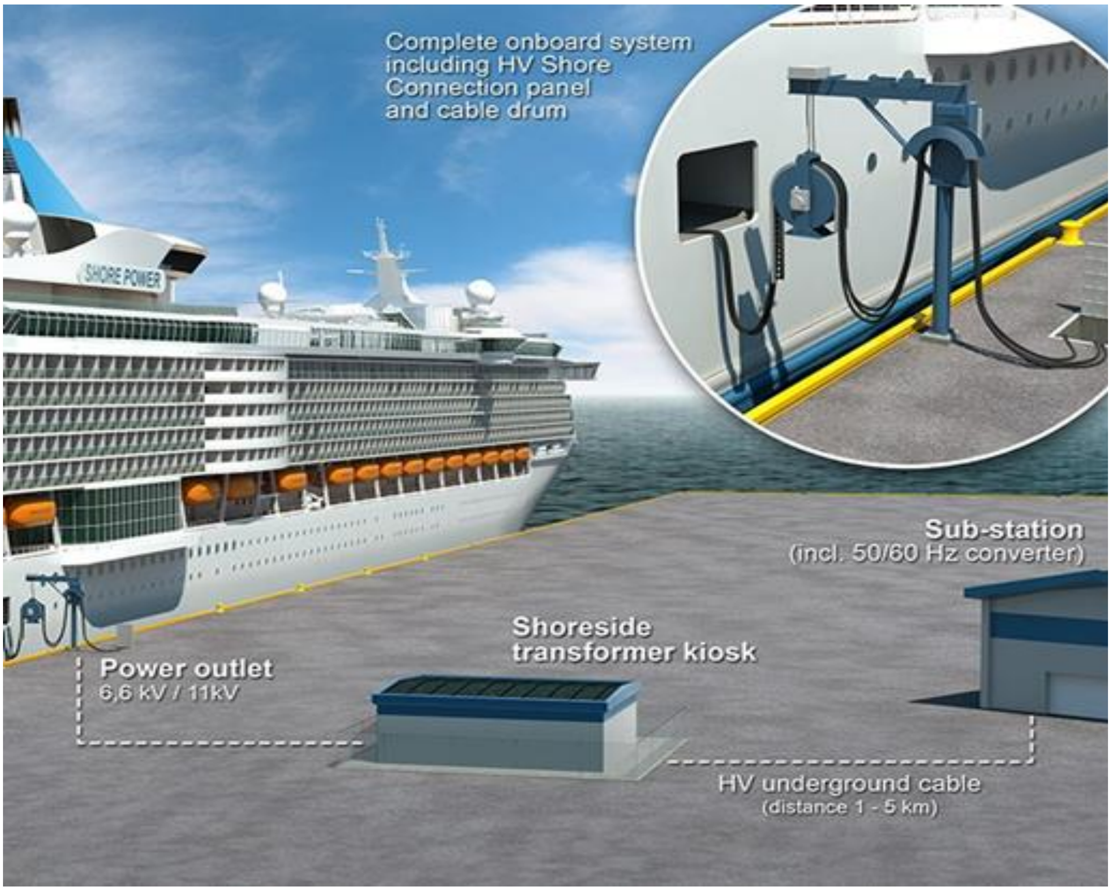
5.A cable reel system, to avoid handling of high voltage cables. (Loading arm, Reel on top, Floater, Crane and cable reel)This might be built on the berth supporting a cable reel, davit and frame. The davit and frame could be used to raise and lower the cables to the vessel. The cable reel and frame could be electro-mechanically powered and controlled.

6. A socket onboard the vessel for the connecting cable.

7.A transformer on board the vessel to transform the high voltage electricity to 400 V.

The electricity is distributed around the ship, and the auxiliary engines switched off. (Dimas, 2006)

Picture 3. Another depiction of Shore-side Electricity Connection (Source: Tec Container)



Picture 4. Shore-side Electricity Cable Reel (Source: Cavotec)

5.0 Ship equipment and cost

Requirements at the Vessel:

- Transformer
- Power distribution system
- Control panel
- Frequency converter (optional for greater flexibility)
- Connectors and cable reel (optional for greater flexibility)

5.1 AMP Connection Procedure

1) First, confirm that the generator is on the minimum load possible and voltage is around 440V. To lower the cable guide, first connect the operation remote to the reel, after which, the reel is ready for operation. The Power On indicator lamp on the Reel control center will light up.

2) Press up and hoist up the cables from their parking position. The reel will stop rotating automatically when the upper limit is reached.

3) Direct the cables to the cable reel guide and prepare it for lowering by pressing down button.

4) Press down button and lower the cables, keep a check there is no snag, twist or turn. Keep lowering the cables until it reaches the port personnel on the jetty.

5) The port personnel must pull the cables towards the connection box while the cable is still unwound, then remove the protective caps on the end of the cables and connect them to the shore terminal. The cable plugs should be connected according to colour coding and should be connected correctly.

6) Once the cables are connected, change the selector switch to automatic mode. The reel should then automatically operate in order to recover any slack that results from ship movements and wind.

7) You will have to confirm with shore personnel whether fibre optic communication will be used or not. If yes, then you will have to turn on fibre optic switch inside main switch mode. If no, then communication can be done via VHF or Phone.

8) Try out the emergency stop on AMP control panel. The pilot ready lamp should turn off confirming positive working of the emergency stop.

9) Try out emergency stop on cable reel control panel. The pilot lamp should turn off confirming positive working of the emergency stop. Reset from the panel.

10) After completion of all tests, you are ready to turn on the VCB and close the breaker. Confirm with the shore personnel that VCB can be closed and upon confirmation, close the VCB

11) After closing the VCB, you are ready for synchronisation. This can be done automatically or manually. First, you need to check shore receiving parameters to check if they are all correct and in range. For automatic synchronisation,

press synchronise on the AMP control panel and the shore power will synchronise with ship's generator power. For manual synchronisation, you can synchronise with synchroscope method or three bulb method

12) Once shore power has synchronised with the ship's generator power, you can offload the ship's generator so that all the load can be taken by shore power. Once the generator is offloaded and the breaker is open, the ship can be said to be running on alternate maritime power.

13) The shore charges for the power it supplies in KWH. So, it is always advisable to have minimum load possible when on alternate maritime power so that costs don't increase significantly.

5.2 AMP Disconnection Procedure

1) Disconnection procedure is reverse of connection procedure. You have to take shore supply offload and ship's generator on-load by following these steps.

2) Start ship's diesel generator and take it on-load by synchronising it with shore power automatically or manually. After the generator is on-load successfully, offload the shore power by opening the VCB. Open the VCB only after confirming with shore personnel.

3) Once the AMP VCB is open, the ship is running on ship's generator and no more cold ironing. Cables should be made ready for disconnection.

4) Change the selector switch to manual mode and press the DOWN button to slacken the cables

5) The port personnel must disconnect the plugs & sockets and re-fit the covers.

6) Press the UP button to retrieve the cable. Avoid dragging the plug protection covers along the jetty, it is preferable that these are manually handled in order to reduce wear.

7) Continue pressing the UP button until the upper limit is reached. With the assistance of another person, press the down button and guide the plugs into the parking zone. Turn off reel control centre.

5.3 Cost for ships

Shore power can be installed for all types of vessel and for all ages with need for power in harbour, and has been used for years especially for smaller vessels, but also some larger passenger vessels. (GreenVoyage2050)

For smaller vessels to draw power from the land based mains supply when docked is not a new phenomenon. Shore power has been used extensively for many years for vessels with moderate power requirements; typically less than 50 to 100 kW. These vessels are capable of making use of normal grid voltage and frequency, and replace the energy from the generators with the shore power with only marginal investments.

For the larger vessels with higher power requirements (100 kW up to 10 to 15 MW) it gets a bit more complicated. To serve these vessels with shore power, dedicated and relatively costly installations are required, both on land and on board the vessels. This may include upgrading the grid capacity, frequency converters and complex high power connectors. Consequently, relatively few vessels and ports are capable of making use of shore power, even though the environmental upsides are considerable. Still, cold ironing may be regarded as a mature technology that has been in regular use since the 1980s.

Table 2. Typical system specs for the different power requirements (Source: Global maritime energy efficiency partnerships)

Power Capacity	Typical spec
<100kW	230/400/440V – 50/60hz
100 – 500kW	400/440/690V – 50/60hz
500-1000kW	690V/6.6/11kV – 50/60hz
>1MW	6.6/11kV – 50/60hz

Table 3. Typical system requirements for different ship types and sizes (Source: Global maritime energy efficiency partnerships)

Vessel types	<= 999	1000 – 4999 GT	5000 – 9999 GT	10000 – 24999 GT	25000 – 49999 GT	50000 – 99999 GT	>= 100000 GT
Oil tankers	230/400/440V – 50/60hz	400/440/690V – 50/60hz	690V/6.6/11kVV – 50/60hz	690V/6.6/11kVV – 50/60hz	690V/6.6/11kVV – 50/60hz	6.6/11kV – 50/60hz	6.6/11kV – 50/60hz
Chemical/product tankers	400/440/690V – 50/60hz	400/440/690V – 50/60hz	690V/6.6/11kVV – 50/60hz	6.6/11kV – 50/60hz	6.6/11kV – 50/60hz		
Gas tankers	400/440/690V – 50/60hz	400/440/690V – 50/60hz	6.6/11kV – 50/60hz	6.6/11kV – 50/60hz	6.6/11kV – 50/60hz	6.6/11kV – 50/60hz	6.6/11kV – 50/60hz

Bulk carriers	230/400/440V – 50/60hz	400/440/690V – 50/60hz	400/440/690V – 50/60hz	400/440/690V – 50/60hz	400/440/690V – 50/60hz	690V/6.6/11kVV – 50/60hz	
General cargo	230/400/440V – 50/60hz	400/440/690V – 50/60hz	400/440/690V – 50/60hz	400/440/690V – 50/60hz	690V/6.6/11kVV – 50/60hz		
Containers vessels		400/440/690V – 50/60hz	400/440/690V – 50/60hz	690V/6.6/11kVV – 50/60hz	6.6/11kV – 50/60hz	6.6/11kV – 50/60hz	6.6/11kV – 50/60hz
Ro Ro vessels	230/400/440V – 50/60hz	400/440/690V – 50/60hz	400/440/690V – 50/60hz	690V/6.6/11kVV – 50/60hz	690V/6.6/11kVV – 50/60hz	6.6/11kV – 50/60hz	
Reefers	230/400/440V – 50/60hz	400/440/690V – 50/60hz	400/440/690V – 50/60hz	690V/6.6/11kVV – 50/60hz			
Passengers vessels	230/400/440V – 50/60hz	400/440/690V – 50/60hz	400/440/690V – 50/60hz	690V/6.6/11kVV – 50/60hz	6.6/11kV – 50/60hz	6.6/11kV – 50/60hz	6.6/11kV – 50/60hz
Offshore supply vessel	230/400/440V – 50/60hz	400/440/690V – 50/60hz	6.6/11kV – 50/60hz				
Other offshore service vessels	230/400/440V – 50/60hz	400/440/690V – 50/60hz	690V/6.6/11kVV – 50/60hz	690V/6.6/11kVV – 50/60hz	690V/6.6/11kVV – 50/60hz	690V/6.6/11kVV – 50/60hz	690V/6.6/11kVV – 50/60hz
Other activitie	230/400/440V –	400/440/690V –	690V/6.6/11kVV –	6.6/11kV – 50/60hz	6.6/11kV – 50/60hz	6.6/11kV – 50/60hz	6.6/11kV – 50/60hz

s	50/60hz	50/60hz	50/60hz				
Fishing vessels	230/400/440V – 50/60hz	400/440/690V – 50/60hz	6.6/11kV – 50/60hz				

Table 4. Estimated cost for implementing shore power on board vessels (Global maritime energy efficiency partnerships

Investment cost for vessel (USD)	**1000 – 4999 GT**	**5000 – 9999 GT**	**10000 – 24999 GT**	**25000 – 49999 GT**	**50000 – 99999 GT**	**>= 100000 GT**
Crude tankers	$50 000 – $350 000	$100 000 – $400 000	$100 000 – $400 000	$100 000 – $400 000	$300 000 – $750 000	$300 000 –$750 000
Chemical / product tankers	$50 000 – $350 000	$100 000 – $400 000	$300 000 – $750 000	$300 000 – $750 000		
Gas tankers	$50 000 – $350 000	$300 000 – $750 000	$300 000 – $750 000	$300 000 – $750 000	$300 000 – $750 000	$300 000 –$750 000
Bulk carriers	$50 000 – $350 000	$50 000 – $350 000	0,5 – 3 Mill	0,5 – 3 Mill	$100 000 – $400 000	

General cargo	$50 000 – $350 000	$50 000 – $350 000	0,5 – 3 Mill	$100 000 – $400 000		
Container vessels	$50 000 – $350 000	$50 000 – $350 000	$100 000 – $400 000	$300 000 – $750 000	$300 000 – $750 000	$300 000 –$750 000
Ro Ro vessels	$50 000 – $350 000	$50 000 – $350 000	$100 000 – $400 000	$100 000 – $400 000	$300 000 – $750 000	
Reefer	$50 000 – $350 000	$50 000 – $350 000	$100 000 – $400 000			
Passenger ship	$50 000 – $350 000	$50 000 – $350 000	$100 000 – $400 000	$300 000 – $750 000	$300 000 – $750 000	$300 000 –$750 000
Offshore supply ship	$50 000 – $350 000	$100 000 – $400 000				
Other offshore service ships	$50 000 – $ 350 000	$100 000 – $400 000	$100 000 – $400 000	$100 000 – $400 000	$100 000 – $400 000	$100 000 – $400 000
Other activities	$50 000 – $ 350 000	$100 000 – $400 000	$300 000 – $750 000	$300 000 – $750 000	$300 000 – $750 000	$300 000 –$750 000

Fishing vessels	$50 000 – $ 350 000	$100 000 – $400 000		

5.4 Retrofit

The system requires modifications on the ship to allow for shore power to be imported aboard, and requires installation ashore of special gantry and cables, quick disconnect connections, cable reels, and other equipment to deliver and control the power. It is estimated that the expense to retrofit an average vessel to such power deliveries is between USD 200,000-400,000. The shore facilities can likewise be fairly expensive to establish. As an example, it was reported in 2006 that the cost to build the shore-side facility for "cold ironing" in the Port of Long Beach for Matson Line liner service ships was about USD 7 million, to be paid for by local port authorities. One difficulty that has been encountered is that there are different voltage and frequency specifications for vessels built and operated in different parts of the world. Most ships operate on low voltage of 440V power, while large container and cruise ships operate on higher voltages of 6.6 to 11KV, and frequency requirements can vary from 50 or 60Hz. One approach to solve this has been to use portable current convertor devices at dockside, called Dual Frequency Multi Voltage, which can overcome the compatibility problem. Perhaps, as the technology matures and becomes more prevalent, standardisation of power specifications will occur.(Gard News 196, 2009)

6.0 Safety

The present section marks the different categories of safety in design and operation of shore-side electricity (SSE) systems.

