European Commission

Clean energy for EU islands:
Energy Upgrades in the Port Infrastructure
Thira, Greece

Clean energy
for EU islands

Energy Upgrades in the Port Infrastructure Thira, Greece

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Clean energy for EU islands

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Glossary

HV	High Voltage
HVSC	High Voltage Shore Connection
LVSC	Low Voltage Shore Connection
MV	Medium Voltage
NER	Neutral Earthing Resistor
OPS	Onshore Power Supply
RoRo	Roll on, Roll off
RO-PAX	Roll on/Roll off passenger ferry
SSE	Shore-Side Electricity

Introduction

Thira applied with the project *Energy Upgrades in the Port Infrastructure of Thira* for the second call for technical assistance from the Clean energy for EU islands secretariat in April 2022. A Scope Definition meeting took place on 31 May 2022 between DAFNI, Protasis and the Islands secretariat to agree on the final scope of the project and define the tasks. This report is the final deliverable of the project.

Thira (Santorini) is a Greek island in the southern Aegean Sea, receiving around 2 million tourists per year. A large part of these tourists arrives by cruises. Around 800 000 cruisers per year reach Santorini. The main harbour of the island (Athinios) cannot accommodate large cruise ships, so most ships use their engines to hold their positions and tourists are brought on land by ferries. The transport of passengers and vehicles from Santorini (Thira) to the neighbouring island of Thirassia is also performed by a ferry. Due to this presence of cruise ships and ferries, Santorini is among the top European locations affected adversely by air pollution emitted by cruise ships.

To mitigate these issues, cold ironing could offer a solution. This technology is an anti-pollution measure, to reduce air pollution produced from diesel generators, using shore electric power as an alternative. It also reduces noise pollution, increases onboard comfort, and reduces the lifecycle cost by reducing fuel consumption and maintenance cost. Cold ironing is a process enabling a ship to turn off its engines while berthed as it plugs into an onshore power source.

With this report, the Islands secretariat assesses cold ironing applications for the ferry responsible for the Thira-Thirasia connection. This is done by providing a literature review, extracting lessons learned for port infrastructure requirements and combined with best practice examples from European ports (on islands). This cold ironing for the Thira-Thirasia ferry could be further investigated and possibly expanded to, at first instance, the ferries between the cruises and in a second instance the cruises themselves.

Assessment

Island description

Santorini or Thira (or Strogyli in the past), is an island belonging to the Cyclades islands and is located in the southern Aegean Sea, west of Anafi, south of Ios and north of Crete. Thira is also the regional unit comprising several islands, including Thira, Thirassia, Aspronissi, Palea and Nea Kameni in the southernmost part of the Cyclades[1]. Thira island is 128 nautical miles from the port of Piraeus and has an area 76.19 square kilometres[2].

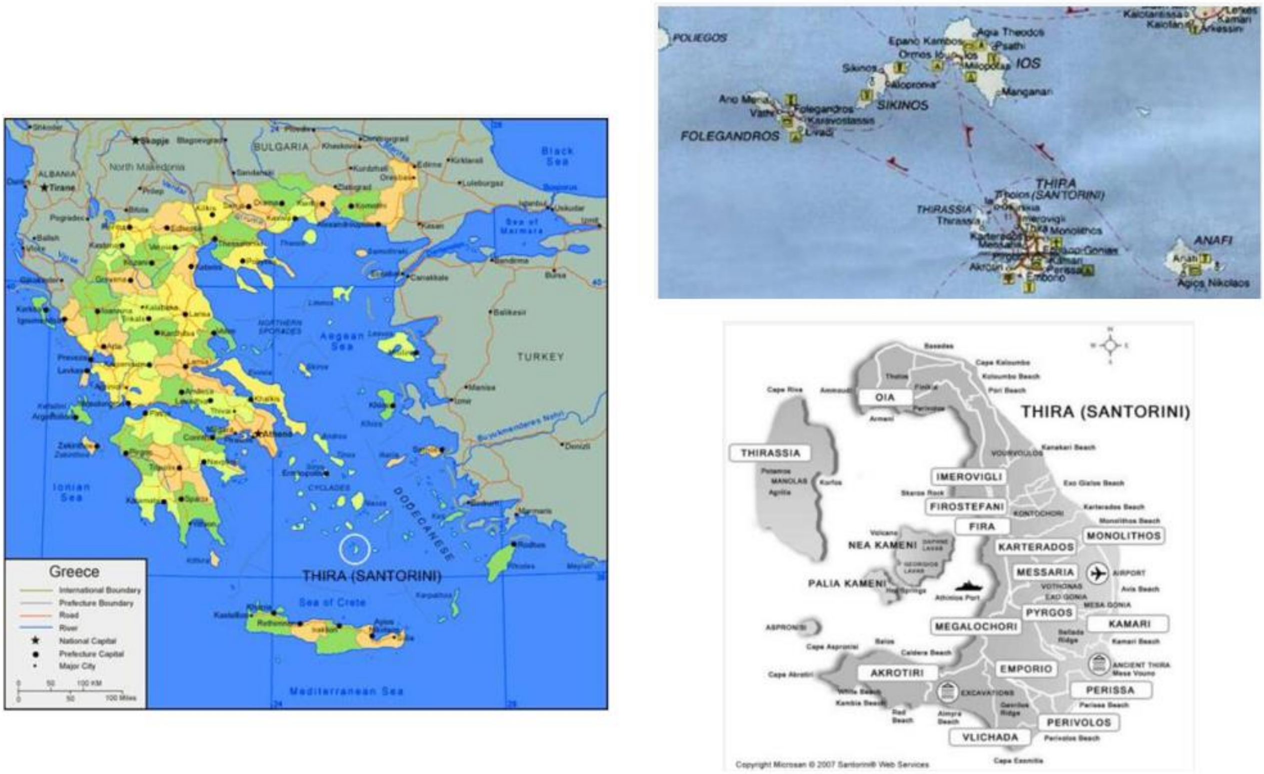

Figure 1 - Thira Location - Source

The approximate population of Santorini is 15 500 permanent residents, with around 2 million tourists arriving at the island every year[3].

[1] https://www.visitgreece.gr/islands/cyclades/santorini/
[2] http://5a.arch.ntua.gr/project/12818/13588
[3] https://www.greeka.com/cyclades/santorini/about/#:~:text=The%20population%20of%20Santorini%20is,in%20the%20tourism%20%26%20hospitality%20industry.

Transport to and from the island

The International Airport of Thira (JTR) has domestic flights from Athens daily and is also linked with several international airports around Europe with direct flights from the United Kingdom, France, Germany, the Netherlands, Spain, Italy, and more[4].

