# Regulatory and Business Innovation in Uncharted Waters: Mandatory Cold-Ironing

**Sean Ennis**
Centre for Competition Policy (CCP), Norwich Business School, University of East Anglia

**Constantinos Mammassis**
Hellenic Electricity Distribution Network Operator (HEDNO) and Department of Industrial Management & Technology, University of Piraeus

**Raphael Markellos**
Centre for Competition Policy (CCP), Norwich Business School, University of East Anglia

**John Prousalidis**
School of Naval Architecture and Marine Engineering, National Technical University of Athens

**Anastasios Manos**
Hellenic Electricity Distribution Network Operator (HEDNO)

**George Loukos**
Hellenic Electricity Distribution Network Operator (HEDNO)

**Neil Tracey**
Centre for Competition Policy (CCP), Norwich Business School, University of East Anglia

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**Contact Details:**
**Sean Ennis** s.ennis@uea.ac.uk

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Sean Ennis[*], Constantinos Mammassis[†‡], Raphael Markellos[*], John Prousalidis[±], Anastasios Manos[†], George Loukos[†], Neil Tracey[*]

[*] *Centre for Competition Policy (CCP), Norwich Business School, University of East Anglia (UEA), UK*

[†] *Hellenic Electricity Distribution Network Operator (HEDNO), Greece*

[‡] *Department of Industrial Management & Technology, University of Piraeus, Greece*

[±] *School of Naval Architecture and Marine Engineering, National Technical University of Athens, Greece*

**Abstract.** This paper examines the economic and regulatory challenges of implementing onshore power supply for ships at berth, commonly known as cold ironing (CI), across the EU. Although CI can significantly reduce port emissions, its deployment is constrained by high upfront capital costs, fragmented stakeholder incentives, and the lack of effective cost recovery mechanisms. Drawing on evidence from 11 major European ports, we discuss concerns around market power, inefficient cost allocation, and risks to grid stability, particularly in smaller markets where ports operate as de facto monopolies. To address these problems, we propose a new "Extension-to-Grid" business model, in which the electricity grid operator assumes responsibility for the CI infrastructure. Our model improves transparency, reduces information asymmetries, mitigates monopolistic pricing, and, facilitates technical coordination. Our study contributes to the energy economics literature by linking regulatory enforcement to business model innovation, and, illustrates how market design, regulatory clarity, and institutional flexibility can improve the implementation of capital-intensive climate policies.

**Keywords:** Cold ironing, onshore power supply, port electrification, electricity regulation, market power, business model innovation, energy transition.

## 1. INTRODUCTION

Cold Ironing (CI), also known as Onshore Power Supply (OPS) or Alternative Maritime Power (AMP), refers to the practice of ships connecting to onshore electricity while berthed, rather than relying on auxiliary engines. This reduces local air pollution, noise, and greenhouse gas emissions in and around port areas.[1] The state of California has led early adoption efforts, mandating shore power use for 80% of fleet visits since 2020.[2] Within the European Union, CI is a central component of the "Fit for 55" legislative package, which aims to achieve climate neutrality by 2050. Under this framework, ports and vessels are required to make significant investments in CI infrastructure by 2030, with initial obligations beginning in 2025. EU-wide estimates suggest that alternative fuels infrastructure investments will amount to €9.9 billion between 2025 and 2050.[3] When broader port infrastructure upgrades are included, total investment costs may reach €80 billion by 2034.[4] Shipowners also face an estimated €25.8 billion in capital costs for retrofitting existing vessels or acquiring compliant new builds.[5] The EU has decided that the significant outlays are justified given the substantial social, environmental, and economic benefits of CI, especially as nearly 180 million EU citizens (approximately 40% of the population) live within 50 kilometres of the coast (European Environment Agency, 2013).

While EU regulators have articulated clear long-term decarbonization targets, they have deliberately left open the specific pathways through which ports and shipping firms must comply. This regulatory flexibility encourages innovation and allows market participants to experiment with different implementation strategies (Hasan & Chen, 2025). However, it also introduces risks, such as market failures, coordination problems, and, lock-in to suboptimal models. In this paper, we examine how 11 major European ports are responding to CI mandates and identify three distinct business models. These models vary in terms of cost structures, revenue mechanisms, energy distribution arrangements, customer segments, and the nature of customer relationships. Through comparative critical analysis, we identify structural trade-

[1] By utilizing CI, ships may increase their energy efficiency as well as decrease their emissions, thus, improving the quality of the air around the ports (Luo, Zhou, Mu, Zhang, & Cao, 2024). A study found that CI adoption by two-thirds of vessels that call at US ports would be associated with an air quality benefit of $70-150 million per year (Vaishnav, Fischbeck, Morgan, & Corbett, 2016). A similar study looking at the EU confirms this result (Ballini & Bozzo, 2015). In 2019, about 15,700 ships spent more than 2 hours at-berth in the 489 major EU ports, demanding nearly 5.9 terawatt-hours of energy; nearly 70% of this energy demand came from the Trans-European Transport Network (TEN-T) network ports (Osipova & Carraro, 2023). The most energy-consuming ship types were tankers, passenger, and cruise ships (67% of the total at-berth energy demand), which were also key contributors of at-berth $CO_2$ emissions.