Table 5. Different dimensions of safety in design and operation of shore-side electricity systems (Source: Shore-Side Electricity Guidance to Port Authorities and Administrations)

Hazards and Failure Modes	Risk Assessment	Risk Management	Safety Checks
Section covering general description of the different types of general hazards and failure modes in SSE systems and operations	Different possible good-practice approached for assessment of safety risk and reliability of SSE systems and operations	Different electrical protection strategies and equipment for mitigation of incidents in the operation of SSE systems	General safety checks to be conducted prior and during SSE/ OPS supply operation.

6.1 Hazards and failure modes

Onshore power supply systems require high safety and reliability levels in order to mitigate the risks of electrical fire/explosions, occupational incident/shock/arcing and blackout during shore power supply.

Figure presents various possible failure modes in different points of an onshore power supply system installation and operation.

GRID

- Power failure/Utility Grid blackout
- Interface problem-Circuit breaker malfunction
- Control failure
- BUS-Loss of integrity/continuity
- Circuit breaker breakdown/contact degradation

- Loss of feeder HV cable continuity

SHORE SIDE INFRASTRUCTURE

- Transformer explosion
- Transformer Winding Overheating
- Transformer distortion, loosening or displacement of wiring
- Frequency Converter High Temperature event/Fire
- Loss of output voltage
- Control failure
- Hardware crash
- Data errors
- Operational Failure
- BUS-loss of integrity/continuity
- Overload
- CB fail-closed condition
- Power Cable failure/loss of continuity
- Occupational hazard

SHIP-SHORE INTERFACE

- Power cables failure/loss of continuity
- Power cable overheating
- Connectors overheating
- Socket-plug connection damaged
- Communication failure
- Control failure
- Cable Management System failure-Mechanical failure
- Cable overtension
- Loss of feeder power cable continuity

- Collision/Interference with ship systems
- CMS control failure
- Occupational hazard/Shock /Arch
- Overcurrent
- Fire in CMS unit

SHIP SIDE

- Synchronisation failure-OPS fails to enter main switchboard
- Intoxication of passengers onboard
- Control failure
- Transformer Explosion
- Transformer Winding Overheating
- Transformer distortion, loosening or displacement of wiring
- Loss of power cable continuity
- Fire in OPS station switchboard
- Occupational hazard/Shock/Arc

(EMSA, 2022)

6.2 Risk assessment

The safety risk assessment for SSE is performed through a combination of different methodologies. The combination of four methods can be a possible solution to visualize the safety risk of SSE systems and operations:

6.2.1 HAZID (Hazard Identification) exercise

Hazard Identification Study (HAZID) is systematic reviews carried out to determine potential hazards that may occur during operation of a process design, or execution of a work project, such as shore-side electricity infrastructure.

Table 6. HAZID matrix, with ranking criteria. (DNV) (Source: Shore-Side Electricity Guidance to Port Authorities and Administrations

Consequence				Probability				
Personnel safety	Environment	Impact on vessel, terminal or its operation		Rare Technically to be excluded, or a failure can only occur by combination of two causes 1	Infrequent Not probable, to be expected that failure does not occur during lifetime of vessel/component under consideration (once in 100yrs) 2	Moderate Remotely probable, to be expected that failure can occur during lifetime of vessel/component under consideration (once in 10 years) 3	Frequent and high Probable, to be expected that failure occurs once per year of operation (1 year) 4	Very high Highly probable, to be expected failure occurs more often than once/yr of operation (<1yr) 5
No impact on persons	None	No damage / undisturbed operation	1	L	L	L	M	M
Single severe or few minor injuries	Minor effect, non-compliance event	Local damage/Operation of non-essential systems disturbed	2	L	L	M	M	M
Multiple severe injuries	Localized effect, response required	Non-severe ship damage/Failure of non-essential systems	3	L	M	M	M	H
One fatality	Major effect, significant response required	Severe damage to asset/ops of essential systems disturbed for <1h	4	M	M	M	H	H
Multiple fatalities	Massive effect damage over large areas	Loss of vessel/Failure of essential systems	5	M	M	H	H	H

6.2.2 FMECA (Failure Modes, Effects, and Criticality Analysis)

FMECA is composed of two separate analyses, the Failure Mode and Effects Analysis (FMEA) and the Criticality Analysis (CA)

IEC-60182 defines FMEA as a systematic procedure for the analysis of a system which target is the identification of the potential failure modes, their causes and effects on system performance.

CA is necessary to plan and focus the efforts according to set of priorities in order to reduce the risk of failures and give to failures with the highest risk the highest priority.

Risk Priority Number (RPN) to each failure mode: RPN=S×O×D, Where S (Severity) represents the severity on the base of the assessment of the worst potential consequences resulting from an item failure, O (Occurrence) denotes the probability of failure mode occurrence and D (Detection) represents the chance to identify and eliminate the failure before the system or customer is affected.

6.2.3 HAZOP (Hazards and Operability Analysis)

Hazard and Operability Analysis (HAZOP) is a structured and systematic technique for system examination and risk management. In particular, HAZOP is often used as a technique for identifying potential hazards in a system and identifying operability problems likely to lead to nonconforming products. HAZOP is based on a theory that assumes risk events are caused by deviations from design or operating intentions

6.3 Risk management

6.3.1 Neutral earthing systems

In HV and LV installations, the neutral may or may not be earthed. The commonly used term is system earthing (also called system grounding), which determines how the neutral point of a transformer or generator and the exposed conductive parts (ECP) of the user's installation are earthed. There are different solutions for earthing. Selecting the right one is a determining factor in terms of continuity of service, trouble-free operation, and protection against overloads and faults. A poor choice may result in damage to equipment, malfunctions, or hazardous situations

A ship could use different earthing methods on board for different areas (machine rooms, cargo holds, passenger cabins), for example.

1. Solid earthing
2. Low-resistance earthing
3. High-resistance earthing
4. Unearthed systems

Table 7. Earthing systems (Source: Shore-Side Electricity Guidance to Port Authorities and Administrations)

Earthing System	Earth fault current	Damage	Transient overvoltages	Phase-to-earth overvoltage healthy phase	Tripping at the first fault
Solid earthing	High, 3-phase fault current	Very high	Low	Very low	Mandatory
Low-resistance Earthing	Medium, above 50A	High	Controlled	Low	Mandatory
High-resistance earthing	Low, up to 25A Charging current increase the current limited by the resistance	Low	Limited if the current limited by the resistance is higher than 2 times the charging current	The phase-to earth voltage is close to the phase-to phase voltage Insulation level needs to be improved	Not Mandatory Location and elimination of the fault are mandatory
Unearthed	Equal to the charging current	Low	High	The phase-to earth voltage is close to the phase-to phase voltage Insulation level needs to be improved	Not Mandatory Location and elimination of the fault are mandatory

6.4 Power Cable Handling Safety

There are electrical hazards inherent to the handling, connection, and disconnection of HV plugs. When performing a connection or a disconnection, the operator can access to power connectors and can be exposed to a shock hazard if the power connectors are not disconnected an earthed.

The possible risks are:

• Failure to disconnect from the shore substation

• Failure to disconnect from ship power system

• Failure to discharge the HV cable

All basic operations must be simple and secure, designed for complete protection of operators. Shore connection and disconnection safety can be achieved with two major ways:

1. Operating instructions and procedures
2. Automatic interlocks managed by a safety system

Furthermore IEC/ISO/IEEE 80005-1 sets additional measures to prevent the risks presented previously. The recommended measures are classified as follows in the standard:

• Emergency shutdown

• Conditions for the shore connection start sequence (conditions for main breaker closing and earthing switch opening)

• Conditions for plug handling during plugging and unplugging (opening the disconnector and closing the earthing switch on both sides).

6.4.1 Safety Verification

Safety verifications can be defined with a view to ensure repeatability and standardization in safety procedures.

This system safety verification procedure should be completed for all IEC/ISO/IEEE 80005-1 compliant ships that have not previously successfully transferred to and from high voltage shore power or have not successfully transferred to and from high voltage shore power within the last 12-months.

A safety verification form aligned with the processes to be checked and signed by the persons in charge on each side.

(EMSA 2022)

7.0 Programs

7.1 CIPORT

The Action addresses the Core maritime Port of Piraeus, located on the Orient East-Med Core Network Corridor. It is part of the Global project which aims to transform the Port of Piraeus into a Green Cruise Hub. The Action aims to provide the final studies and engineering designs for the development of on-shore power supply (OPS) technology for four cruise vessels positions at the Themistoklis coast in the core maritime Port of Piraeus.

The Action includes the elaboration of the following main studies:

•Technical studies for the installation of OPS for the four identified cruise vessels positions, including the infrastructure that will allow the connection ofthe Port's grid to the city's local grid;

• Technical requirements and operational procedures for the electric connection and power provision to cruise vessels by the Port;

• Environmental studies required for the installation and operation ofthe OPS system;

• A Cost-Benefit Analysis;

• A study for the appropriate commercial model for the electricity supply to cruise vessels as well as a calculation ofthe appropriate pricing methodology, and;

• Tender documents for the subsequent works.

The completion of the Action will lead to the launch of the tender for the subsequent works after the Action's end. (PPA, 2022)

In the frame of CIPORT, PPA SA will implement all studies to prepare and accelerate the effective launch of cold ironing in the cruise sector. Additionally, PPA SA, as Lead Partner, is responsible for the successful implementation of the project at management and dissemination level.

PARTNERS

Lead Partner: Piraeus Port Authority SA

- HEDNO SA - Hellenic Electricity Distribution Network Operator SA
- PROTASIS SA
- HYDRUS Engineering SA
- National Technical University of Athens
- GATES – Global Transport and Engineering Systems

(PPA, 2022)

7.2 ELECTRIPORT

ELECTRIPORT provides all the detailed studies that are needed for “cold ironing” to become eligible for funding timely and effectively. Apart from the Technical options, studies cover the economic and financial aspects, delivering the financial dimensions in a complete input – output CBA approach.

The expected outcomes contribute to the development of know-how, implementation of environmental policies, reduction of CO2 emissions in the port and consequently in the neighboring Port–City of Heraklion.

The partnership covers all aspects of ELECTRIPORT, reflecting capacity and know-how regarding the scientific, technical and managerial aspects of the project.

ELECTRIPORT guarantees exploitation and dissemination on a local, regional, national and EU levels through globally established partnerships and established Project multipliers.

The partnership of the ELECTRIPORT project consists of:

- Heraklion Port Authority S.A., Lead Partner
- Wartsilla Hellas
- Premium Consulting
- BMG Marine – Electromechanical Engineers,
- Hellenic Mediterranean University (ELMEPA)
- ANELIXIS Development Consultants S.A
- MSI Hellas, Private Security Company
- National Technical University of Athens

7.3 ELEMED

The specific objective of the Action is to analyse and assess all necessary requirements for facilitating the introduction of cold ironing in three ports of the South East Mediterranean area: Port of Piraeus (Greece), Port of Killini (Greece) and Port of Limassol (Cyprus). A pilot testing of cold ironing and electrification on a real vessel will be carried out in the Port of Killini.

More specifically the Action will review worldwide cold ironing case studies (Juneau and Los Angeles in US, Gothenburg in Sweden etc.) in addition to the impact of installing energy storage devices for peak smoothening (such as flow batteries or other alternatives). Moreover, the installation of cold ironing facilities in the four ports will be assessed and a modern regulatory framework to tackle barriers and encourage the wide use of Cold Ironing will be formulated. (European Commission)

7.4 EALING

EALING studies propose a concrete approach towards the establishment of a suitable framework for the transition to electrification for at least 16 of the EU maritime ports involved in the EALING consortium. (PPA, 2022)

The activities carried out in each port aim at performing all the necessary studies on port equipment, infrastructure, performance and safety upgrade in order to accelerate the maturity and implementation of the electrification.

Activity 1: Harmonised Framework for the electrification of the participating TEN-T maritime ports

Activity 1 concerns the implementation of a detailed analysis on the current status of technical, legal and regulatory framework – at Member States level and at EU level – concerning the implementation of OPS in EU ports, with particular reference to the those participating in the EALING Consortium.

The Activity also aims at proposing recommendations based on the analysis, focused on how to implement a workable and coordinated framework boosting the development of OPS in ports of the TEN-T Network, considering cold ironing and electric bunkering procedures regarding the electricity market in the ports analysed.