Santorini is also reachable by ferry from Athens and from several islands of the Aegean (Mykonos, Crete, Paros, Naxos & more)[5]. Ferries depart on a daily basis from the port of Piraeus in Athens. During summer, ferries depart from Rafina port, too. Rafina is smaller but lies closer to the International Airport of Athens. Santorini is connected via ferry with many Cyclades islands, a few islands of the Dodecanese complex, and Crete.

Santorini is the most popular cruising destination of all Greek islands, with high season being from July through August[6]. The touristic season runs from March to December, but the majority of the cruise ships (peak season) dock from May to October. The island receives more than 800 000 cruisers per year. As Santorini was getting too crowded with visitors, in 2017 the port authority limited the number of cruise passengers who could visit the island to 12 000 per day.[7] In 2018, this limit was further pushed down to 8 000 per day. The island's cruise port schedule for 2018 had a total of 439 ship calls (409 in 2017). For season 2019 592 ship calls were handled with 870 000 passengers[8].

Santorini's Cruise Port is located at the bottom of the Caldera Cliffs in Fira, the capital of Santorini, which does not have a cruise terminal and visitors are tendered ashore by small boats[9]. The main harbour of the island (Athinios) cannot accommodate large cruise ships, so most ships use their engines to hold their positions into the cone of the volcano (now extinct) and make adjustments at times. Thus, cruise passengers are brought to land with ferries.

Figure 2 - Map of Thira and its ports - Source

The transport of passengers and vehicles from Santorini (Thira) to the neighbouring island of Thirassia is performed by the F/B Kato Nisi ferry which has the capacity to carry 200 passengers and about 50 vehicles. It normally runs three to four times a day and stops at both ports in Thirasia, namely Riva and Korfos. This ferry has an annual energy demand of 91.62 MWh and emits 981 tonnes of CO_2 emissions annually. Annex A contains more information on this Thira-Thirassia ferry. A picture of the ship is provided in Figure 3.

[4] https://www.greeka.com/cyclades/santorini/travel/
[5] https://www.greeka.com/cyclades/santorini/travel/
[6] https://www.cruisemapper.com/ports/santorini-island-port-69#:~:text=In%202018%2C%20this%20limit%20was,ship%20calls%20with%20~870%2C000%20passengers.
[7] https://www.santoriniport.com/category/timetables/
[8] https://www.cruisemapper.com/ports/santorini-island-port-69#:~:text=In%202018%2C%20this%20limit%20was,ship%20calls%20with%20~870%2C000%20passengers.
[9] https://www.santoriniport.com/


Figure 3 - Kato Nisi Ferry[10]

According to the data provided by the island representatives and summarised in Annex A, the ferry has an average power consumption of 5.1 kW during hotel (i.e. when the ferry is berthed and demand mainly arises from auxiliary functions such as lighting) and of 149.6 kW during transport.

Accounting for the weekly and seasonal schedules, the annual energy demand of the ferry can be estimated and broken down into the following:

- Hotel consumption: 59.4 MWh
- Travel consumption: 32.2 MWh

Nevertheless, many other types of ferries berth at the port of Thira, with varying sizes and likely different consumption levels. For example, Adamantios Korais and Blue Star Chios have a deadweight tonnage of 8324 t and 13955 t respectively, which is more than an order of magnitude larger than Kato Nisi.

[10] https://www.marinetraffic.com/en/photos/of/ships/shipid:872314/ships

Cold ironing

When ships are berthed, they use their auxiliary engines to support some basic functions while generating SOx, NOx, CO_2, and particle discharge as well as noise and vibration[11]. Santorini is among the top European locations affected adversely by air pollution emitted by cruise ships, according to the European Federation for Transport and Environment[12]. Tests carried out found that concentrations of dangerous ultrafine particles were up to 100 times higher near the ships than in surrounding areas[13].

Cold Ironing is the process of providing shoreside electrical power to a ship at berth, while its main and auxiliary engines are turned off[14]. During cold ironing, the ship plugs into an onshore power source. The ship's power load is then transferred to the shore-side power supply without disrupting onboard services, as shown in Figure 4[15].

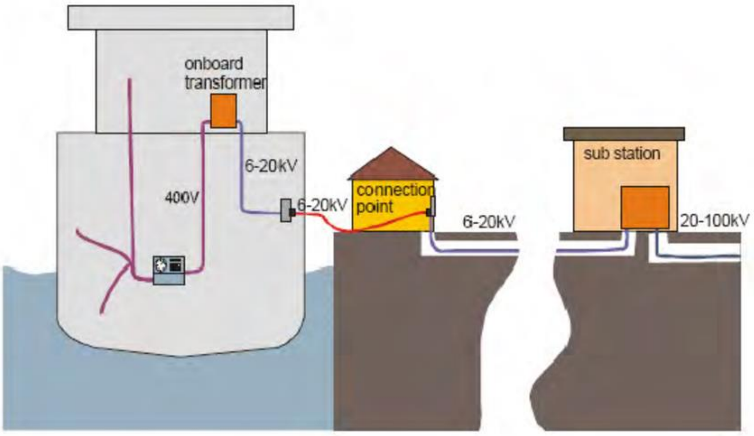

Figure 4 - Typical cold ironing scheme - Source

Cold ironing also:

- Has a positive impact on noise pollution.
- Increases the onboard comfort while berthed.
- Reduces lifecycle cost by fewer fuel consumption and maintenance cost.

This section assesses the cold ironing applications for the ferry responsible for the Thira-Thirasia connection. This is done by providing a literature review, extracting lessons learned for port infrastructure requirements and combined with best practice examples from European ports (on islands). This cold ironing for the Thira-Thirasia ferry could be further investigated and possibly expanded to, at first instance, the ferries between the cruises and in a second instance the cruises themselves.

Directives and standards

The Directive 2014/94/EU of the European Parliament and of the Council of 22 October 2014 on the deployment of alternative fuels infrastructure[16], or 'Directive on Alternative Fuels Infrastructure (DAFI)' was adopted by the European Parliament and the Council on 29 September 2014. The Directive requires all ports to have cold ironing provision by the end of 2025:

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[11] https://safety4sea.com/cm-cold-ironing-the-role-of-ports-in-reducing-shipping-emissions/
[12] https://www.transportenvironment.org/wp-content/uploads/2021/07/One-Corporation-to-Pollute-Them-All_English.pdf
[13] https://www.independent.co.uk/climate-change/news/air-pollution-santorini-greek-island-cruise-ships-nabu-tourism-a8550031.html#:~:text=Huge%20spikes%20in%20toxic%20air,ships%20than%20in%20surrounding%20areas.
[14] https://safety4sea.com/cm-cold-ironing-the-role-of-ports-in-reducing-shipping-emissions/
[15] https://safety4sea.com/cm-cold-ironing-the-role-of-ports-in-reducing-shipping-emissions/
[16] Available here: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32014L0094

Article 4
Electricity Supply for transport
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.