[2] See California Air Resource Board's (CARB) 2020 At Berth Regulation.

[3] *European ports becoming 'fit for 55'*, European Parliament, 2022.

[4] European Sea Ports Organisation (ESPO) *Port Investment Study*, 2024.

[5] *Impact Assessment, Regulation of the European Parliament and of the Council on the use of renewable and low-carbon fuels in maritime transport* (SWD/2021/636 final), European Commission.

offs across the models and propose an alternative approach: a business model in which the electricity grid operator assumes a central role in both investment and operational coordination. We argue that this model offers specific advantages, particularly in consumer protection and in extending CI infrastructure to smaller electricity markets. The remainder of this paper proceeds as follows. Section 2 presents an overview of the regulations and literature on the technical implementation of CI. Section 3 presents the results of our empirical research on best practices and proposes a new business model that addresses the weaknesses of existing approaches. Section 4 concludes.

## 2. REGULATION AND TECHNICAL IMPLEMENTATION

### *2.1. Regulation*

In September 2021, the European Union introduced the "2030 Climate Plan," also known as the European Green Deal, which aims to reduce greenhouse gas emissions by 55% by 2030 and achieve carbon neutrality by 2050. To support this transition, the EU subsequently adopted the "Fit for 55" legislative package, which combines both mandatory and incentive-based measures to accelerate decarbonization. Within this framework, two key regulations were adopted in July 2023: the FuelEU Maritime Regulation (2023/1805/EU) and the Alternative Fuels Infrastructure Regulation (AFIR; 2023/1804/EU). The former requires container and passenger vessels of at least 5,000 gross tonnages (GT) to connect to onshore power supply while at berth by 2030. The latter mandates that in the 320 core and comprehensive TEN-T ports in which container and passenger ships larger that 5,000 GT have a minimum berthing duration of 2 hours and meet the port call thresholds (i.e., cargos: >100 calls/year; Ro-Ro & high-speed: >40 calls/year; Cruises: >25 calls/year) must provide shore-side electricity covering ≥90% of those port calls by the end of 2029 (European Commission, 2024). By applying these criteria, 189 EU ports qualify for CI implementation by 2030. Together, these regulations compel significant investment on both the ship and port sides, forming the backbone of the EU's strategy to implement CI as part of its broader energy and climate targets.

As of 2023, only 51 ports across 15 EU coastal member states are equipped with CI infrastructure, delivering a combined 309 MW of shore power, 283 MW of which is designated for container, passenger, and cruise vessels (Osipova & Carraro, 2023). According to the International Council on Clean Transportation (ICCT), this capacity will need to at least triple, if not quadruple, by 2030 for the EU to meet its commitments under the FuelEU Maritime Regulation and AFIR (Osipova & Carraro, 2023). The European Parliament's Think Tank estimates that port-side CI infrastructure alone will require approximately €7.4 billion in investment between 2025 and 2050 (Jacobs, 2022), with individual systems costing between $300,000 and $4 million per berth, depending on port scale and vessel type (Bakar, Bazmohammadi, Vasquez, & Guerrero, 2023). On the maritime side, the EU-flagged fleet includes roughly 3,000 container ships (representing 20% of the global total), 300–350 cruise ships, and 5,000–6,000 passenger vessels (European Maritime Safety Agency, 2023), the majority of which exceed the 5,000 GT threshold and would therefore fall under CI compliance obligations. Currently, 5% of vessels have CI connectivity, which is expected to double by 2030.[6] Retrofitting these vessels is estimated to cost between $300,000 and $2 million per ship (Bakar et al., 2023). Cumulatively, ship-side investments could surpass €25 billion in the coming years, underscoring the scale of financial commitment required to meet the EU's CI objectives.