Activity 2: Maritime fleet adaptation

Activity 2 concerns the study of the maritime electrification standards across the ports of the consortium and the vessels operating in these ports (including ro-ro vessels, containerships and car carriers): it will provide operational recommendations, taking IMO guidelines as a reference, for a harmonised technical, legal and regulatory framework on maritime fleet adaptation for electrification.

Considering that many vessels are not ready for OPS and electrical standards and regulatory framework are not uniform as well as the procedures of connecting and disconnecting the shore power supply,several scenarios will be examined within the Activity including a variety of general arrangements for different ships, including recommendations on best practices for their retrofitting.

Furthermore the identification of technical elements to be harmonised could derive on a proposal to IMO.

Activity 3: Technical studies for the electrification infrastructure of the participating TEN-T maritime ports

Activity 3 concerns the implementation of technical design studies for the electrification infrastructure necessary for the ports of the consortium: this includes the development of front-end engineering design (FEED) studies and other necessary technical studies to be used for the tender preparation, needed to enable ports launching the works phase right after the end of the Action.

Activity 4: Environmental studies

Activity 4 concerns the implementation of environmental studies, which scope is customised on the final needs of each participating port within the EALING Consortium. The studies will take into account the provisions stated in the Strategic Environmental Assessment (SEA) Directive (2001/42/EC) and the Environmental Impact Assessment (EIA) Directive (2014/52/EU), contributing, if necessary, to obtain the permits on the projected works for the future OPS infrastructure in the ports of the consortium.

Activity 5: Clean power supply plans and tender documents

Activity 5 concerns the preparation or updating of the clean power supply plans of the participating ports of the EALING Consortium, depending on the baseline identified for each port: the new OPS functionalities must be integrated in the internal Port Authorities' overall strategy concerning sustainability, expectations for future traffic growth and redefinition of the way the port users should operate.

Furthermore Activity 5 will deliver, within an harmonised framework, the tender documents for all proposed investments concerning construction works: electrification infrastructure developments will maximize the efficiency, effectiveness, safety and environmental compliance of the ports of the consortium and will serve more effectively potential electric vessels calling at the ports.

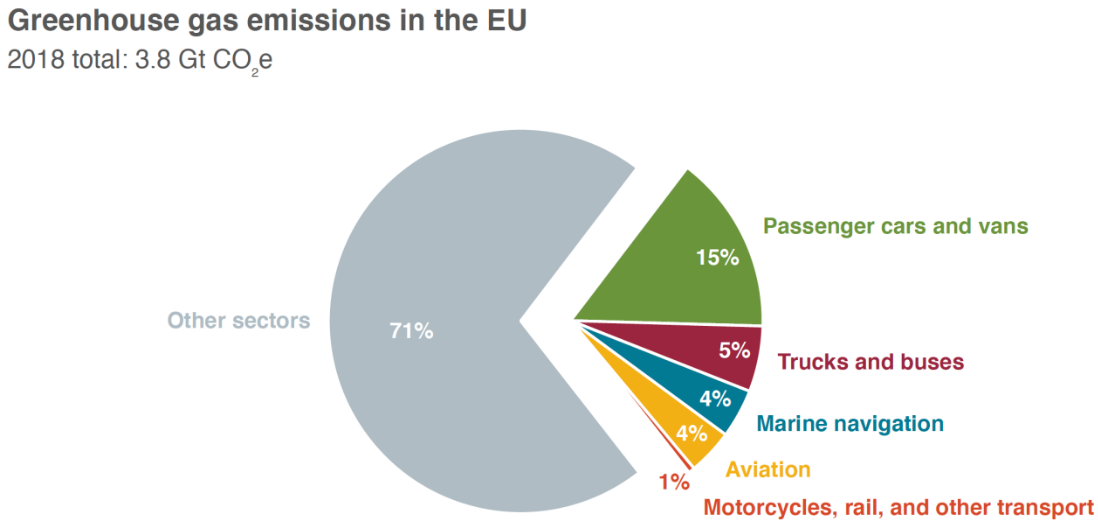
Activity 6: Cost-benefit analysis and Financial blending schemes

Activity 6 concerns the realisation of a Cost-benefit analysis (CBA) in compliance with CEF and REGIO guidelines for each OPS project of the maritime ports involved in the EALING Action, in order to assess the benefits and competiveness of the electrification solution as alternative source of energy and to enable decision on implementation of OPS equipment and infrastructure in the ports of the Consortium.

Furthermore the Activity will design suitable investment schemes based on the specific features of the OPS investments proposed under Activities 1 to 5 so that the ports of the consortium could use the available and upcoming financial structures by taking advantage of specific mechanisms such as Public Private Partnerships (PPPs) or the future Energy Communities, and ultimately proceed to the Financial Investment Decisions. (EALING Site)

8.0 Emissions from ships

Maritime industry is considered to be one of the most efficient ways of transporting goods and people as shown in the picture below. Nevertheless there is high pressure from global organizations for further reduction of gas production.



Source: The International Council of Clean Transportation

While bearthed, ship engines generate a number of harmful gases like Carbon Monoxide (CO), Hydrocarbons (HC), Nitrogen Dioxide (NOx), Lead (Pb), Particulate Matter (PM) and Sulfur dioxide (SO2) which are analyzed further more below.

8.1 Carbon Monoxide (CO)

Carbon monoxide poisoning occurs when carbon monoxide builds up in the blood. When too much carbon monoxide is in the air, the body replaces the oxygen in the red blood cells with carbon monoxide. This can lead to serious tissue damage, or even death.

Carbon monoxide is gas that has no odor, taste or color. Burning fuels, including gas, wood, propane or charcoal, make carbon monoxide. Appliances and engines that aren't well vented can cause the gas to build up to dangerous levels. A tightly enclosed space makes the buildup worse.

Carbon monoxide poisoning affects the brain and heart the most. Exposure over time might lead to symptoms that can be mistaken for the flu without the fever.

Clearer symptoms of carbon monoxide poisoning can include:

- Headache.
- Weakness.
- Dizziness.
- Nausea or vomiting.
- Shortness of breath.
- Confusion.
- Blurred vision.
- Drowsiness.
- Loss of muscle control.
- Loss of consciousness.

(Mayo Clinic, 2023)

8.2 Hydrocarbons (HC)

The term hydrocarbon refers to an organic chemical compound that is composed exclusively of hydrogen and carbon atoms. Hydrocarbons are naturally-occurring and form the basis of crude oil, natural gas, coal, and other important energy sources. They are highly combustible and produce carbon dioxide, water, and heat when they are burned. As such, hydrocarbons are highly effective as a source of fuel.

Impact of Hydrocarbons:

Environmental effects

There is a serious environmental cost to using hydrocarbons as a primary source of energy. Fossil fuel sources like crude oil, natural gas, and coal contain hydrogen and carbon. When they're burned, they release greenhouse gasses into the air, mainly carbon dioxide. Releasing them into the air contributes to climate change.

But it isn't just consumption that contributes to the deterioration of the environment. The process of oil and gas extraction also does considerable damage to the surface environment and surrounding groundwater of the extraction site by releasing pollutants. There is also a major threat of unexpected spills, which also has a negative impact on marine and aquatic life.

Economic effects

Not only does the use of hydrocarbons have an environmental impact but it also has economic implications. Proponents say that this sector is a major economic driver because of how vital it is in terms of the number of jobs it creates. And let's not forget how useful hydrocarbons are to society. After all, consumers need energy sources to fuel their cars, heat their homes, and light up their rooms

But there's a clear downside. Many economists argue that hydrocarbon energy production involves substantial negative externalities that are not sufficiently represented in the market price of oil and gas. In fact, considering the mounting cost of climate-change-related phenomena, many argue that these externalities significantly outweigh any cost savings associated with hydrocarbons. (Fernando, 2023)

8.3 Nitrogen Dioxide (NOx)

Nitrogen Dioxide (NO2) is one of a group of highly reactive gases known as oxides of nitrogen or nitrogen oxides (NOx). Other nitrogen oxides include nitrous acid and nitric acid. NO2 is used as the indicator for the larger group of nitrogen oxides.

NO_2 primarily gets in the air from the burning of fuel. NO_2 forms from emissions from cars, trucks and buses, power plants, and off-road equipment.

Health effects

Breathing air with a high concentration of NO_2 can irritate airways in the human respiratory system. Such exposures over short periods can aggravate respiratory diseases, particularly asthma, leading to respiratory symptoms (such as coughing, wheezing or difficulty breathing), hospital admissions and visits to emergency rooms. Longer exposures to elevated concentrations of NO_2 may contribute to the development of asthma and potentially increase susceptibility to respiratory infections. People with asthma, as well as children and the elderly are generally at greater risk for the health effects of NO_2.

NO_2 along with other NO_x reacts with other chemicals in the air to form both particulate matter and ozone. Both of these are also harmful when inhaled due to effects on the respiratory system.

Environmental effects

NO_2 and other NO_x interact with water, oxygen and other chemicals in the atmosphere to form acid rain. Acid rain harms sensitive ecosystems such as lakes and forests.

The nitrate particles that result from NO_x make the air hazy and difficult to see though. This affects the many national parks that we visit for the view.

NO_x in the atmosphere contributes to nutrient pollution in coastal waters. (Environmental Protection Agency, 2023)

8.4 Lead (Pb)

Lead is a bluish-white lustrous metal. It is very soft, highly malleable, ductile, and a relatively poor conductor of electricity. It is very resistant to corrosion but tarnishes upon exposure to air. Lead isotopes are the end products of each of the three series of naturally occurring radioactive elements.

Health effects

Lead is a soft metal that has known many applications over the years. It has been used widely since 5000 BC for application in metal products, cables and pipelines, but also in paints and pesticides. Lead is one out of four metals that have the most damaging effects on human health. It can enter the human body through uptake of food (65%), water (20%) and air (15%).

Foods such as fruit, vegetables, meats, grains, seafood, soft drinks and wine may contain significant amounts of lead. Cigarette smoke also contains small amounts of lead. Lead can enter (drinking) water through corrosion of pipes. This is more likely to happen when the water is slightly acidic. That is why public water treatment systems are now required to carry out pH-adjustments in water that will serve drinking purposes.

Environmental effects

Not only leaded gasoline causes lead concentrations in the environment to rise. Other human activities, such as fuel combustion, industrial processes and solid waste combustion, also contribute.

Lead can end up in water and soils through corrosion of leaded pipelines in a water transporting system and through corrosion of leaded paints. It cannot be broken down; it can only converted to other forms.

Lead accumulates in the bodies of water organisms and soil organisms. These will experience health effects from lead poisoning. Health effects on shellfish can take place even when only very small concentrations of lead are present. Body functions of phytoplankton can be disturbed when lead interferes. Phytoplankton is an important source of oxygen production in seas and many larger sea-animals eat it. That is why we now begin to wonder whether lead pollution can influence global balances.

Lead is a particularly dangerous chemical, as it can accumulate in individual organisms, but also in entire food chains. (Lenntech)

8.5 Particulate Matter (PM)

Airborne particulate matter (PM) is not a single pollutant, but rather is a mixture of many chemical species. It is a complex mixture of solids and aerosols composed of small droplets of liquid, dry solid fragments, and solid cores with liquid coatings. Particles vary widely in size, shape and chemical composition, and may contain inorganic ions, metallic compounds, elemental carbon, organic compounds, and compounds from the earth's crust. Particles are defined by their diameter for air quality regulatory purposes. Those with a diameter of 10 microns or less (PM10) are inhalable into the lungs and can induce adverse health effects. Fine particulate matter is defined as particles that are 2.5 microns or less in diameter (PM2.5). Therefore, PM2.5 comprises a portion of PM10. (California Air Resources Board)

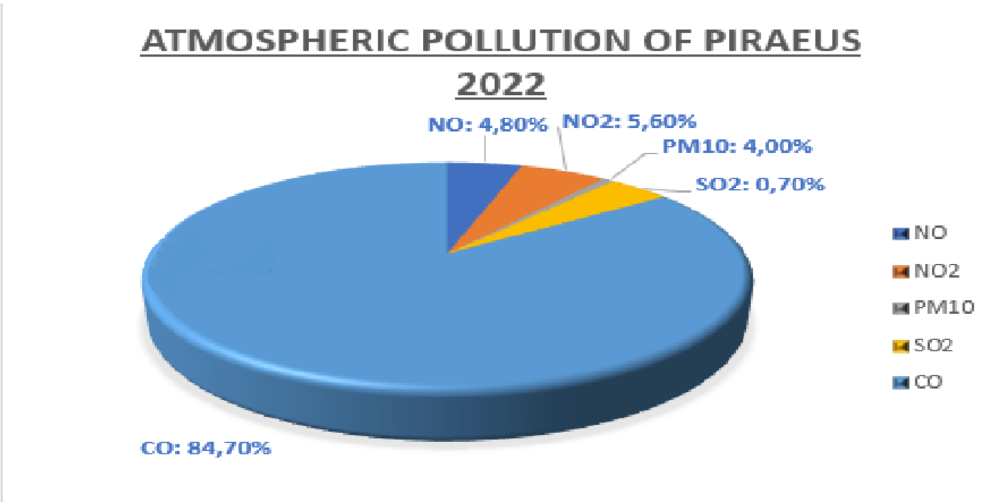
8.6 Sulfur dioxide (SO2)

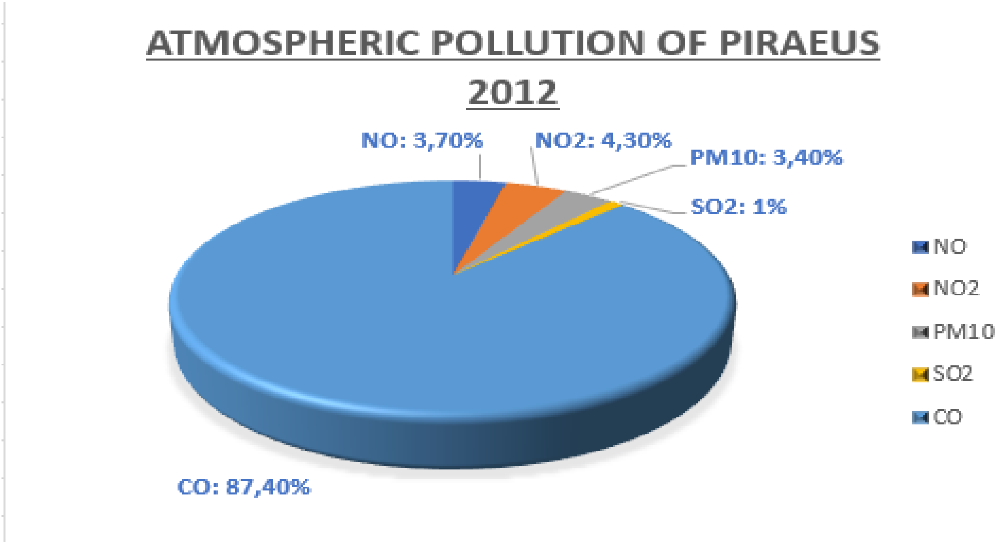
Sulfur dioxide is a gaseous air pollutant composed of sulfur and oxygen. SO2 forms when sulfur-containing fuel such as coal, oil, or diesel is burned. Sulfur dioxide also converts in the atmosphere to sulfates, a major part of fine particle pollution in the eastern U.S. (American Lung Association, 2023)

Short-term exposures to SO_2 can harm the human respiratory system and make breathing difficult. People with asthma, particularly children, are sensitive to these effects of SO_2.