The technical standard IEC 80005-3 provides guidelines for the design, construction, testing, and commissioning of cold ironing, also known as shore-to-ship power systems, or Alternative Maritime Power (AMP). The standard applies for shore connection systems not exceeding 1 MVA, but beyond 300 V and 125 A per cable. Therefore, while the principles are valid for all cold ironing concepts, the IEC does not fully apply to the smallest harbours where the power needs may be smaller, as may be the case of Thira[17]. As pinpointed earlier though, the harbour of Thira also hosts larger ferries than the Kato Nisi. Such ferries fall under the prescriptions of the standard.

This standard focuses on ensuring the safety, reliability, and performance of the power supply systems while also addressing environmental concerns. It provides detailed requirements and recommendations for the following aspects of shore-to-ship power systems:

- <u>Power electronics equipment</u>: The standard covers the design, construction, and testing of power electronic equipment that converts the shore-side electrical power to the voltage and frequency used on the ship.
- <u>Control and protection systems</u>: The standard also covers the design, construction, and testing of the control and protection systems that ensure the safe and reliable operation of the shore-to-ship power system. This includes the protection of the ship's electrical system and equipment against over-currents, short-circuits, and other abnormal conditions.
- <u>Cabling and connections</u>: The standard covers the design, construction, and testing of the cabling and connections between the shore-side equipment and the ship's electrical system. This includes the selection of cable materials, insulation, and over-current protection.
- <u>Safety and environmental requirements</u>: The standard addresses safety requirements such as fire protection, personal protection, and environmental protection. It also covers environmental concerns related to the potential impact of the shore-to-ship power system on the surrounding area.

[17] As from the data received, the full demand of all ships berthed at the port is unknown. However, from the size of the port, it seems unlikely to exceed the threshold of 1MVA.

Literature review

Several papers and articles have been published on the topic of cold ironing. Since the EU requires European ports to provide facilities to enable cold ironing by 2025 (via Directive 2014/94/EU), many of those papers focus on policy and regulation. While those may be interesting for a conceptual perspective, below we provide an overview of standards, papers, and articles with a focus more on technical and economic aspects.

Thalis P.V.Zis (2019)[18] conducted a literature review of recent academic work in the field and presents the status of this technology worldwide and the current barriers for its further implementation. This paper constructs a quantitative framework for the examination of the technology considering all stakeholders. The methodology can be useful to port and ship operators in examining the benefits of using cold ironing as an emissions reduction action. Illustrative case studies are presented that consider the perspective of ship operators of various ship types, and terminal operators that opt to invest in shore power facilities.

Alexander Innes and Jason Monios (2018)[19] examined the feasibility of installing cold ironing in a medium sized port with several small berths, based on the case of Aberdeen.
The port of Aberdeen is of medium size, with ship traffic orders of magnitude larger than what was identified for the Port of Thira: Aberdeen has a total hotelling energy demand of more than 2 900 kW for only the nine largest ships visiting the harbour. Individual ships usually have a hotelling consumption of more than 100 kW. Design details are drafted based on the recommendations of the IEC85005-3:2014 which does not apply for systems with a voltage lower than 300 V or a current consumption lower than 125 A per cable. Therefore, design considerations are only partly relevant for smaller island harbours. The relevant barriers identified in the paper are: (1) Various operating frequencies and voltages used by ships from different countries, and (2) Large capital expenditures for ship owners to allow for cold ironing.

Other studies also investigated the configurations and designs accessible for cold ironing. Sciberras EA et al (2016)[20] for example looked at the various electrical configurations available for cold ironing of berthed vessels. They present a methodology regarding the quantitative assessment of various shore supply electrical topologies by modelling different shore network configurations and using power profiles from a Roll-on Roll-off (RoRo)[21] port in the north-west of Spain. They utilised a search algorithm to identify the optimal configurations in terms of system cost and emissions produced. Shoreside generation using liquefied natural gas as an alternative fuel was also considered as a complement to cold ironing. They conclude that for the implementation of shipside, onshore, or shoreside power supply, significant capital expenditure is needed and the cost-effectiveness thereof needs an in-depth operational study taking into account the size, frequency, and duration of ships visiting a particular port.

Javier Dorta Herrera[22] from the University of La Laguna discussed specific requirements, challenges and advantages of cold ironing in the Canary Islands. Based on ongoing projects on

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[18] Thalis P.V. Zis, Prospects of cold ironing as an emissions reduction option, Transportation Research Part A: Policy and Practice, Volume 119, 2019, Pages 82-95, ISSN 0965-8564, https://doi.org/10.1016/j.tra.2018.11.003

[19] Alexander Innes, Jason Monios, Identifying the unique challenges of installing cold ironing at small and medium ports – The case of Aberdeen, Transportation Research Part D: Transport and Environment,
Volume 62, 2018, Pages 298-313, ISSN 1361-9209, https://doi.org/10.1016/j.trd.2018.02.004

[20] Cold ironing and onshore generation for airborne emission reductions in ports, Sciberras EA, Zahawi B, Atkinson DJ, Juandó A, Sarasquete A., Proceedings of the Institution of Mechanical Engineers, Part M: Journal of Engineering for the Maritime Environment. 2016;230(1):67-82, https://doi.org/10.1177/1475090214532451

[21] RoRo stands for roll-on / roll-off which means it's a vessel that has been designed to carry wheeled cargo

[22] https://riull.ull.es/xmlui/bitstream/handle/915/20836/Cold%20Ironing%20en%20Canarias.pdf?sequence=1&isAllowed=y

these islands, this paper provides, among others, an overview of the infrastructural requirements in the port to provide cold ironing. It presents a detailed assessment of cold ironing in the port of Tenerife which can be used as a case study. It also assesses the electrical power demand of ships in ports and delivers an overview of the approximate differences in power required by each type of vessel, as shown in the table below.

Table 1 - Estimated electrical power for each type of ship. Source: Ericsson & Fazlagic[23]. (2008)

	Estimated power required for berthing (kW)	Peak power required (kW)
Container ship	1 200	8 000
Cruise	7 500	11 000
Ro-Ro	1 500	2 00
Tanker	1 400	2 700

A. Rolán et al. (2019)[24] surveyed research developments on cold ironing in order to show the state-of-the-art on the problem of greenhouse gases emitted by ships while docked and how to tackle it. Their study proposes the use of a cold ironing system in the port of Barcelona, where the power generation is entirely given by renewable energy systems (wind turbines and photovoltaic panels). The idea is to contribute to the wide spread of cold ironing within smart port microgrids to achieve the goal of zero emissions from berthed ships. The infrastructure requirements presented in this paper are utilised in the section below.