While EU regulations mandate the deployment of CI, its economic viability remains highly uncertain. Adoption is hindered by ambiguity over who should bear the investment burden, alongside the high capital and maintenance costs associated with CI infrastructure (Williamsson, Costa, Santén, & Rogerson, 2022) and the diffuse benefits. These challenges are especially acute for small and medium-sized ports, which often face limited access to finance (Bullock, Higgins, Crossan, & Larkin, 2023). Importantly, current cost estimates exclude the substantial grid upgrade expenditures required to deliver stable electricity to ports. These include high-voltage substations, dedicated lines, and distribution network reinforcements. A single cruise ship can demand up to 10 MVA, comparable to the electricity needs of a small town, placing a sudden and heavy load on the grid (Sciberras, Zahawi, & Atkinson, 2015). Grid stability, therefore, emerges as a critical constraint, particularly in regions with underdeveloped infrastructure. Moreover, demand-side uncertainty further complicates investment decisions: only a minority of ships currently calling at EU ports are equipped to use CI (European Environment Agency, 2021). In sum, the rollout of CI faces multiple systemic barriers, including high upfront costs across stakeholders, fluctuating demand, technical limitations (Bakar et al., 2023; Sciberras et al., 2015), spatial constraints (Zis, 2019), and policy uncertainty (Department for Transport, 2022; Radwan et al., 2019).

To ensure interoperability across CI systems, a unified set of technical standards has been developed by the International Electrotechnical Commission (IEC), the International Organization for Standardization (ISO), and the Institute of Electrical and Electronics Engineers (IEEE). The resulting standard (IEC/ISO/IEEE 80005-1) defines key specifications for shore-side distribution systems, ship-to-shore interfaces, frequency converters, and other system components (IEEE Standards Association, 2019). The European Union mandates compliance with this standard under Directive 2014/94, making it the technical baseline for all CI infrastructure deployed within EU ports.

[6] Based on data from Clarkson's World Fleet Register, January 2024.

### *2.2. Structures for Technical Implementation*

The literature on how CI could be technically implemented in ports identifies three distinct technical structures for the provision of CI in ports (Lyridis, Prousalidis, Lekka, Georgiou, & Nakos, 2023; Manos, Lyridis, & Prousalidis, 2023). In the first configuration, the port acts as a Closed Distribution Network Operator (CDNO) and is responsible for the consistent and robust distribution of electric energy into the zone of its authority. However, it cannot have any other activity such as being an energy provider or producer. In this structure, energy travels from suppliers through the national grid to the port's closed distribution network and, finally, to consumers (i.e., the ships). In the second alternative, the port still operates as a CDNO, but it can, under certain circumstances, also be an energy provider or producer. Specifically, this can occur through forming a new legal entity (e.g., a subsidiary), in which its board members are different to those of the port (see regulation 2019/944/EU). The port may also produce and provide energy to its customers (i.e., the ships). In the third configuration, the port and ships can engage in an energy community through the port aggregator. The aggregator combines all the loads of various consumers (including ships and the port itself) and can negotiate for the best price on the market. Hence, the energy community is involved in the production, storage, distribution, and consumption of electricity (Lyridis et al., 2023; Manos et al., 2023). In line with this third alternative, recent work further explores the possibility of integrating CI operations into the port's microgrid to supply CI with a more sustainable mix of electricity than is in the grid itself (Bakar et al., 2023). Microgrids in this model (like aggregators) connect energy resources, renewable energy supply, and energy storage systems with ships' CI systems and then connect to the larger grid network. Hence, the microgrid supplies ships with power generated from renewable energy sources, drawing from the grid when it is unable to meet supply (Bakar et al., 2023).

While literature on the technical implementation of CI has outlined the potential alternatives for its successful adoption, it has fallen short in explaining how these structures may uniquely affect the diverse interests of the stakeholders involved in the implementation of CI, namely ports, ships, grid operators and policy makers. In other words, the literature does not yet explain how the regulations prompted by the EU may influence the goals and strategies of the CI stakeholders and how those could be further aligned to ensure the effective and widespread adoption of the CI regulations. Our work aims to bridge this gap by examining the relationships between key players in the CI market, the potential revenue streams, and investment in CI infrastructure. To do so, we first characterize the current business models employed by ports and how those are influenced by factors such as the scale of their operations, the customer segments that they serve, and the competitive environment in which they operate. Second, we build upon our findings to suggest an alternative business model that may alleviate the limitations of the current CI business models. Third, we discuss our findings and recommend specific actions for policy makers and regulators that may enable the quick adoption of improved EU regulations.