SO_2 emissions that lead to high concentrations of SO_2 in the air generally also lead to the formation of other sulfur oxides (SO_x). SO_x can react with other compounds in the atmosphere to form small particles. These particles contribute to particulate matter (PM) pollution. Small particles may penetrate deeply into the lungs and in sufficient quantity can contribute to health problems. (Environmental Protection Agency)

On the following figures we can see the difference of the atmospheric pollution of Piraeus between years 2012 and 2022. The analyzed gases are NO, NO2, PM10, SO2 and CO and the data was collected from reports of Ministry of Environment and Energy. Each report had 24 measurements, one for each hour of the day, for the 365 days of each year. By adding all the measurements of the year, we had the total sum for each pollutant. Then we add the sums of all the pollutants to calculate the multitude. Finally we divided the sum of each pollutant with the total multitude and we came up with a mean (percentage) for every pollutant. As we can see there are no significant differences within the decade. CO has the leading role because the major producer is automobile machines (cars, ships, equipment), which is foreseeable if we consider the conjunction of Piraeus port from cars and trucks and also the vast amount of port calls from numerous ships.





8.7 External cost of atmospheric pollution

Despite the health problems derived from air pollution, there is a number of economic burdens too such as external costs. External cost is a usual way to express the impact of air pollution and it occurs when the actions of a group or individual have an impact on another group or individual. Despite the air pollution there are more external drivers of shipping like: discharges into the sea, solid and liquid waste generation abroad, resource consumption and recycling of ships. (Stefanos D. Chatzinikolaou, Stylianos D. Oikonomou, Nikolaos P. Ventikos., 2015).

According to the annual inventory of Greece, total navigation emissions account for 218.73kt for NO_x, 7.85kt for NMVOC (Non-methane volatile organic compound), 81.99kt for SO_x and 15.09kt for PM_{10} . Therefore the contribution of shipping activity in Piraeus port is 2.00%, 2.50%, 0.23% and 1.25%, for NO_x, NMVOC, SO_x and PM_{10} respectively. (Ioannis Sebos, Athena G Progiou, L. Kallinikos, Panagiota Eleni, 2016)

The anticipated damages ship emissions impose, which include health effects, crop losses and biodiversity loss, can reach to 19.9M€. The individual contribution of each pollutant was 13.33 M€ for NO_x, 1.76 M€ for SO_2 and 4.79M€ for $PM_{2.5}$. Obviously, the main polluters, passenger ships and container ships, contribute the most to the above costs.

Additionally, external costs due to ground emissions were calculated. Despite these costs being lower, due to the lower emissions, they reach 3.84 M€ with 2.33 M€ from SO_2, 0.45 M€ from NO_x and 1.05 M€ from $PM_{2.5}$. (A.G. Progiou, E. Bakeas, E. Evangelidou, Ch. Kontogiorgi, E. Lagkadinou, I. Sebos, 2021)

The table below refers to the external cost for the value of Euro in 2000.
External cost factors (in Euro, year 2000) per ton of pollutant

Pollutant	Human Health	Ecosystem Quality	Climate Change	Total
CO2	0	0	21	21
SO2	6.300	200	0	6.500
NOx	5.700	1.000	0	6.700
PM	35.000	0	0	35.000

In order to make a safe assumption about the today's cost we have to take into consideration the inflation rate. The average inflation rate from 2000 to 2023 is 2.43%, thus Euro experienced a price difference of 0.74 €. Therefore, Table 1 converts to Table 2.

Pollutant	Human Health	Ecosystem Quality	Climate Change	Total
CO2	0	0	37	37
SO2	10.941	347	0	11.288
NOx	9.899	1.736	0	11.635
PM	60.784	0	0	60.784

9.0 European Ports with Cold Ironing

9.1 Port of Kyllini

The port of Kyllini is a four berth Roll-On Roll-Off (RoRo) ferry terminal. The topographical top view of the port is presented in figure 4 along with the berthing positions and the major port distances.

There are, currently, five ferries which visit the port of Kyllini in daily basis. Four of them have an electrical system operating at 440 V, 60 Hz, while, one of them operates at 380 V, 50 Hz. Their electrical power demands at berth vary shortly from around 300 kVA to 450 kVA.

The cold ironing implementation in the port of Kyllini will consists of two shore supply positions at berth points 1 and 2 which are going to be constructed in two individual stages. The first shore supply position will be constructed within the framework of the ELEMED project and more specifically activity 13 "Pilot: Shore Power Installation in the Port of Kyllini". The project is anticipated to be completed before October 2018.

The complete shore – side installation for Kyllini AMP project will consist of two shore side substations one per supply position. The first substation shall include:

- one medium Voltage Switchgear
- one Step Down Power Dyn Transformer of Dyn
- one Incoming Low Voltage Switchgear
- one static Frequency Converter
- one Isolation Transformer dyn, 1:1 ratio which will provide galvanic isolation from other connected ferries and consumers;
- one Neutral Earthing Resistor (NER) installed at the neutral point of the isolation transformer for limiting the ground fault current between the shore box and the vessel's infrastructure;
- one Outgoing Low Voltage Switchgear which will supply the shore socket outlets; The second shore side substation will be identical to the first one except the medium voltage Switchgear. Each supply point shall consist of two

standardized socket-outlets The interconnection cables between the supply point on shore and the receiving point on the vessel shall consist of two XLPE parallel cables, 185mm2, 3 Phases + Earth + 4 Pilot wires.

Picture 5, presents the cost estimation for the pilot implementation (one shore-side power supply position) and the complete cold ironing solution (two shore-side power supply positions) for the Kyllini project.

Picture 5. Kyllini Project Cost Estimation (Source: The ports as smart micro-grids: development perspectives)

De Description	Pilot Project Cost (€)	Complete Project Cost (€)
Civil Works	27.000	53.500
Electrical Utilities	37.500	63.500
Shore Box Equipment	272.000	522.000
Socket Outlets and Plugs	7.500	15.000
Earthing System	7.500	14.000
Cable management system	100.000	200.000
Sum	451.500	868.000
Total cost (Subcontractor profit 18%, Uncertain expenses 15%, VAT 24%)	780.000	1.475.000

In order to make the best out of Cold Ironing technology the electricity supplying the vessels should come from zero emission sources such as photovoltaic panels and wind generators, especially if combined with a battery storage system

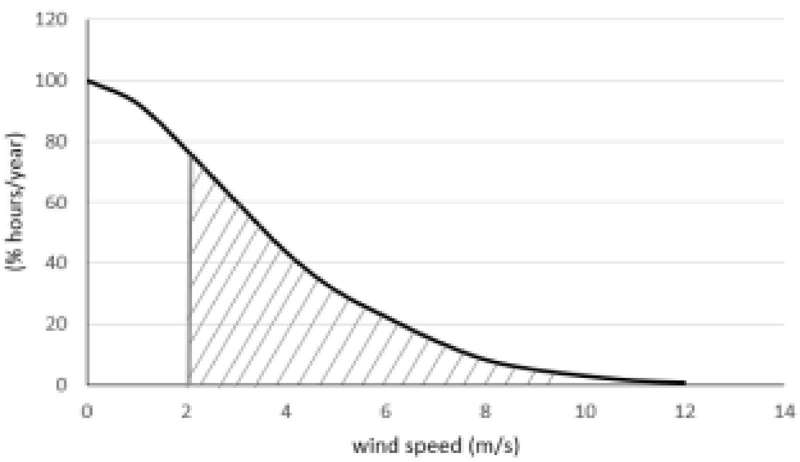
The battery storage system can be charged through the installed solar panels and wind generators when no vessel is supplied from the port's grid and act as supplementary to the renewable sources when the demand of the supplied vessel exceeds the power generated from renewable sources. All the measured data are gathered in a central power management system server which controls the functions of the local microgrid.

In order to decide whether to choose between solar energy or wind energy, local authorities with the aid of scientists collected meteorological data from the ports weather station. They came to the conclusion that solar energy is preferable because solar irradiance is more intense in the summer when vessels use extensively utilization of air condition systems so cold ironing implementations

An investment on renewable source depends on the available space at the port area and the local weather conditions. In order to determine the available power generation resources, the meteorological data from the port's weather station were collected. Picture 6 depicts the cumulative distribution of the hourly average wind speed over a period of one year, while table II presents the average monthly solar irradiance.

As observed in picture 6, in no more than 20% of the hours of the year the wind speed is less than 2m/s which is the cut in wind speed for vertical axis wind turbines. As expected, the solar irradiance is more intense in the summer which is extremely beneficiary for cold ironing implementations since during summer months the vessels power demand reaches a maximum due to the extensive utilization of air condition systems. (P. Mertikas, S.E. Dallas, Spathis Dimos, Thodoris Kourmpelis, 2018)

Picture 6. Cumulative distribution of the hourly average wind speed at the port of Kyllini (Source: The ports as smart micro-grids: development perspectives)



Unfortunately, the project of cold iron was miscontinued and operated only for the opening ceremony.

9.2 Long Beach

The Port of Long Beach has completed more than $185 million worth of dockside power hookups and other infrastructure to facilitate shore power. Beginning in 2017, California mandated that at least half of all container ships run on shore-side electricity at berth. Carriers are subject to an additional requirement: Each fleet must reduce its total emissions by 70 percent.

The rule affects fleets calling at the ports of Long Beach, Los Angeles, San Diego, Oakland, San Francisco and Hueneme and applies to all operators.

Unlike some other California ports, the Port of Long Beach is not involved in electricity billing or shore power charges. Each terminal has its own account and rate structure with Southern California Edison, the local electricity provider.

There are very few funding opportunities for shipside retrofits, and grant programs generally require shore power usage levels that exceed the regulatory requirements. When the Port becomes aware of funding opportunities, it makes every attempt to notify shipping lines. One potential funding source is the Carl Moyer Program, which is administered locally by the South Coast Air Quality Management District. Eligibility criteria and long-term shore power usage levels apply. (Port of Long Beach)

9.3 Los Angeles

On June 21, 2004, the Port of Los Angeles and China Shipping Container Line announced the opening of the West Basin Container Terminal at Berth 100, the first container terminal in the world to use Alternative Maritime Power. Nearly two months later on August 9, 2004, the Port welcomed the world’s first container vessel to be built with AMP specifications already in mind, shipping line NYK’s NYK Atlas.

In July 2012, the international HVSC standard was published. The Port was an active participant in the development of the IEC/ISO/IEEE 80005-1 international standard. The Port’s shoreside installations meet the IEC/ISO/IEEE 80005-1 international standard.

The Port of Los Angeles has invested millions of dollars equipping its terminals for AMP. As of 2020, the Port of Los Angeles has 79 AMP vaults — more than any other port in the world. (Port of Los Angeles)

9.4 Port of Rotterdam

The municipality of Rotterdam and the Port of Rotterdam Authority conduct a joint strategy and development program to accelerate and scale up shore-based power for sea-going vessels, with the aim of having a high percentage of sea-going vessels plugged in at the quay by 2030. Diesel generators can then be switched off, which is favourable for air quality and carbon neutrality. In the next five years, the municipality and the port together with the companies in the port and the shipping companies will be working on accelerating and scaling up shore-based power. Depending on the experiences gained by these efforts, the targets can be adjusted in 2025.

Various sections of vessels already have the right configuration that makes the transition to shore-based power possible and scaling up of shore-based power easy. In other sections, however, this is more difficult, or connecting to shore-based power is not possible at all for technical reasons. Innovation and standardisation are therefore necessary for these sections. For the improvement of air quality, reduction of nitrogen deposition, and making shipping more sustainable, we opt for wide development based on three pillars:

1. Focus on the living environment quality;
2. Big steps forward where this is possible;
3. Encouraging innovation and standardisation where this is required.

(Port of Rotterdam)

9.5 Southampton

ABP (Associated British Ports) Southampton announced in 2019 that it was investing in onshore power for its new Horizon Cruise Terminal, subsequently announcing a second shore power connection, for Mayflower Cruise Terminal, in 2021. Shore power-enabled ships can now plug in at the port's Horizon Cruise Terminal and Mayflower Cruise Terminal, for zero emissions at berth. AIDA Cruises' brand-new AIDAcosma and Cunard's iconic Queen Mary 2 can now use the port's shore power. Further cruise ships are scheduled for commissioning this month and throughout the year. The total shore power project cost was £9 million ($11.8 million), supported by a grant from the Solent Local Growth Deal, arranged through the Solent Local Enterprise Partnership (LEP) (Associated British Ports, 2022).