Lloyd's Register's Rules and Regulations[25] set appropriate standards for the design, construction and lifetime maintenance of ships, offshore units and land-based installations. The Rules and Regulations for the Classification of Ships includes, among others a Part 7 titled 'Other Ship Types and Systems'. Chapter 13 thereof deals with On-Shore power supply.

Finally, the European Maritime Safety Agency published a guide to port authorities and administrations to assist them in complying with the requirement to provide short-side electricity supply by 2025. The guide provides an extensive overview of equipment technologies and equipment available for shore-side electricity infrastructure projects and provides guidelines for project implementation and safe and reliable operation[26].

Infrastructure requirements and implementation

Based on the above papers, articles, and standards, the typical infrastructural requirements for cold ironing in port medium-sized ports are summarised below.

- Connection to the island electrical grid, which generally operates at higher voltages.
- A local substation and transformer that reduces the voltage to the ships' operational voltage (typically 400 V to 690 V).
- A frequency converter if ships operate at various frequencies (this is however unlikely in Thira).
- A distribution system for the network to reach all the berths, with their respective counters.

[23] Shore-side power supply - a feasibility study and a technical solution for an on-shore electrical infrastructure to supply vessels with electrical power while in port, https://hdl.handle.net/20.500.12380/174062
[24] Integration of Cold Ironing and Renewable Sources in the Barcelona Smart Port, A. Rolán, P. Manteca, R. Oktar and P. Siano, EEE Transactions on Industry Applications, vol. 55, no. 6, pp. 7198-7206, Nov.-Dec. 2019, 10.1109/TIA.2019.2910781
[25] Lloyd's Register, OPS Rule requirements Part 7 Chapter 13 – Lloyds' register rules and regulations, https://www.lr.org/en/rules-and-regulations-for-the-classification-of-ships/
[26] EMSA, 2022, Shore-Side Electricity, Guidance to Port Authorities and Administrations

- A cable hoisting system to avoid the handling of medium or high-voltage cables. For example, the installation of cranes that can raise and lower the cables with tides.
- A connector in the ship in which the port cable is plugged.

The essential equipment to provide electricity to berthed ships consists of a step-down transformer, a power converter, a step-up transformer, a shore-to-ship cable, a shore-side switchboard, and a ship-side switchboard, as depicted in Figure 5.

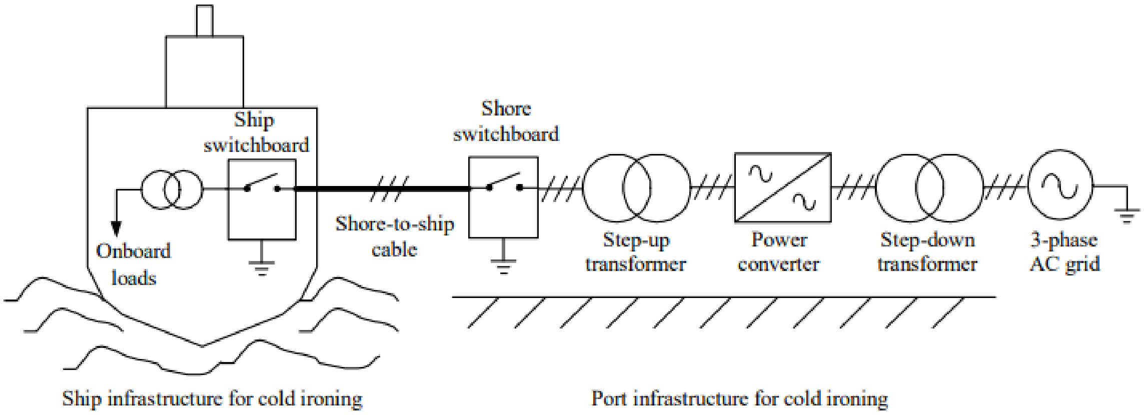

Figure 5 - Infrastructure requirements of a cold ironing system - Source: Rolán et al. (2019)

Detailed technical requirements can be defined upon conceptual design based on the characteristics of the harbour. First, the expected energy demand needs to be calculated for each berth, along with frequency and voltage requirements based on the historical vessel call data at the harbour. Electrical configurations can then be modelled using a modelling software suite such as ERACS or PowerFactory. Upon design, detailed bill of quantities and expected costs can be inferred.

The following sections provide guidance on the type of infrastructure, design, and implementation considerations for each of the main components identified above. The descriptions are based on the guidance from the European Maritime Safety Agency [27].

Power source

The source of power for the Shore-Side Electricity (SSE) system shall be designed to provide electricity with defined parameters such as current, voltage, phase, and frequency. The operating frequencies of the ship and shore systems should match, otherwise a frequency converter should be used. Different voltage nominal values may be considered for ships operating in certain berths. The source of power is a critical element for the feasibility, sustainability, and security of the SSE energy supply chain. Depending on the available sources and the energy mix of the island, the power source may be:

- The national electricity distribution system,
- Port generators,
- Renewable energy plants,
- Stationary energy storage.

[27] EMSA, 2022, Shore-Side Electricity, Guidance to Port Authorities and Administrations

One challenge in developing onshore power supply (OPS) for ships lie in the multiplicity of voltages and frequencies used by ships. Depending on the ship size and use, voltage may vary from less than 440 V (fishing ships, containerships, RO-PAX, etc.) up to 11 kV (cruise ships, larger containerships, and passenger ships). Technical information on the voltage level of the Kato Nisi ferry has not been received. However, considering the electricity consumption during hotel and transport, the voltage level is likely to be 400 V or 690 V. However, since many other ferry types berth at the port, the system shall be able to accommodate for different voltage levels, likely beyond 1 kV.

The port authorities should consider combining different power sources for onshore electricity supply projects and integrating them into the wider range of energy demand and supply in the area. For the integration of renewable energy sources with the island grid, one shall assess the local availability of renewable energy, the feasibility of high or medium voltage connection, and the total ship power demand, in order to design the system based on the whole fleet visiting the harbour.

The connection of the port to the utility network should follow an agreed project, reflecting specific user requirements, including maximum supply size, total installed power, location for the reception substation, and type of metering equipment.

Power cables

The primary function of Medium (MV) and High Voltage (HV) cables is to transfer electrical power between designated locations, while meeting performance and environmental conditions, and also insulating energised components from earthed structures. These cables are used in transmission line infrastructure equipment, and the HV electricity infrastructure within a port area will depend on factors such as the port area layout, incoming transmission lines, cold ironing connection points, and different berth locations.