9.6 Stockholm

Today a large part of the regular ferry services to and from Ports of Stockholm connect to onshore power. Ports of Stockholm is working together with energy providers, other ports, and shipping customers for further expansion of the infrastructure.

At Port of Stockholm, Viking Line and Tallink Silja vessels are connected to onshore power. At Port of Nynäshamn Polferries and Destination Gotland vessels are connected. A project for onshore power connection of Finnline's ferry traffic is also underway in Port of Kapellskär. The archipelago and charter boat services all connect to electricity at the quayside in Stockholm.

The services already connected to onshore power, or are next in line, are also those where onshore power connection has the greatest impact, as those vessels constitute by far the most frequent traffic. The same vessels operate on routes to and from the same ports. A small number of obvious partners are involved and can jointly agree on one solution and funding.

Ports of Stockholm has been awarded Swedish government funding, and together with the Baltic Sea ports of Copenhagen/Malmö, Aarhus and Helsinki EU funding, for investing in onshore power supply for cruise vessels. For Ports of Stockholm the investment means equipping two central quays in Stockholm with high voltage. The work will be completed, respectively, in 2023 and 2024. When the project is completed, the assessment is that at least 45 percent of the cruise calls to Ports of Stockholm can connect to onshore power.

Ports of Stockholm is working from a plan of action to be able to offer more vessels onshore power connection at the quayside. This is a long-term effort, as it requires collaboration and dialogue with the shipping companies and with the other Baltic Sea ports. It also requires a high power output supply and major investment. (C.Solerud, 2024).

10.0 Case study

In order to understand the importance of Cold Ironing, we have to specify the energy needs of various types of ships (Container ships, Ro-Ro, Cruise ships). Therefore we would understand which type of ship, thus terminal has the most need of shore power supply. Three ships from each type were chosen randomly and analyzed as per the time at port and the KW they need while berthed.

The total amount of annual energy demand will be calculated with the following simple mathematical relation:

- **ENERGY (KWh) = POWER (KW) x TIME (h)**

Where:

1) Power = energy demand while berthed
2) Time = time spent while berthed

Each vessel, depending the kind and the engine type has different power demands in order to cover all the power needs while hoteling in port. As we can see from Table 1.1, cruise ships are the ones in the most need of power, since they host a large number of passengers.

Table 8: Required power supply for different types of ships (Source: American Association of Port Authoritie)

VESSEL TYPE	AVERAGE POWER DEMAND (KW)	MAXIMUM POWER DEMAND (KW)	MAXIMUM POWER DEMAND FOR 95% OF VESSELS (KW)
CONTAINER SHIPS (<140m)	170	1000	800
CONTAINER SHIPS (>140m)	1200	8000	5000
CONTAINER SHIPS (IN TOTAL)	800	8000	4000
RO-RO	1500	2000	1800
TANKERS	1400	2700	2500
CRUISE SHIPS (<200m)	4100	7300	6700
CRUISE SHIPS (>200m)	7500	11000	9500
BULK CARRIERS	300	1000	850
REEFERS	600	2000	1700

Energy needs of Container ships

CONTSHIP SEA

Source: Contships Management

CONTSHIP SEA is a container ship with a loading capacity up to 1574 TEUs. From the image below we can see how much time CONTSHIP SEA stayed berthed at the port of Piraeus from 13/1/2023 to 24/12/2023.

CONTSHIP SEA – Time at port for year 2023

Vessel Name	Port Call Type	Port At Call	Ata/atd
CONTSHIP SEA	DEPARTURE	PIRAEUS	1/13/2023 13:24
CONTSHIP SEA	DEPARTURE	PIRAEUS	1/29/2023 5:34
CONTSHIP SEA	DEPARTURE	PIRAEUS	2/15/2023 21:06
CONTSHIP SEA	DEPARTURE	PIRAEUS	3/6/2023 21:15
CONTSHIP SEA	DEPARTURE	PIRAEUS	3/18/2023 13:54
CONTSHIP SEA	DEPARTURE	PIRAEUS	4/10/2023 4:11
CONTSHIP SEA	DEPARTURE	PIRAEUS	4/24/2023 1:19
CONTSHIP SEA	DEPARTURE	PIRAEUS	5/7/2023 4:29
CONTSHIP SEA	DEPARTURE	PIRAEUS	5/20/2023 21:17
CONTSHIP SEA	DEPARTURE	PIRAEUS	6/4/2023 22:53
CONTSHIP SEA	DEPARTURE	PIRAEUS	6/18/2023 20:19
CONTSHIP SEA	DEPARTURE	PIRAEUS	7/2/2023 4:41
CONTSHIP SEA	DEPARTURE	PIRAEUS	7/16/2023 4:40
CONTSHIP SEA	DEPARTURE	PIRAEUS	8/6/2023 7:34
CONTSHIP SEA	DEPARTURE	PIRAEUS	8/19/2023 4:01
CONTSHIP SEA	DEPARTURE	PIRAEUS	9/2/2023 20:29
CONTSHIP SEA	DEPARTURE	PIRAEUS	9/16/2023 11:38
CONTSHIP SEA	DEPARTURE	PIRAEUS	10/1/2023 3:50
CONTSHIP SEA	DEPARTURE	PIRAEUS	10/16/2023 15:30
CONTSHIP SEA	DEPARTURE	PIRAEUS	10/28/2023 16:05
CONTSHIP SEA	DEPARTURE	PIRAEUS	11/9/2023 21:28
CONTSHIP SEA	DEPARTURE	PIRAEUS	11/26/2023 9:30
CONTSHIP SEA	DEPARTURE	PIRAEUS	12/10/2023 16:23
CONTSHIP SEA	DEPARTURE	PIRAEUS	12/24/2023 15:15

Time At Port(Hours)	Time At Port(Minutes)	
36	48	
30	56	
33	21	
38	19	
38	18	
38	16	
27	55	
33	12	
27	48	
28	30	
38	44	
44	53	
53	46	
34	37	
37	43	
28	54	
30	16	
40	16	
25	30	
42	41	
32	10	
39	13	
45	14	
41	51	
856	**791**	**36 DAYS/791 HOURS**

By adding the time period from the column ‘’Time at Port’’ we come to the conclusion that CONTSHIP SEA stayed for 36 days with 24 calls. 36 days equals to 791 hours and taking into consideration the table 8 we have :

ENERGY (KWh) = POWER (KW) x TIME (h) = 1200 x 791 = 949.200 KWh

CONTSHIP ECO

CONTSHIP ECO is a container ship with a loading capacity up to 1574 TEUs. From the image below we can see how much time CONTSHIP ECO stayed berthed at the port of Piraeus from 01/01/2023 to 27/12/2023

CONTSHIP ECO – Time at port for year 2023

Vessel Name	Port Call Type	Port At Call	Ata/atd
CONTSHIP ECO	DEPARTURE	PIRAEUS	1/1/2023 19:09
CONTSHIP ECO	DEPARTURE	PIRAEUS	1/7/2023 6:36
CONTSHIP ECO	DEPARTURE	PIRAEUS	1/13/2023 22:47
CONTSHIP ECO	DEPARTURE	PIRAEUS	1/24/2023 5:09
CONTSHIP ECO	DEPARTURE	PIRAEUS	2/2/2023 20:10
CONTSHIP ECO	DEPARTURE	PIRAEUS	2/9/2023 16:59
CONTSHIP ECO	DEPARTURE	PIRAEUS	2/16/2023 16:50
CONTSHIP ECO	DEPARTURE	PIRAEUS	2/22/2023 21:10
CONTSHIP ECO	DEPARTURE	PIRAEUS	3/6/2023 14:09
CONTSHIP ECO	DEPARTURE	PIRAEUS	3/13/2023 5:17
CONTSHIP ECO	DEPARTURE	PIRAEUS	3/20/2023 19:47
CONTSHIP ECO	DEPARTURE	PIRAEUS	3/31/2023 18:28
CONTSHIP ECO	DEPARTURE	PIRAEUS	4/9/2023 6:32
CONTSHIP ECO	DEPARTURE	PIRAEUS	4/18/2023 15:57
CONTSHIP ECO	DEPARTURE	PIRAEUS	4/29/2023 1:07
CONTSHIP ECO	DEPARTURE	PIRAEUS	5/8/2023 11:44
CONTSHIP ECO	DEPARTURE	PIRAEUS	5/18/2023 4:24
CONTSHIP ECO	DEPARTURE	PIRAEUS	5/29/2023 20:16
CONTSHIP ECO	DEPARTURE	PIRAEUS	6/6/2023 20:41
CONTSHIP ECO	DEPARTURE	PIRAEUS	6/16/2023 4:02
CONTSHIP ECO	DEPARTURE	PIRAEUS	6/24/2023 12:38
CONTSHIP ECO	DEPARTURE	PIRAEUS	7/7/2023 11:53
CONTSHIP ECO	DEPARTURE	PIRAEUS	7/18/2023 4:18
CONTSHIP ECO	DEPARTURE	PIRAEUS	8/3/2023 7:29
CONTSHIP ECO	DEPARTURE	PIRAEUS	8/15/2023 11:19
CONTSHIP ECO	DEPARTURE	PIRAEUS	8/26/2023 10:56
CONTSHIP ECO	DEPARTURE	PIRAEUS	9/4/2023 4:32
CONTSHIP ECO	DEPARTURE	PIRAEUS	9/5/2023 4:57
CONTSHIP ECO	DEPARTURE	PIRAEUS	9/17/2023 6:26
CONTSHIP ECO	DEPARTURE	PIRAEUS	9/26/2023 22:36
CONTSHIP ECO	DEPARTURE	PIRAEUS	10/16/2023 4:50
CONTSHIP ECO	DEPARTURE	PIRAEUS	10/25/2023 10:40
CONTSHIP ECO	DEPARTURE	PIRAEUS	11/2/2023 18:46
CONTSHIP ECO	DEPARTURE	PIRAEUS	11/11/2023 5:02
CONTSHIP ECO	DEPARTURE	PIRAEUS	11/21/2023 20:07
CONTSHIP ECO	DEPARTURE	PIRAEUS	12/3/2023 19:40
CONTSHIP ECO	DEPARTURE	PIRAEUS	12/14/2023 5:38
CONTSHIP ECO	DEPARTURE	PIRAEUS	12/27/2023 14:39

Time At Port(Hours)	Time At Port(Minutes)	
31	55	
31	56	
17	28	
17	45	
28	54	
50	1	
24	47	
24	3	
19	44	
24	12	
27	37	
33	34	
30	21	
35	14	
23	22	
35	6	
22	58	
33	12	
40	4	
30	11	
20	42	
30	43	
23	21	
41	29	
39	9	
36	19	
0	9	
24	34	
25	22	
25	29	
23	18	
30	17	
27	18	
23	45	
47	9	
32	33	
27	37	
81	4	
1126	**1002**	**48 DAYS/1143 HOURS**

We come to the conclusion that CONTSHIP ECO stayed for 48 days or 1143 hours with 38 calls. Taking into consideration the table 8 we have :

ENERGY (KWh) = POWER (KW) x TIME (h) = 170 x 1143 = 194.310 KWh

ARIANA A

ARIANA A is a container ship with a loading capacity up to 1574 TEUs. From the image below we can see how much time ARIANA A stayed berthed at the port of Piraeus from 13/1/2023 to 19/12/2023

ARIANA A – Time at port for year 2023

Vessel Name	Port Call Type	Port At Call	Ata/atd
ARIANA A	DEPARTURE	PIRAEUS	7/19/2023 14:05
ARIANA A	DEPARTURE	PIRAEUS	8/6/2023 12:26
ARIANA A	DEPARTURE	PIRAEUS	8/22/2023 5:09
ARIANA A	DEPARTURE	PIRAEUS	9/8/2023 0:26
ARIANA A	DEPARTURE	PIRAEUS	9/20/2023 12:20
ARIANA A	DEPARTURE	PIRAEUS	10/4/2023 4:10
ARIANA A	DEPARTURE	PIRAEUS	10/17/2023 4:30
ARIANA A	DEPARTURE	PIRAEUS	11/1/2023 13:07
ARIANA A	DEPARTURE	PIRAEUS	11/15/2023 13:33
ARIANA A	DEPARTURE	PIRAEUS	12/6/2023 15:09
ARIANA A	DEPARTURE	PIRAEUS	12/19/2023 2:48

Time At Port(Hours)	Time At Port(Minutes)	
14	11	
22	52	
45	9	
36	49	
24	0	
32	21	
35	36	
31	3	
37	14	
40	3	
45	1	
361	**199**	**15 DAYS/365 HOURS**

We come to the conclusion that ARIANA A stayed for 15 days or 280 hours with 11 calls. Taking into consideration the table 8 we have :

ENERGY (KWh) = POWER (KW) x TIME (h) = 1200 x 365 = 438.000 KWh

On the following table we can see the total KWh needed for every containership we analyzed.

VESSEL NAME	HOURS	CALLS	KW	KWh
CONTSHIP SEA	791	24	1200	942.200
CONTSHIP ECO	1143	38	170	194.310
ARIANA A	365	11	1200	438.000

Energy needs of Ro-Ro Ships

NEPTUNE OKEANIS

Source: Vessel Finder

NEPTUNE OKEANIS is a RO-RO Cargo ship with a carrying capacity of 2200 cars. The below Table was formed with information collected from Marine Traffic about the vessel name, the port call type, the port at call and the time spent berthed. Therefore, it was possible to find the exact time in days and hours she stayed berthed at the port of Piraeus from 23/1/2023 to 9/10/2023.

NEPTUNE OKEANIS – Time at port for year 2023

Vessel Name	Port Call Type	Port At Call	Ata/atd
NEPTUNE OKEANIS	DEPARTURE	PIRAEUS	1/4/2023 12:56
NEPTUNE OKEANIS	DEPARTURE	PIRAEUS	1/13/2023 12:12
NEPTUNE OKEANIS	DEPARTURE	PIRAEUS	1/23/2023 14:09
NEPTUNE OKEANIS	DEPARTURE	PIRAEUS	2/4/2023 19:32
NEPTUNE OKEANIS	DEPARTURE	PIRAEUS	2/15/2023 14:27
NEPTUNE OKEANIS	DEPARTURE	PIRAEUS	2/26/2023 5:40
NEPTUNE OKEANIS	DEPARTURE	PIRAEUS	3/7/2023 13:16
NEPTUNE OKEANIS	DEPARTURE	PIRAEUS	3/12/2023 18:32
NEPTUNE OKEANIS	DEPARTURE	PIRAEUS	3/30/2023 12:13
NEPTUNE OKEANIS	DEPARTURE	PIRAEUS	4/8/2023 16:39
NEPTUNE OKEANIS	DEPARTURE	PIRAEUS	4/23/2023 16:54
NEPTUNE OKEANIS	DEPARTURE	PIRAEUS	5/4/2023 11:10
NEPTUNE OKEANIS	DEPARTURE	PIRAEUS	5/13/2023 10:54
NEPTUNE OKEANIS	DEPARTURE	PIRAEUS	6/6/2023 18:56
NEPTUNE OKEANIS	DEPARTURE	PIRAEUS	6/21/2023 18:32
NEPTUNE OKEANIS	DEPARTURE	PIRAEUS	7/5/2023 18:38
NEPTUNE OKEANIS	DEPARTURE	PIRAEUS	7/17/2023 19:16
NEPTUNE OKEANIS	DEPARTURE	PIRAEUS	8/24/2023 12:36
NEPTUNE OKEANIS	DEPARTURE	PIRAEUS	8/31/2023 16:48
NEPTUNE OKEANIS	DEPARTURE	PIRAEUS	9/12/2023 13:49
NEPTUNE OKEANIS	DEPARTURE	PIRAEUS	9/24/2023 10:29
NEPTUNE OKEANIS	DEPARTURE	PIRAEUS	10/9/2023 3:39
NEPTUNE OKEANIS	DEPARTURE	PIRAEUS	10/20/2023 17:43
NEPTUNE OKEANIS	DEPARTURE	PIRAEUS	11/6/2023 4:40
NEPTUNE OKEANIS	DEPARTURE	PIRAEUS	11/20/2023 18:28
NEPTUNE OKEANIS	DEPARTURE	PIRAEUS	11/24/2023 19:10
NEPTUNE OKEANIS	DEPARTURE	PIRAEUS	12/2/2023 4:53
NEPTUNE OKEANIS	DEPARTURE	PIRAEUS	12/17/2023 11:18

Time At Port(Hours)	Time At Port(Minutes)
7	36
7	5
26	42
73	50
8	59
24	8
18	46
13	19
20	20
6	17
12	48
17	35
23	5
49	42
151	17
34	20

85	37	
18	42	
12	29	
57	26	
24	8	
23	28	
13	19	
18	5	
13	29	
8	59	
18	13	
41	24	
818	**788**	**35 DAYS/831 HOURS**

As we can see, the total time spent at port is 35 days or 831 hours with 28 calls. Taking into consideration the table 8 we have :

ENERGY (KWh) = POWER (KW) x TIME (h) = 1500 x 831 = 1.246.500 KWh

NEPTUNE PHOS

NEPTUNE PHOS is a RO-RO Cargo ship with a carrying capacity of 3800 cars. From the table below we can see how much time she stayed berthed at the port of Piraeus from 6/1/2023 to 24/11/2023:

NEPTUNE PHOS – Time at port for year 2023

Vessel Name	Port Call Type	Port At Call	Ata/atd
NEPTUNE PHOS	DEPARTURE	PIRAEUS	1/6/2023 9:11
NEPTUNE PHOS	DEPARTURE	PIRAEUS	2/23/2023 4:49
NEPTUNE PHOS	DEPARTURE	PIRAEUS	3/29/2023 17:32
NEPTUNE PHOS	DEPARTURE	PIRAEUS	5/10/2023 17:57
NEPTUNE PHOS	DEPARTURE	PIRAEUS	6/7/2023 13:55
NEPTUNE PHOS	DEPARTURE	PIRAEUS	7/12/2023 17:23
NEPTUNE PHOS	DEPARTURE	PIRAEUS	8/20/2023 4:07
NEPTUNE PHOS	DEPARTURE	PIRAEUS	9/19/2023 4:33
NEPTUNE PHOS	DEPARTURE	PIRAEUS	10/17/2023 18:38
NEPTUNE PHOS	DEPARTURE	PIRAEUS	11/24/2023 12:50

Time At Port(Hours)	Time At Port(Minutes)	
13	23	
16	46	
7	4	
49	11	
9	50	
24	6	
23	32	
14	54	
8	32	
18	52	
181	**310**	**8 DAYS/186 HOURS**

As we can see, the total time spent at port is 8 days or 186 hours with 10. Taking into consideration the table 8 we have:

ENERGY (KWh) = POWER (KW) x TIME (h) = 1500 x 186 = 279.000 KWh

NEPTUNE THELISIS

NEPTUNE THELISIS is a RO-RO Cargo ship with a carrying capacity of 2200 cars. From the table below we can see how much time she stayed berthed at the port of Piraeus from 13/1/2023 to 04/11/2023:

NEPTUNE THELISIS – Time at port for year 2023

Vessel Name	Port Call Type	Port At Call	Ata/atd
NEPTUNE THELISIS	DEPARTURE	PIRAEUS	1/8/2023 17:39
NEPTUNE THELISIS	DEPARTURE	PIRAEUS	1/27/2023 19:34
NEPTUNE THELISIS	DEPARTURE	PIRAEUS	2/14/2023 17:30
NEPTUNE THELISIS	DEPARTURE	PIRAEUS	3/1/2023 18:13
NEPTUNE THELISIS	DEPARTURE	PIRAEUS	3/11/2023 19:04
NEPTUNE THELISIS	DEPARTURE	PIRAEUS	3/17/2023 19:27
NEPTUNE THELISIS	DEPARTURE	PIRAEUS	3/26/2023 17:32
NEPTUNE THELISIS	DEPARTURE	PIRAEUS	4/12/2023 3:59
NEPTUNE THELISIS	DEPARTURE	PIRAEUS	4/27/2023 8:49
NEPTUNE THELISIS	DEPARTURE	PIRAEUS	5/9/2023 10:55
NEPTUNE THELISIS	DEPARTURE	PIRAEUS	6/17/2023 3:43
NEPTUNE THELISIS	DEPARTURE	PIRAEUS	6/27/2023 11:12
NEPTUNE THELISIS	DEPARTURE	PIRAEUS	7/9/2023 16:31
NEPTUNE THELISIS	DEPARTURE	PIRAEUS	8/9/2023 18:31
NEPTUNE THELISIS	DEPARTURE	PIRAEUS	8/16/2023 4:03
NEPTUNE THELISIS	DEPARTURE	PIRAEUS	8/23/2023 22:41
NEPTUNE THELISIS	DEPARTURE	PIRAEUS	9/5/2023 14:48
NEPTUNE THELISIS	DEPARTURE	PIRAEUS	9/18/2023 17:00
NEPTUNE THELISIS	DEPARTURE	PIRAEUS	9/22/2023 15:19
NEPTUNE THELISIS	DEPARTURE	PIRAEUS	10/2/2023 11:17
NEPTUNE THELISIS	DEPARTURE	PIRAEUS	10/24/2023 18:29
NEPTUNE THELISIS	DEPARTURE	PIRAEUS	11/4/2023 23:32
NEPTUNE THELISIS	DEPARTURE	PIRAEUS	12/7/2023 12:47
NEPTUNE THELISIS	DEPARTURE	PIRAEUS	12/18/2023 19:28
NEPTUNE THELISIS	DEPARTURE	PIRAEUS	12/30/2023 10:46

Time At Port(Hours)	Time At Port(Minutes)	
30	10	
14	2	
23	33	
12	52	
8	36	
14	30	
8	21	
45	26	
15	47	
51	50	
56	27	
15	49	
80	39	
124	53	
9	47	
12	50	
24	15	
12	20	
11	7	
16	40	
6	56	
30	39	
24	58	
10	23	
17	45	
666	**875**	**29 DAYS/681 HOURS**

As we can see, the total t0ime spent at port is 29 days or 681 hours with 25 calls. Taking into consideration the table 8 we have:

ENERGY (KWh) = POWER (KW) x TIME (h) = 1500 x 681 = 1.021.500 KWh

The following table shows the hours, calls, KW and KWh of each Ro-Ro ship

VESSEL NAME	HOURS	CALLS	KW	KWh
NEPTUNE OKEANIS	831	28	1500	1.246.500
NEPTUNE PHOS	186	10	1500	279.000
NEPTUNE THELISIS	681	25	1500	1.021.500

Energy needs of Cruise Ships

VIKING SKY

Source: Wikipedia

VIKING SKY is a cruise ship of the Viking Cruises company with a total length of 228m, beam 6.45m and the ability to host 930 guests.

From the image below we can see how much time VIKING SKY stayed berthed at the port of Piraeus from 1/4/2023 to 4/11/2023:

VIKING SKY – Time at port for year 2023

Vessel Name	Port Call Type	Port At Call	Ata/atd
VIKING SKY	DEPARTURE	PIRAEUS	1/4/2023 16:37
VIKING SKY	DEPARTURE	PIRAEUS	1/18/2023 16:16
VIKING SKY	DEPARTURE	PIRAEUS	2/8/2023 15:36
VIKING SKY	DEPARTURE	PIRAEUS	2/18/2023 16:16
VIKING SKY	DEPARTURE	PIRAEUS	3/25/2023 16:17
VIKING SKY	DEPARTURE	PIRAEUS	5/6/2023 15:15
VIKING SKY	DEPARTURE	PIRAEUS	5/19/2023 15:27
VIKING SKY	DEPARTURE	PIRAEUS	7/1/2023 15:17
VIKING SKY	DEPARTURE	PIRAEUS	7/14/2023 15:29
VIKING SKY	DEPARTURE	PIRAEUS	8/26/2023 15:26
VIKING SKY	DEPARTURE	PIRAEUS	9/8/2023 15:21
VIKING SKY	DEPARTURE	PIRAEUS	10/21/2023 15:15
VIKING SKY	DEPARTURE	PIRAEUS	11/4/2023 16:20

Time At Port(Hours)	Time At Port(Minutes)	
35	53	
35	34	
58	47	
40	4	
35	48	
35	26	
35	51	
35	37	
35	58	
35	42	
35	52	
35	56	
60	6	
508	**514**	**22 DAYS/517 HOURS**

We come to the conclusion that VIKING SKY stayed for 22 days with 13 calls. 22 days equals to 517 hours and taking into consideration the table 8 we have :

ENERGY (KWh) = POWER (KW) x TIME (h) = 7500 x 517 = 3.877.500 KWh

MSC SPLENDIDA

Source: Wikipedia

MSC SPLENDIDA is a cruise ship of the Viking Cruises company with a total length of 333m, beam m and the ability to host 3971 guests.

From the image below we can see how much time MSC SPLENDIDA stayed berthed at the port of Piraeus from 25/4/2023 to 21/10/2023: (μεχρι τελος του χρονου εβαλα από προγραμμα κρουαζ)

MSC SPLENDIDA – Time at port for year 2023

Vessel Name	Port Call Type	Port At Call	Ata/atd
MSC SPLENDIDA	DEPARTURE	PIRAEUS	4/25/2023 14:45
MSC SPLENDIDA	DEPARTURE	PIRAEUS	5/3/2023 18:08
MSC SPLENDIDA	DEPARTURE	PIRAEUS	5/12/2023 15:34
MSC SPLENDIDA	DEPARTURE	PIRAEUS	5/21/2023 16:50
MSC SPLENDIDA	DEPARTURE	PIRAEUS	5/30/2023 15:48
MSC SPLENDIDA	DEPARTURE	PIRAEUS	6/26/2023 13:46
MSC SPLENDIDA	DEPARTURE	PIRAEUS	7/14/2023 15:59
MSC SPLENDIDA	DEPARTURE	PIRAEUS	8/1/2023 15:42
MSC SPLENDIDA	DEPARTURE	PIRAEUS	8/28/2023 15:21
MSC SPLENDIDA	DEPARTURE	PIRAEUS	9/15/2023 15:32
MSC SPLENDIDA	DEPARTURE	PIRAEUS	10/3/2023 15:09
MSC SPLENDIDA	DEPARTURE	PIRAEUS	10/21/2023 15:35

Time At Port(Hours)	Time At Port(Minutes)	
11	27	
7	48	
11	25	
12	57	
11	56	
10	9	
12	24	
12	1	
11	39	
11	45	
11	10	
11	17	
130	**358**	**6 DAYS/136 HOURS**

We come to the conclusion that MSC SPLENDIDA stayed for 6 days with 12 calls. 6 days equals to 136 hours and taking into consideration the table 8 we have :

ENERGY (KWh) = POWER (KW) x TIME (h) = 7500 x 136 = 1.020.000 KWh

CELEBRITY CONSTELLATION

Source: Wikipedia

CELEBRITY CONSTELLATION is a cruise ship of the Viking Cruises company with a total length of 228m, beam 6.45m and the ability to host 930 guests.