The routing of HV cables in a port area is an important aspect to consider, as the local infrastructure and safety must be taken into account. The main aspects that need to be considered when it comes to distribution cabling, are:

- Identification of HV electrical distribution/transmission system
- Conductor Sizing and Protection
- Installation requirements for cable systems
- Determination of the smallest allowable cross-sectional area
- Short circuit current calculation
- Protective Earthing conductor design
- Neutral conductor design
- Equipotential conductor design

The present section highlights the key aspects that are related to the distribution cabling infrastructure, not covered by the IEC/IEEE 80005-1. Only general principles are presented and, where technical aspects are indicated, the relevant standard/reference document is also indicated. General best practice principles are indicated with a view to the case of SSE installations.

The major components of an HV distribution cable system include:

- Cable (single or multi-core)
- Connections
- Terminations at substations
- Cable link boxes - Earthing and bonding system to manage safety and minimize losses
- Monitoring system components (for cable temperature monitoring and joint Partial Discharge (PD) measurements)

Cabling can be routed into and within the port area in different ways, depending on the local infrastructure aspects. Amongst the key aspects to consider are the mitigation of mechanical, fire, and occupational hazards, ensuring a safe distribution of electrical power throughout the different substations and SSE connection point in the port area. The underground routing of HV cables within the port area is generally preferred for safety and infrastructure reasons.

Protection systems

The system shall include devices to protect both the equipment, the installed network, and the operator. The system shall follow a monitoring-alarm-trip principle and follow the prescriptions of the IEC80005-1, sections 6.3, 6.5.4, 8.3.3, 8.5.4.

Substations

Substations house important, safety critical, and sensitive equipment in the SSE port grid, and the layout, location, and degree of protection are fundamental for the resilience of the cold ironing at berth. The number of substations is a direct function of the architectural choices and topologies for the cold ironing grid, such as the levels of voltage step-down transformation and/or frequency conversion equipment. There are four types of substations: indoor within a building, outdoor fixed, outdoor mobile in a modular containerized unit and outdoor without housing, with outdoor substations being the preferred option due to the flexibility for installation and ease of access in case of cold ironing applications. The substation equipment includes the connection to the utility, internal HV/MV and LV interconnections, earthing circuits, power transformers, switchgear, and protection and monitoring devices.

The substations shall be designed in accordance with the EC 62271-202 standard (IEC 62271-202:2014 High-voltage switchgear and control gear.

Switchboards

A switchboard is an assembly of one or more panels containing switches that direct electricity from one or more sources of supply to several consumers or other switchboards. Inside a switchboard, there are busbars (flat strips of copper or aluminium) to which the switchgear is connected, which carry large currents through the switchboard and are supported by insulators. The operator is protected from electrocution by safety switches and fuses, and there may also be controls for the supply of electricity to the switchboard and gauges for frequency and current intensity. Switchboards incorporate elements such as incoming and outgoing cables, circuit conductors, internal busbars, main isolating switches, circuit breakers, fuses, protection relays, metering equipment, over-voltage and current surge protection, earth fault monitoring, fault detection equipment, and earth switches.

The number of switchboards in SSE infrastructure applications will depend on the architecture of the whole system, such as the number of interfaces, substations, and energy storage elements. A minimum number of switchboards can be considered based on standards IEC/IEEE 80005-1 and 3. The SSE supply switchboard should be located at a convenient location, taking into consideration the port/terminal SSE infrastructure design, and can be located at the incoming station, central substation, or berth station. The HV circuit breaker on the secondary side of the transformer must open all insulated poles in the event of certain conditions, and the protection systems should have battery back-up for at least 30 minutes. The SSE incoming switchboard and ship receiving switchboard should be designed, manufactured, and tested in accordance with a recognised standard such as IEC 62271-200. These switchboards should be equipped with various protections and instruments such as over-voltage, earth fault overcurrent, and earth fault detector.

Circuit breakers

Circuit breakers are a type of switchgear used to control and protect electrical installations. They are the only switchgear that can simultaneously satisfy all the basic functions necessary for an electrical installation, such as protection and control. Additionally, circuit breakers can provide a wide range of other functions, like indication, undervoltage tripping, and remote control, through auxiliary units. This makes circuit breakers/disconnectors the basic unit of switchgear for any electrical installation, including cold ironing electrical installations.

The choice of a circuit breaker for applications in SSE-OPS installations should comply with the technical and operating requirements laid out in IEC/IEEE 80005-1/3. These include the electrical characteristics of the installation, environmental factors, and the prospective short-circuit current at the point of installation. The rated making capacity of the circuit breaker and the earthing switch must not be less than the prospective peak value of the short-circuit current calculated in accordance with IEC 61363-1. Additionally, specific HV interlocking and selectivity requirements must be met. Short-circuit withstand current ratings vary based on the ship type, such as 16kA RMS for 1s and 40 kA peak for RO-Pax, Containerships and Tankers, and 25kA RMS for Cruise ships and LNG carriers.

Relevant standards are as follows and are referred to in various sections of the IEC80005-1

- IEC 62271-200:2011 High-voltage switchgear and control gear - Part 200: AC metal-enclosed switchgear and control gear for rated voltages above 1 kV and up to and including 52 kV
- IEC 60947-2:2016+AMD1:2019 CSV: Low-voltage switchgear and control gear - Part 2: Circuit-breakers

Transformers

There are two main types of power transformers relevant for cold ironing applications:

- Dry-type transformers
- Oil-filled transformers

Two types of oil-filled transformers are commonly used: with expansion tank (conservator) and sealed. In both types, the windings and core are immersed in oil, which serves as both insulation and cooling fluid. Sealed oil-filled transformers are mainly used in distribution networks up to

52 kV and a rated power of up to 2.5 MVA, although some manufacturers have built them up to 30 MVA. Both types can be installed outdoors due to the protection provided by the tank.

Dry-type transformers are a suitable solution for energy distribution with optimized safety, require less maintenance and space, and have better fire safety compared to oil-filled transformers. They are not suitable for outdoor operation and have a maximum voltage of 36 kV and power of 20 MVA -25 MVA.

Dry-type transformers are the preferred type for cold ironing applications due to their low fire load, lack of need for special fire and ground water protection measures, and continuous overload capacity up to 120-130% of the rated power. They can also be used as "hot standby" redundancy to increase supply reliability, and do not experience loss of service life when used in this way.

Relevant standards for the design of transformers in low voltage cold ironing applications are: ISO/IEEE80005-1 and IEC60076-1 on Power Transformers.

Inverters and rectifiers

An inverter is a power electronic device that converts direct current (DC) to alternating current (AC). The resulting AC frequency depends on the device used. Inverters do the opposite of converters, which convert AC to DC.

The input and output voltage, frequency, and power handling depend on the device or circuitry design. The inverter does not produce any power, it is provided by the DC source. In shore-side electricity supply, inverters may be used for:

- Frequency conversion,
- Charging batteries.

Frequency conversion

The electricity frequency produced by the grid across the EU may not be compatible with the electricity required by ships. Europe has a frequency of 50 Hz, while ships use either 50 Hz or 60 Hz. A ship designed for 60 Hz electricity may be able to use 50 Hz electricity for some equipment, but not for motor-driven equipment such as pumps, winches, and cranes. 60 Hz electricity will require to be converted to 50 Hz by an electricity converter. The majority of ships produce 60 Hz electricity and are equipped for that specific frequency, but some ships may use 50 Hz for domestic operation if all ports have 50 Hz supply.

Two main types of frequency converters exist:

- Rotary frequency rotors
- Static frequency converters

Rotary frequency converters are used to convert the frequency of the electricity supply from one value to another, this is done by changing the rotational speed of the generator or the number of poles in the motor and generator. These converters can also change the voltage at the same time. They provide the required kVA, frequency, and voltage and have a precision voltage regulator to maintain the output voltage.

Static frequency converters also convert the source power and have no moving parts except for cooling fans. They are built on a dynamic platform and use the latest technology in solid-state, which are ideal for applications where space, noise, and control are a priority. They come in modular configurations, which allows for a versatile and flexible architecture, making them suitable for SSE systems.

Design requirements for shore connection converter equipment are provided in the IEC/IEEE 80005-1 and 3, for High Voltage Shore Connection (HVSC) and Low Voltage Shore Connection (LVSC), respectively, both in Part 2, Section 4.3.

Physical connection to the ship

Several options are available as off-the shelf solutions for electrical power supply for vessels depending on the vessel type and technical requirements. Solutions are most relevant for smaller harbours that best rely on standardised and modular systems. Typical systems are as follows:

- Cable reels: most suitable for container vessels, reels consist in windings of low or medium voltage cables with a telescopic roller rack able to automatically compensate for tidal range. Reels allow avoid handling high-voltage equipment. Control equipment can either be located at quay or in an on-board container.
- Fixed cable cranes: such systems can be operated by a single operated and generally feature an automatic tidal range compensation, as shown in Figure 6.

Figure 6: Fixed cable crane (Shore-Link[28])

- Mobile carrier systems: flexible solution where the cable is being un-winded up to the location of the ship with a vehicle featuring a telescopic are and automatic tidal range compensation, as shown in Figure 7.

[28] https://shore-link.eu/

Figure 7: Mobile carrier system for onshore power supply (ShoreCONNECT[29])

All systems can generally accommodate for large voltage ranges and both most commonly used frequencies. However, these systems do not provide voltage or frequency transformation.

Examples

Below we provide a high-level overview of cold ironing projects in European ports. The examples have been selected based on geographical (Mediterranean and/or islands) and/or technical similarities (ferries or passenger vessels). Best practices and lessons learned are brought forward. These can serve as practical examples on how to implement cold ironing in Thira.

EU-wide

The EALING project[30] - European Flagship Action for cold ironing in ports, is a 36 months long Connecting Europe Facility project aiming at proposing a common EU harmonised and interoperable framework for the transition to electrification for at least 16 EU maritime ports in different sea basins. The 16 EU Ports belonging to different sea basins - Mediterranean, Black Sea and Atlantic Sea – are the pilot sites for the studies defining the technical, legal and regulatory framework to accelerate the implementation of Onshore Power Supply (OPS) solutions.

At this stage in the EALING project, not many results are publicly available yet. One available public deliverable is a survey[31] in which one of the questions regarded the types of ship where OPS is ambitioned/planned/piloted/available. Respondents indicated that about 33% of larger ships operating in European harbours already have an OPS solution implemented, while a significantly lower share of harbour have such solutions implemented. The majority of respondents indicated 'RO-PAX' as category of ships for cold-ironing. RO-PAX is the acronym of Roll on/Roll off passenger ferry and works as a freight vehicle transport with passenger accommodation[32]. This was followed by containerships and then passenger ships[33]. As to the question what the main issues to be considered are when evaluating alternative OPS solution for ships the results are shown in Table 2 for RO-PAX and Passenger (1 less relevant / 5 more relevant).

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[29] https://www.shoreconnect.com/en/shore-connection
[30] https://ealingproject.eu/
[31] https://ealingproject.eu/wp-content/uploads/2022/05/Activity-2-Executive-Summary.pdf
[32] https://timesofindia.indiatimes.com/city/guwahati/assam-ro-pax-vessels-float-with-icons-names/articleshow/81102752.cms
[33] https://ealingproject.eu/wp-content/uploads/2022/05/Port-Questionnaires-Executive-Summary.pdf

Table 2 Results of the Survey of EALING project, namely to the question: What are the main issues to be considered when evaluating alternative OPS solutions for ships? (1 – less relevant, 5- more relevant)

TYPE OF SHIP	Technical specifications	Feasible cost benefit analysis	Standards and regulations supporting the facilities	Incentives and financing mechanisms	Collaboration between stakeholders involved	Society benefits boosting green port cities	Requests from ports
RO-PAX	3.0	2.0	3.67	3.5	3.5	3.5	3
PASSENGER	3.67	2.00	3.67	3.5	3.5	3.5	3.0

This demonstrates that technical specifications and standards and regulations supporting the facilities are the most important aspects to consider.

As to best practices, the following can be retained[34]:

- OPS Rule requirements Part 7 Chapter 13 of Lloyd´s Register Rules and Regulations[35]
- Standardisation of the equipment and installations
- Standardisation of procedures and interfaces

As to lessons learned the following can be retained[36]:

- Use must be supported by the availability of appropriate port infrastructure
- Early engagement with all the various stakeholders across the supply chain

Port of Killini, Greece

Greece's Port of Killini, a four berth Roll-On Roll-Off (RoRo) ferry terminal, at the west side of the country towards the Ionian Sea, is involved in a shore-to-ship (STS) electrical supply connection project[37]. Through the ELEMED project[38] - *ELectrification of the Eastern MEDiterranean area through the extensive use of Cold Ironing and the introduction of electricity as a propulsion alternative Motorways of the Sea (MoS)*[39] – a green pioneering cold-ironing facility was developed. There are five ferries operating at the port on a daily basis.