From the image below we can see how much time VIKING SKY stayed berthed at the port of Piraeus from 21/5/2023 to 10/9/2023:

CELEBRITY CONSTELLATION – Time at port for year 2023

Vessel Name	Port Call Type	Port At Call	Ata/atd
CELEBRITY CONSTELLATION	DEPARTURE	PIRAEUS	5/21/2023 15:53
CELEBRITY CONSTELLATION	DEPARTURE	PIRAEUS	6/3/2023 15:05
CELEBRITY CONSTELLATION	DEPARTURE	PIRAEUS	6/18/2023 16:23
CELEBRITY CONSTELLATION	DEPARTURE	PIRAEUS	7/13/2023 16:53
CELEBRITY CONSTELLATION	DEPARTURE	PIRAEUS	7/29/2023 14:36
CELEBRITY CONSTELLATION	DEPARTURE	PIRAEUS	8/13/2023 16:28
CELEBRITY CONSTELLATION	DEPARTURE	PIRAEUS	9/10/2023 16:35
CELEBRITY CONSTELLATION	DEPARTURE	PIRAEUS	9/23/2023 15:02
CELEBRITY CONSTELLATION	DEPARTURE	PIRAEUS	10/9/2023 14:24

Time At Port(Hours)	Time At Port(Minutes)	
14	31	
13	16	
15	42	
12	3	
12	50	
14	40	
16	6	
13	59	
12	57	
121	**304**	**6 DAYS/126 HOURS**

We come to the conclusion that CELEBRITY CONSTELLATION stayed for 6 days or 126 hours with 9 calls. 6 days equals to 126 hours and taking into consideration the table 8 we have:

ENERGY (KWh) = POWER (KW) x TIME (h) = 7500 x 126 = 945.000 KWh

VESSEL NAME	HOURS	CALLS	KW	KWh
VIKING SKY	517	13	7500	3.877.500
MSC SPLENDIDA	136	12	7500	1.020.000
CELEBRITY CONSTELLATION	126	9	7500	945.000

On the following table we represent the total KWh of the 3 categories of ships. As we can see, the highest demand is needed from the Cruise ships. This result is expected if we consider the nature of those ships. A/C, lights, equipment and other operations for thousands of passengers and crew members require tens of thousands of kilowatts.

VESSEL TYPE	**TOTAL KWh**
CONTAINER SHIPS	1.574.510
RO-RO	2.547.000
CRUISE SHIPS	5.842.500

Moving on to further investigation of the ships, we will try to determine the total cost of cold iron implementation for each ship. The tool we used is called OPS (Onshore Power Supply). OPS is one of the strategies suggested from the World Port Climate Initiative for reducing the impacts of berthed ships to environment.

The main concept of OPS calculator is to compare the investment operational and ecological cost of cold iron implementation between auxiliary engines.

From various sources and scientific researches, the average cost for shore side electricity equipment and facilities is 750.000€ / Megawatt. As per the cost of retrofitting the vessels with this system, it is estimated to be between 200.000 USD-400.000 USD. So, for every ship of our case we will take into consideration the mean cost which is 300.000 USD.

Having calculated the investment cost of terminals and ships, we will proceed with the operational costs of each vessel, which include:

- Electricity price: 0.023€/KWh as per Eurostat Data browser
- Tax: 0,04€/KWh as per Eurostat Data browser
- Consumption (ton/h): Further to excessive research, auxiliary engine type of each vessel was found. Furthermore, taking into consideration table 8 the Special Fuel Consumption was found for each ship with the help of Maximum Continuous Rating (MCR). MCR is the maximum power output engine can produce while running continuously at safe limits and conditions. (Karan Chopra, 2021). Then the Special Fuel Consumption was converted from g/kWh to tonnes per hour. Known the total days the ships stayed berthed in port of Piraeus, it was easy to find the total fuel consumption.
- Consumption (KW): The electric need of each ship while berthed as given from table 8
- Maintenance per engine (€/h) = -3.0 as per article: Technical analysis and economic evaluation of a complex shore-to-ship power supply system, DanieleColarossi,PaoloPrincipi
- Number of engines: Specific for each vessel.
- Diesel (USD/ton): The price of Marine Gas Oil (MGO) is 899USD/metric tonne.

- EU mix: 5 / Electricity generated by coal, gas and other fossil fuels, (https://ember-climate.org/insights/research/european-electricity-review-2023/).

Estimated % load of MCR (Maximum Continuous Rating) of Main and Auxiliary Engine for different ship activity

Phase	% load of MCR Main Engine	% time all Main Engine operating	% load of MCR Auxiliary Engine
Cruise	80	100	30
Manoeuvring	20	100	50
Hotelling (except tankers)	20	5	40
Hotelling (tankers)	20	100	60

Source: Entec[8]

NEPTUNE OKEANIS

OPERATIONAL COSTS

Input		Yearly costs (€)
Electricity costs		
Electricity price (€/ kWh)	0,23	
tax (€/ kWh)	0,04	9.423.540
Consumption (kW)	1.500	
Saved maintenance		
Maintainance per engine (€/ h)	-3	-139608
number of engines	2	
TOTAL COSTS (€)		**9.283.932**

POLLUTION

Input		pollution units
Electricity source	EU mix	
Pollutants	Emissions (ton)	Pollution units
CO2	12215,7	
NOx	12,2	12.216
PM	0,1	1.340
SO2	16,1	35.321
Total		48.877

OPERATIONAL COSTS

Input terminal		Yearly costs (€)
Fuel costs		
Diesel (USD/ton)	899	38.656.338
Consumption (ton/h)	2,8	
ETS costs		
ETS CO2 price	50	12544
		38.668.882

POLLUTION

Input		pollution units
Fuel	Diesel	
Pollutants	Emissions (ton)	Pollution units
CO2	208481,3	
NOx	4430,2	4.430.227
PM	136,8	1.751.243
SO2	325,8	716.654
Total		6.898.124

Total yearly costs (€)	**29.384.950-**
cost effectiveness (€ / pollution unit)	**4,3-**

Emission reductions electricity	
NOx	100%
PM	100%
SO2	95%
CO2	94%

NEPTUNE THELISIS

OPERATIONAL COSTS		
Input		Yearly costs (€)
Electricity costs		
Electricity price (€/ kWh)	0,23	
tax (€/ kWh)	0,04	6.895.125
Consumption (kW)	1.500	
Saved maintenance		
Maintainance per engine (€/ h)	-3	-102150
number of engines	2	
TOTAL COSTS (€)		6.792.975

OPERATIONAL COSTS		
Input terminal		Yearly costs (€)
Fuel costs		
Diesel (USD/ton)	899	28.284.518
Consumption (ton/h)	2,8	
ETS costs		
ETS CO2 price	50	11200
		28.295.718

POLLUTION		
Input		pollution units
Electricity source	EU mix	
Pollutants	Emissions (ton)	Pollution units
CO2	8938,1	
NOx	8,9	8.938
PM	0,1	981
SO2	11,7	25.844
Total		35.763

POLLUTION		
Input		pollution units
Fuel	Diesel	
Pollutants	Emissions (ton)	Pollution units
CO2	152544,0	
NOx	3241,6	3.241.560
PM	100,1	1.281.370
SO2	238,4	524.370
Total		5.047.300

Total yearly costs (€)	21.502.743-
cost effectiveness (€ / pollution unit)	4,3-

Emission reductions electricity	
NOx	100%
PM	100%
SO2	95%
CO2	94%

NEPTUNE PHOS

OPERATIONAL COSTS		
Input		Yearly costs (€)
Electricity costs		
Electricity price (€/ kWh)	0,23	
tax (€/ kWh)	0,04	753.300
Consumption (kW)	1.500	
Saved maintenance		
Maintainance per engine (€/ h)	-3	-5580
number of engines	1	
TOTAL COSTS (€)		747.720

OPERATIONAL COSTS		
Input terminal		Yearly costs (€)
Fuel costs		
Diesel (USD/ton)	899	2.648.670
Consumption (ton/h)	2,4	
ETS costs		
ETS CO2 price	50	3840
		2.652.510

POLLUTION		
Input		pollution units
Electricity source	EU mix	
Pollutants	Emissions (ton)	Pollution units
CO2	976,5	
NOx	1,0	977
PM	0,0	107
SO2	1,3	2.823
Total		3.907

POLLUTION		
Input		pollution units
Fuel	Diesel	
Pollutants	Emissions (ton)	Pollution units
CO2	14284,8	
NOx	303,6	303.552
PM	9,4	119.992
SO2	22,3	49.104
Total		472.648

Total yearly costs (€)	1.904.790-
cost effectiveness (€ / pollution unit)	4,1-

Emission reductions electricity	
NOx	100%
PM	100%
SO2	94%
CO2	93%

CONTSHIP ECO

OPERATIONAL COSTS		
Input		Yearly costs (€)
Electricity costs		
Electricity price (€/ kWh)	0,23	
tax (€/ kWh)	0,04	1.993.621
Consumption (kW)	170	
Saved maintenance		
Maintainance per engine (€/ h)	-3	-130302
number of engines	1	
TOTAL COSTS (€)		**1.863.319**

OPERATIONAL COSTS		
Input terminal		Yearly costs (€)
Fuel costs		
Diesel (USD/ton)	899	23.194.017
Consumption (ton/h)	0,9	
ETS costs		
ETS CO2 price	50	5472
		23.199.489

POLLUTION		
Input		pollution units
Electricity source	EU mix	
Pollutants	Emissions (ton)	Pollution units
CO2	2584,3	
NOx	2,6	2.584
PM	0,0	284
SO2	3,4	7.472
Total		10.340

POLLUTION		
Input		pollution units
Fuel	Diesel	
Pollutants	Emissions (ton)	Pollution units
CO2	125089,9	
NOx	2658,2	2.658.161
PM	82,1	1.050.755
SO2	195,5	429.997
Total		4.138.913

Total yearly costs (€)	**21.336.170-**
cost effectiveness (€ / pollution unit)	**5,2-**

Emission reductions electricity	
NOx	100%
PM	100%
SO2	98%
CO2	98%

CONTSHIP SEA

OPERATIONAL COSTS		
Input		Yearly costs (€)
Electricity costs		
Electricity price (€/ kWh)	0,23	
tax (€/ kWh)	0,04	6.150.816
Consumption (kW)	1.200	
Saved maintenance		
Maintainance per engine (€/ h)	-3	-56952
number of engines	1	
TOTAL COSTS (€)		**6.093.864**

OPERATIONAL COSTS		
Input terminal		Yearly costs (€)
Fuel costs		
Diesel (USD/ton)	899	39.423.883
Consumption (ton/h)	3,5	
ETS costs		
ETS CO2 price	50	13440
		39.437.323

POLLUTION		
Input		pollution units
Electricity source	EU mix	
Pollutants	Emissions (ton)	Pollution units
CO2	7973,3	
NOx	8,0	7.973
PM	0,1	875
SO2	10,5	23.054
Total		31.902

POLLUTION		
Input		pollution units
Fuel	Diesel	
Pollutants	Emissions (ton)	Pollution units
CO2	212620,8	
NOx	4518,2	4.518.192
PM	139,5	1.786.015
SO2	332,2	730.884
Total		7.035.091

Total yearly costs (€)	**33.343.459-**
cost effectiveness (€ / pollution unit)	**4,8-**

Emission reductions electricity	
NOx	100%
PM	100%
SO2	97%
CO2	96%

ARIANA A

OPERATIONAL COSTS

Input		Yearly costs (€)
Electricity costs		
Electricity price (€/ kWh)	0,23	
tax (€/ kWh)	0,04	1.300.860
Consumption (kW)	1.200	
Saved maintenance		
Maintainance per engine (€/ h)	-3	-12045
number of engines	1	
TOTAL COSTS (€)		**1.288.815**

POLLUTION

Input		pollution units
Electricity source	EU mix	
Pollutants	Emissions (ton)	Pollution units
CO2	1686,3	
NOx	1,7	1.686
PM	0,0	185
SO2	2,2	4.876
Total		6.747

OPERATIONAL COSTS

Input terminal		Yearly costs (€)
Fuel costs		
Diesel (USD/ton)	899	10.958.396
Consumption (ton/h)	4,6	
ETS costs		
ETS CO2 price	50	8096
		10.966.492

POLLUTION

Input		pollution units
Fuel	Diesel	
Pollutants	Emissions (ton)	Pollution units
CO2	59100,8	
NOx	1255,9	1.255.892
PM	38,8	496.447
SO2	92,3	203.159
Total		1.955.498

Total yearly costs (€)	**9.677.677-**
cost effectiveness (€ / pollution unit)	**5,0-**

Emission reductions electricity	
NOx	100%
PM	100%
SO2	98%
CO2	97%

VIKING SKY

OPERATIONAL COSTS		
Input		Yearly costs (€)
Electricity costs		
Electricity price (€/ kWh)	0,23	
tax (€/ kWh)	0,04	13.610.025
Consumption (kW)	7.500	
Saved maintenance		
Maintainance per engine (€/ h)	-3	-40326
number of engines	2	
TOTAL COSTS (€)		13.569.699

OPERATIONAL COSTS		
Input terminal		Yearly costs (€)
Fuel costs		
Diesel (USD/ton)	899	9.172.028
Consumption (ton/h)	2,3	
ETS costs		
ETS CO2 price	50	4784
		9.176.812

POLLUTION		
Input		pollution units
Electricity source	EU mix	
Pollutants	Emissions (ton)	Pollution units
CO2	17642,6	
NOx	17,6	17.643
PM	0,2	1.936
SO2	23,2	51.012
Total		70.591

POLLUTION		
Input		pollution units
Fuel	Diesel	
Pollutants	Emissions (ton)	Pollution units
CO2	49466,6	
NOx	1051,2	1.051.164
PM	32,5	415.519
SO2	77,3	170.041
Total		1.636.725