According to the report 'Furthering the Electricity to Ships and Ports: the ELEMED Project'[40] "the cold ironing implementation in the port of Kyllini consists of two shore supply positions. 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;

[34] https://ealingproject.eu/wp-content/uploads/2022/05/Activity-2-Executive-Summary.pdf
[35] https://www.lr.org/en/rules-regulations/
[36] https://ealingproject.eu/wp-content/uploads/2022/05/Activity-2-Executive-Summary.pdf
[37] https://safety4sea.com/greek-port-to-inaugurate-first-shore-power-supply-in-east-mediterranean/
[38] https://www.elemedproject.eu/single-post/2018/11/21/inauguration-ceremony-in-port-of-killini
[39] https://www.onthemosway.eu/wp-content/uploads/2017/05/fiche_2015-eu-tm-0236-s_final.pdf
[40] Mertikas, P. & Dallas, S.E. & Dimos, Spathis & Kourmpelis, Thodoris & Georgakopoulos, I.P. & Prousalidis, J.M. & Lyridis, Dimitrios & Nakos, L. & Mitrou, P. & Georgiou, V.. (2018). Furthering the Electricity to Ships and Ports: the ELEMED Project. 2542-2548. 10.1109/ICELMACH.2018.8506729

- 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)."

The port of Killini is also assessing whether the electricity for the cold ironing could be provided with locally generated onsite renewable energy. For more information, please refer to the full report 'Furthering the Electricity to Ships and Ports: the ELEMED Project'[41].

Port of Palma, Mallorca, Spain

The Port of Palma in Mallorca on the Spanish Balearic Islands is involved in a cold ironing project. The ferries that dock at the Paraires quay or the Commercial quays at the port of Palma will be connected to the onshore power grid while they are moored[42]. The port authorities of the Balearic Islands and Barcelona have jointly applied for European CEF-Transport aid, which will finance 40% of this investment.

According to the port authorities "Following a trial period, in collaboration with Baleària's Eleanor Roosevelt, the facility will be prepared to connect to the power grid a ferry with a maximum power demand of 1 600 kW (medium voltage) and another fast ferry (small Passenger ferries) with 800 kW (low voltage), although not simultaneously. For the onshore electrical connection, the system has 275 metres of medium voltage underground lines, a transformation centre and a frequency elevating substation in the service area of the port of Palma."[43]'

More information can be found in the sources below:
- Port of Balears – Tender for the first medium-voltage cold ironing project for ferries in Spain.
- Universidad Politécnica de Cataluña - Estudio y análisis de la tecnología "cold ironing" en el puerto de Palma de Mallorca, (in Spanish)

Port of Genoa, Italy

In the cruise and ferry port of Genoa, Italy, a cold ironing project is ongoing. The project foresees the installation shoreside of electric power converters for the provision of cold ironing at six passenger berths in the Port of Genoa to reduce air and noise pollution. The range of major infrastructure works would have an estimated cost of €19.2 million.

In Genoa, Nidec ASI will build six berths which will allow the cruise ships and ferries docked at the port to switch off their on-board generators, connecting to the electricity grid to meet their

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[41] Mertikas, P. & Dallas, S.E. & Dimos, Spathis & Kourmpelis, Thodoris & Georgakopoulos, I.P. & Prousalidis, J.M. & Lyridis, Dimitrios & Nakos, L. & Mitrou, P. & Georgiou, V.. (2018). Furthering the Electricity to Ships and Ports: the ELEMED Project. 2542-2548. 10.1109/ICELMACH.2018.8506729

[42] https://www.portsdebalears.com/en/en/noticia/apb-will-invest-123-million-euros-implementation-cold-ironing-systems-ports-palma-alc%C3%BAdia

[43] https://www.portsdebalears.com/en/en/noticia/apb-will-invest-123-million-euros-implementation-cold-ironing-systems-ports-palma-alc%C3%BAdia

operational needs[44]. In order to adapt the voltage and frequency of the power supply network to what the ships require, a conversion system consisting of distribution panels, transformers and converters that will allow the ships to be powered simultaneously will be implemented.

More information can be found in the sources below:

- Ports of Genoa – Cold ironing in the cruise and ferry terminar (P.2346)
- Ports of Genoa – Cold ironing receives de go-ahead in the Ports of Genoa and Savona
- The Medi-telegraph – Ports of Genoa propose incentives on cold ironing

Port of Heraklion, Crete

A cold-ironing project is also ongoing in the port of Heraklion, Crete. A feasibility study in 2022 focused on larger ships with significant power demand and berth time[45]. Such ships include cruise ships and ferries with a capacity from 500 to 4000 passengers with high hotelling power demand.

The port authorities' original plan was "to study the possibility of providing electricity to all ship berths, but technical and financial constraints led them to abandon this maximalist design and adapt to a more sustainable, lightweight version. They are now proceeding to cover the provision of electricity in five ship berths, namely three for coastal shipping and two for cruise ships or commercial ships. The maximum power we will be able to provide simultaneously to the docked ships is 15 MW, and this is a limitation from the local grid data. With this power (they) will be able to cover a large cruise ship, two coastal shipping vessels and an even smaller cruise ship or commercial ship.*"*[46]

More information can be found in the sources below:

- Hellas Posts - "Green the port of Heraklion: Gets electric power for ships – The main issues and "thorns"- Heraklion
- Hellenic Mediterranean University – HMY participates as a partner at the ELECTRIPORT Project

Port of Marseilles, France

RoPax shipowners La Meridionale & Corsica Linea have invested together with the Grand Port Maritime of Marseille-Fos in Cold Ironing. La Meridonale started to connect their ships in 2017 followed by Corsica Linea in 2019. The two companies have fitted Cold ironing equipment in six ships[47]. The Port of Marseilles is planning to install additional shore side connection technology for the Corsica Linea ferry berth in the Eastern Harbour[48].

More information can be found in the sources below:

- Marseille Fos – Connexion électrique des navires à quai (In French)
- Corsica Linea - Connexion électrique des navires à quai (In French)

[44] https://www.bunkerspot.com/europe/58033-europe-nidec-contracted-for-cold-ironing-projects-genoa-and-savona
[45] https://iopscience.iop.org/article/10.1088/1742-6596/2339/1/012016/pdf
[46] https://hellas.postsen.com/local/234870/Green-the-port-of-Heraklion-Gets-electric-power-for-ships-%E2%80%93-The-main-issues-and-thorns-%E2%80%93-Heraklion.html
[47] https://medports.org/wp-content/uploads/2022/04/Mistre-Alain.pdf
[48] https://www.worldcargonews.com/in-depth/in-depth/more-cold-ironing-in-marseilles

Others

Other ports around Europe that are working on cold ironing, but on a larger scale (cruises and tankers) are Gothenburg (Sweden), Las Palmas (Gran Canaria, Spain), Civitavecchia (Italy), Antwerp (Belgium), La Valetta (Malta), Helsinki (Finland).