Total yearly costs (€)	4.392.887
cost effectiveness (€ / pollution unit)	2,8

Emission reductions electricity	
NOx	98%
PM	100%
SO2	70%
CO2	64%

CELEBRITY CONSTELLATION

OPERATIONAL COSTS		
Input		Yearly costs (€)
Electricity costs		
Electricity price (€/ kWh)	0,23	
tax (€/ kWh)	0,04	2.296.350
Consumption (kW)	7.500	
Saved maintenance		
Maintainance per engine (€/ h)	-3	-3402
number of engines	1	
TOTAL COSTS (€)		2.292.948

OPERATIONAL COSTS		
Input terminal		Yearly costs (€)
Fuel costs		
Diesel (USD/ton)	899	538.278
Consumption (ton/h)	0,8	
ETS costs		
ETS CO2 price	50	1152
		539.430

POLLUTION		
Input		pollution units
Electricity source	EU mix	
Pollutants	Emissions (ton)	Pollution units
CO2	2976,8	
NOx	3,0	2.977
PM	0,0	327
SO2	3,9	8.607
Total		11.910

POLLUTION		
Input		pollution units
Fuel	Diesel	
Pollutants	Emissions (ton)	Pollution units
CO2	2903,0	
NOx	61,7	61.690
PM	1,9	24.386
SO2	4,5	9.979
Total		96.054

Total yearly costs (€)	1.753.518
cost effectiveness (€ / pollution unit)	20,8

Emission reductions electricity	
NOx	95%
PM	99%
SO2	14%
CO2	-3%

MSC SPLENDIDA

OPERATIONAL COSTS		
Input		Yearly costs (€)
Electricity costs		
Electricity price (€/ kWh)	0,23	
tax (€/ kWh)	0,04	3.304.800
Consumption (kW)	7.500	
Saved maintenance		
Maintainance per engine (€/ h)	-3	-4896
number of engines	1	
TOTAL COSTS (€)		**3.299.904**

POLLUTION		
Input		pollution units
Electricity source	EU mix	
Pollutants	Emissions (ton)	Pollution units
CO_2	4284,0	
NOx	4,3	4.284
PM	0,0	470
SO_2	5,6	12.387
Total		17.141

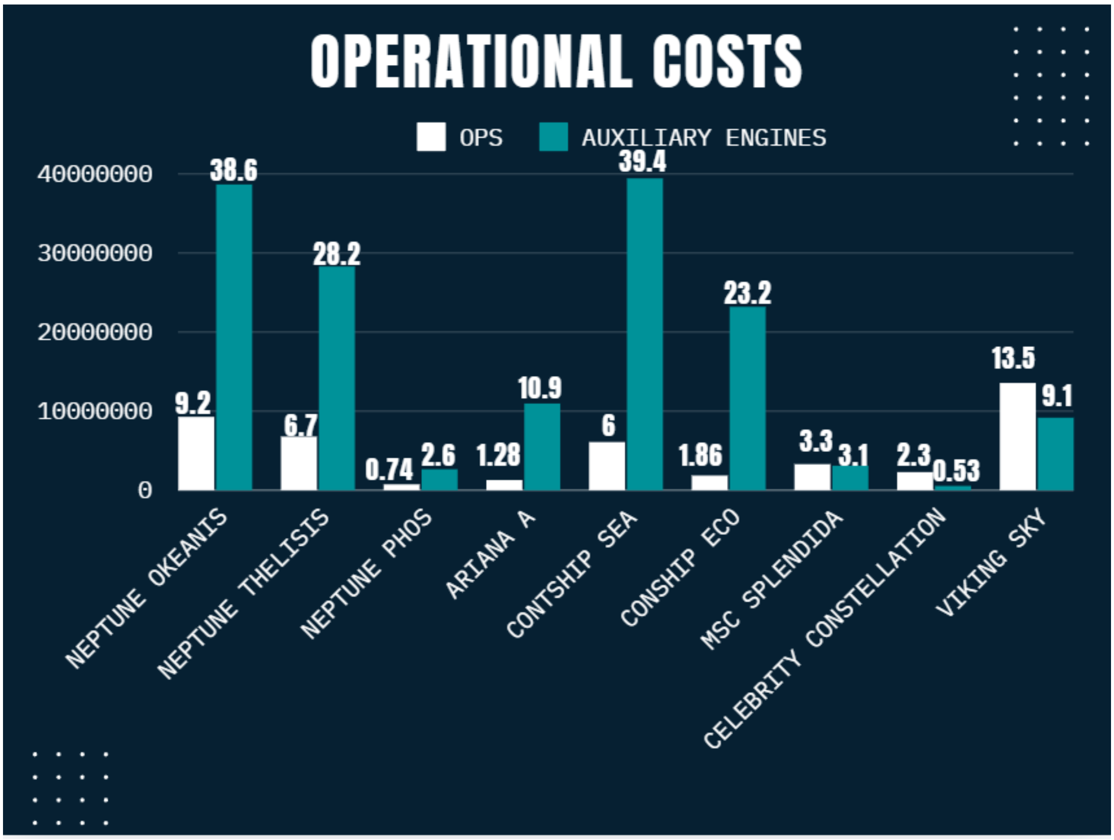
OPERATIONAL COSTS		
Input terminal		Yearly costs (€)
Fuel costs		
Diesel (USD/ton)	899	3.098.659
Consumption (ton/h)	3,2	
ETS costs		
ETS CO_2 price	50	6144
		3.104.803

POLLUTION		
Input		pollution units
Fuel	Diesel	
Pollutants	Emissions (ton)	Pollution units
CO_2	16711,7	
NOx	355,1	355.123
PM	11,0	140.378
SO_2	26,1	57.446
Total		552.948

Total yearly costs (€)	**195.101**
cost effectiveness (€ / pollution unit)	**0,4**

Emission reductions electricity	
NOx	99%
PM	100%
SO_2	78%
CO_2	74%

On the following chart we can see the comparison between OPS and Auxiliary engines cost of each vessel

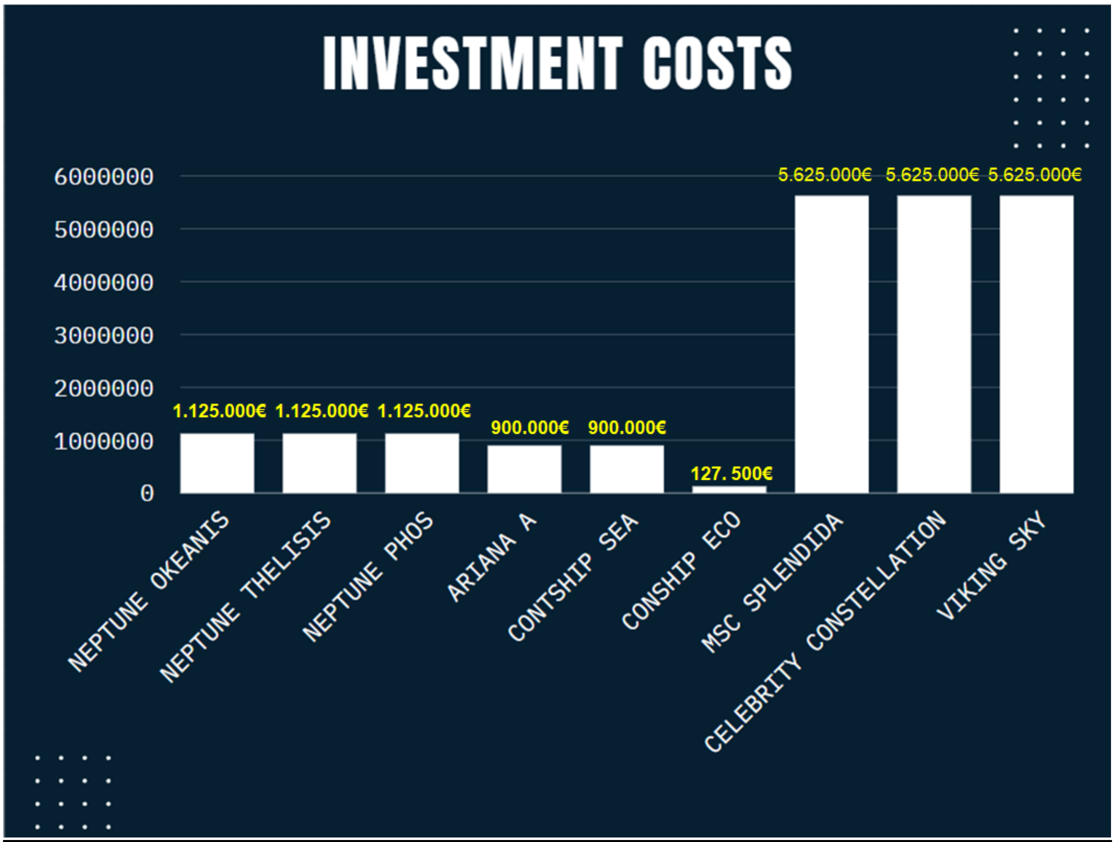


Proceeding to the calculation of investment costs, we multiply the average cost of shore side electricity equipment and facilities being around 750.000€/MW and the required power supply of each vessel. Therefore, we have the following results for every ship:

RO-ROs	**COST**
NEPTUNE OKEANIS	1.125.000€
NEPTUNE THELISIS	1.125.000€
NEPTUNE PHOS	1.125.000€

CONTAINER SHIPS	**COST**
CONTSHIP ECO	127.500€
CONTSHIP SEA	900.000€
ARIANA A	900.000€

CRUISE SHIPS	COST
VIKING SKY	5.625.000€
CELEBRITY CONSTELLATION	5.625.000€
MSC SPLENDIDA	5.625.000€



As we can see from the above table and bar chart results, cruise ships have a significant higher cost of energy due to the fact that they generate electricity for cooking and lighting for a large amount of passengers and personnel. Also power is distributed around the ship to cabins, restaurants and entertainment via hundreds of kilometers of cables. (cruises.com).

Despite the economic benefits that OPS offer to all the involved parties, there are many environmental advantages as well. Nevertheless in order to have a “greener’’ method of energy supply end-to-end, the production of energy should be sustainably. Continuing with OPS Calculator, the following chart shows the different emission reductions electricity produced with different electricity source.

	RO/ROs		
VESSELS	**NEPTUNE OKEANIS**	**NEPTUNE THELISIS**	**NEPTUNE PHOS**
ELECTRICITY SOURCE / **POLLUTANTS**	**NATURAL GAS** / **COAL** / **WIND-WATER-NUCLEAR** (TONS)		
CO_2	**14030,6/31481,6/0,0**	**10266,1/23034,8/0,0**	**1121,6/2516,6/0,0**
NO_x	**12,3/14,2/0,0**	**9,0/10,4/0,0**	**1,0/1,1/0,0**
PM	**0,0/0,1/0,0**	**0,0/0,1/0,0**	**0,0/0,0/0,0**
SO_2	**0,5/12,9/0,0**	**0,4/9,5/0,0**	**0,0/1,0/0,0**

	CONTAINER SHIPS		
VESSELS	**CONTSHIP ECO**	**CONTSHIP SEA**	**ARIANA A**
ELECTRICITY SOURCE / **POLLUTANTS**	**NATURAL GAS** / **COAL** / **WIND-WATER-NUCLEAR** (TONS)		
CO_2	**2968,3/6660,2/0,0**	**9157,9/20548/0,0**	**1936,8/4345,8/0,0**
NO_x	**2,6/3,0/0,0**	**8,1/9,3/0,0**	**1,7/2,0/0,0**
PM	**0,0/0,0/0,0**	**0,0/0,1/0,0**	**0,0/0,0/0,0**
SO_2	**0,1/2,7/0,0**	**0,4/8,4/0,0**	**0,1/1,8/0,0**

	CRUISE SHIPS		
VESSELS	**VIKING SKY**	**CELEBRITY CONSTELLATION**	**MSC SPLENDIDA**
ELECTRICITY SOURCE	**NATURAL GAS** / **COAL** / **WIND-WATER-NUCLEAR** (TONS)		

POLLUTANTS			
CO2	**20263,8/4567,6/0,0**	**3419,0/7671,5/0,0**	**4920,5/11040,5/0,0**
NOx	**17,8/20,5/0,0**	**3,0/3,5/0,0**	**4,3/5,0/0,0**
PM	**0,0/0,2/0,0**	**0,0/0,0/0,0**	**0,0/0,0/0,0**
SO2	**0,8/18,7/0,0**	**0,1/3,2/0,0**	**0,2/4,5/0,0**

As we can see from the above tables, the source with zero thus the most environmental friendly footprint is wind, water and nuclear powered. This is an obvious outcome because non of these sources use carbon fuel. In second place comes natural gas with almost half the amount of CO_2 compared to coal. The least environmental friendly source is coal with a huge amount especially of CO_2 emissions.

CONCLUSIONS

In current thesis the environmental and economic benefits of onshore power supply were analyzed. It's a great way of minimizing Green House Gases, noise and pollutants, enhancing the quality of air at near coast locations.

Nonetheless it is a project with high cost of implementation as for shipping companies (retrofit/newbuilding ships) so for ports (structures/cost of maintanance).

Another major concern is the consistency in the use of environmental friendly sources for electricity production. In order for cold ironing to be considered a green way of power supply, the whole process of electricity production must be green and that can be accomplished only with the use of renewable energy sources.

Another major issue is the limited number of ports with proper infrastructures to provide cold ironing services. Thus, small ports probably will not make use of this method.

In search for the most cost effective and environmental friendly way for port of Piraeus, onshore power supply tends to be the most suitable choice. Taking into account wind water or nuclear power is the source for electricity, then we accomplish zero environmental footprint.

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