Conclusions

This report assessed the maritime passenger transport situation of Thira and delved into the concept of cold ironing to cope with the air and noise pollution caused by it. This is relevant since the Directive on Alternative Fuels Infrastructure requires all ports to have cold ironing provision by the end of 2025, as well as of the presence of a high number of cruise ships and ferries.

The Thira stakeholders should consider the IEC 80005-3 standard as the starting point, as it provides the guidelines for the design, construction, testing, and commissioning of shore-to-ship power systems - although it does not fully apply to the smallest harbours where the power needs may be smaller, as may be the case of Thira.

Several papers and articles have been published on the topic of cold ironing. While many of those focus on the policy and regulatory aspects, the Islands secretariat has made a literature review of the most relevant ones for further assessment by the Thira stakeholders. They provide a starting point for the technical and economic aspects to be assessed. Based on those papers, articles, and standards the typical infrastructural requirements for cold ironing in medium-sized ports is summarised. Detailed technical requirements can be defined upon conceptual design based on the characteristics of the harbour. First, the expected energy demand needs to be calculated for each berth, along with frequency and voltage requirements based on the historical vessel call data at the harbour. Electrical configurations can then be modelled using a modelling software suite such as ERACS or PowerFactory. Upon design, detailed bill of quantities and expected costs can be inferred.

Finally, a high-level overview of cold ironing projects in European ports is presented. The selection was conducted based on geographical (Mediterranean and/or islands) and/or technical similarities (ferries or passenger vessels). Best practices and lessons learned are brought forward. These can serve as practical examples on how to implement cold ironing in Thira.

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Author(s): Lloyd's Register

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Annex A - Thira-Thirassia ferry Data

The transport of passengers and vehicles from Santorini (Thira) to the neighbouring island of Thirassia is performed by the F/B KATO NISI which has the capacity to carry 200 passengers and about 50 vehicles. In the following tables, the basic characteristics of the ferry and the route are presented:

Size	
Length	48.5m
Width	13m
Gross Tonnage	247

Vessel Type: **Passenger Landing Craft**

Vessel Voyage as seen bellow:

Summer-time Voyage (May – August)

Mon		Tue		Wed		Thu		Fri		Sa	
08:00	Korfos (Thirasia)	14:00	Korfos (Thirasia)	14:00	Korfos (Thirasia)	14:00	Korfos (Thirasia)	08:00	Korfos (Thirasia)	08:00	Korfos (Thirasia)
08:15	Riva (Thirasia)	14:15	Riva (Thirasia)	14:15	Riva (Thirasia)	14:15	Riva (Thirasia)	08:15	Riva (Thirasia)	08:15	Riva (Thirasia)
09:15	Fira (Santorini)	15:30	Athinios (Santorini)	15:30	Athinios (Santorini)	15:30	Athinios (Santorini)	09:15	Fira (Santorini)	09:20	Athinios (Santorini)
15:30	Athinios (Santorini)	16:35	Riva (Thirasia)	16:35	Riva (Thirasia)	16:35	Riva (Thirasia)	15:30	Athinios (Santorini)	09:40	Fira (Santorini)
15:50	Fira (Santorini)	end	Korfos (Thirasia)	end	Korfos (Thirasia)	end	Korfos (Thirasia)	15:50	Fira (Santorini)	10:40	Riva (Thirasia)
16:50	Riva (Thirasia)							16:50	Riva (Thirasia)	port stay 3h10m	Korfos (Thirasia)
end	Korfos (Thirasia)							end	Korfos (Thirasia)	14:00	Korfos (Thirasia)
										14:15	Riva (Thirasia)
										15:15	Fira (Santorini)
										15:35	Athinios (Santorini)
										15:55	Fira (Santorini)
										16:55	Riva (Thirasia)
										end	Korfos (Thirasia)

Winter-time Voyage (September - April)

Mon		Tue		Wed		Thu		Fri		Sa	
08:00	Korfos (Thirasia)	14:00	Korfos (Thirasia)	14:00	Korfos (Thirasia)	14:00	Korfos (Thirasia)	08:00	Korfos (Thirasia)	14:00	Korfos (Thirasia)
14:00	Korfos (Thirasia)	14:15	Riva (Thirasia)	14:15	Riva (Thirasia)	14:15	Riva (Thirasia)	08:15	Riva (Thirasia)	14:15	Riva (Thirasia)
14:15	Riva (Thirasia)	15:30	Athinios (Santorini)	15:30	Athinios (Santorini)	15:30	Athinios (Santorini)	09:15	Fira (Santorini)	15:30	Athinios (Santorini)
15:30	Athinios (Santorini)	16:35	Riva (Thirasia)	16:35	Riva (Thirasia)	16:35	Riva (Thirasia)	15:30	Athinios (Santorini)	16:35	Riva (Thirasia)
16:35	Riva (Thirasia)	end	Korfos (Thirasia)	end	Korfos (Thirasia)	end	Korfos (Thirasia)	15:50	Fira (Santorini)	end	Korfos (Thirasia)
end	Korfos (Thirasia)							16:50	Riva (Thirasia)		
end	Korfos (Thirasia)							end	Korfos (Thirasia)		

Loads
Hotel Loads 5.1 kW (estimates)
Sea Voyage 149.6 kW (estimates)

Summer	Mon	Tue	Wed	Thu	Fri	Sat	Sun
Route length (km)	22	20	20	20	20	40	0
Travel time (h)	1.65	1.1	1.1	1.1	1.65	3.0	0
Hours of stay (h)	15.2	21.4	21.4	21.4	15.2	18.25	24
Energy – Voyage (kWh)	246.8	164.6	164.6	164.6	246.8	452.5	0.0
Energy – Hotel (kWh)	76.9	108.6	108.6	108.6	76.9	92.5	121.7
Total energy (kWh)	323.7	273.1	273.1	273.1	323.7	545.1	121.7

Winter	Mon	Tue	Wed	Thu	Fri	Sat	Sun
Route length (km)	22	20	20	20	22	20	0
Travel time (h)	1.65	1.1	1.1	1.1	1.65	1.1	0
Hours of stay (h)	15.2	21.4	21.4	21.4	15.2	21.4	24
Energy – Voyage (kWh)	246.8	164.6	164.6	164.6	246.8	164.6	0.0
Energy – Hotel (kWh)	76.9	108.6	108.6	108.6	76.9	108.6	121.7
Total energy (kWh)	323.7	273.1	273.1	273.1	323.7	273.1	121.7

Annual energy demand (MWh) 91.62
Annual MGO demand (MWh) 305.41
Annual CO2 emissions (tons) 981.00