## 3. THE BUSINESS MODELS OF COLD-IRONING

A business model refers to the "*…design or architecture of the value creation, delivery, and capture mechanisms*" (Teece, 2010, p. 172) of a firm. In our case, the port is the primary agent of the CI implementation and, thus, it is necessary to understand how the adoption of CI would create value for the port as well as how it affects port's relationships with its stakeholders. Specifically, we aim to identify CI's business model core elements: namely its value proposition for the port, the market segment(s) it creates, the structure of the value chain necessary for fulfilling the value proposition, and how these elements are linked together in the port's architecture (Foss & Saebi, 2017). [7] In this way, we will be able to draw the necessary connections on how information is directed through the different CI stakeholders, how CI market works, and how incentives are designed and allocated to the key CI players.

We use the Business Model Canvas (BMC), which is a strategic tool that helps managers visualize, design, and innovate their business models in a structured way (Osterwalder & Pigneur, 2010, 2013), to perform a desktop analysis of 11 major CI projects across Europe. BMC is widely used because it provides a clear, concise, and adaptable framework for analyzing business opportunities. For instance, Kotha, Vissa, Lin, and Corboz (2023) used BMC to indicate how business model design drives entrepreneurial growth by helping entrepreneurs frame their business strategies effectively and align their strategy with execution. Santamaria, Abolfathi, and Mahmood (2024) used BMC to highlight that successful entrepreneurs need to early and deeply engage with customers to identify and mitigate business risks. Romme et al. (2015) argued on the importance of BMC as a design tool that encourages flexibility and iterative improvements in business models through experimentation. While BMC has undeniable strengths, it also presents some limitations. For instance, it does not capture detailed financial projections or operational complexities, it does not inherently account for dynamic market changes (due to its static nature), and it is not industry specific. However, it may be considered as a valuable tool to identify and examine CI's business model core elements.

The CI projects were randomly selected from all projects with enough information available to perform our desktop analysis, which included looking at media coverage, financial statements, investor relations materials, and information released by government/regulatory entities. In addition, we conducted three semi-structured interviews of 40 minutes with three different port authorities to verify and/or extend our findings. Specifically, we interviewed a CI engineer and project manager at the Port of Helsinki (Finland), two senior port officials involved in CI operations at the Port of Oslo (Norway), and the CI project manager at the Port of Kapellskär (Sweden). The *Key Activity* for all projects was supplying power to ships through CI infrastructure. *Key Partners* included customers (either cruise, shipping, or ferry

[7] For a similar approach, see the electric vehicles' business model analysis in Bohnsack, Pinkse, and Kolk (2014).

companies), the port, the grid operator, the electric supplier(s), and a CI operator (either the port, the customer, or an external company). The *Value Proposition* of CI was driven by regulatory compliance. *Key Resources* for CI included the grid connection, energy supply, the port CI system, the ship/port interface, and the ship CI system.

**Table 1.** Ten Core Elements of the Business Models of Cold-Ironing

| Core Elements | Alternate Conditions | | |
|---|---|---|---|
| **Investment** | Port | Ships | Public (e.g., government / EU grants) |
| **Construction** | Port | Contractor | |
| **Scale of operations** | Low to high volume of supply | | |
| **Customer segment** | High frequency customers | Mix of high and low frequency customers | |
| **Electricity Path** | Direct to ship | Port as an intermediary | |
| **Collaboration with ships** | Technical | Operational | Information on demand |
| **Collaboration with the grid operator** | Information on demand | Grid data sharing | Upgraded connection |
| **Revenue - grid operator** | Grid tariff | Connection fee | Grid development |
| **Pricing methods** | Fee for operation | Margin on electricity | Environmental tariff |
| **Pricing determination** | Set by port | Negotiated with customer | |

The business models of CI differed across cost structures, revenue streams, energy distribution channels, customer segments and customer relationships. The most common *Cost Structures* we identified were financing by the government, financing by ports, or financing by customers (i.e., shipping companies). *Revenue structures* included up-charging on electricity, charging connection fees, or a combination of both. We also identified different energy *Distribution Channels* including integrated grid/energy provider to port to ship, integrated grid/energy provider to ship, energy provider to port to ship, and energy provider to ship. Another area of difference was in *Customer Segments*. Ports may build CI terminals specifically for the exclusive use of a customer, for the general public, or predominantly for an important customer while keeping the system open to other clients. Customer relationships also vary, largely depending on customer segments. Usage agreements help ports ensure that CI infrastructure is commercially viable (Port of Kapellskär, 2024). Customers with usage agreements were more likely to be able to negotiate on prices, energy distribution channels, and timelines for CI projects implementation (Port of Kapellskär, 2024). Using these initial findings, we identified ten core elements that determine ports' business models (see Table 1).

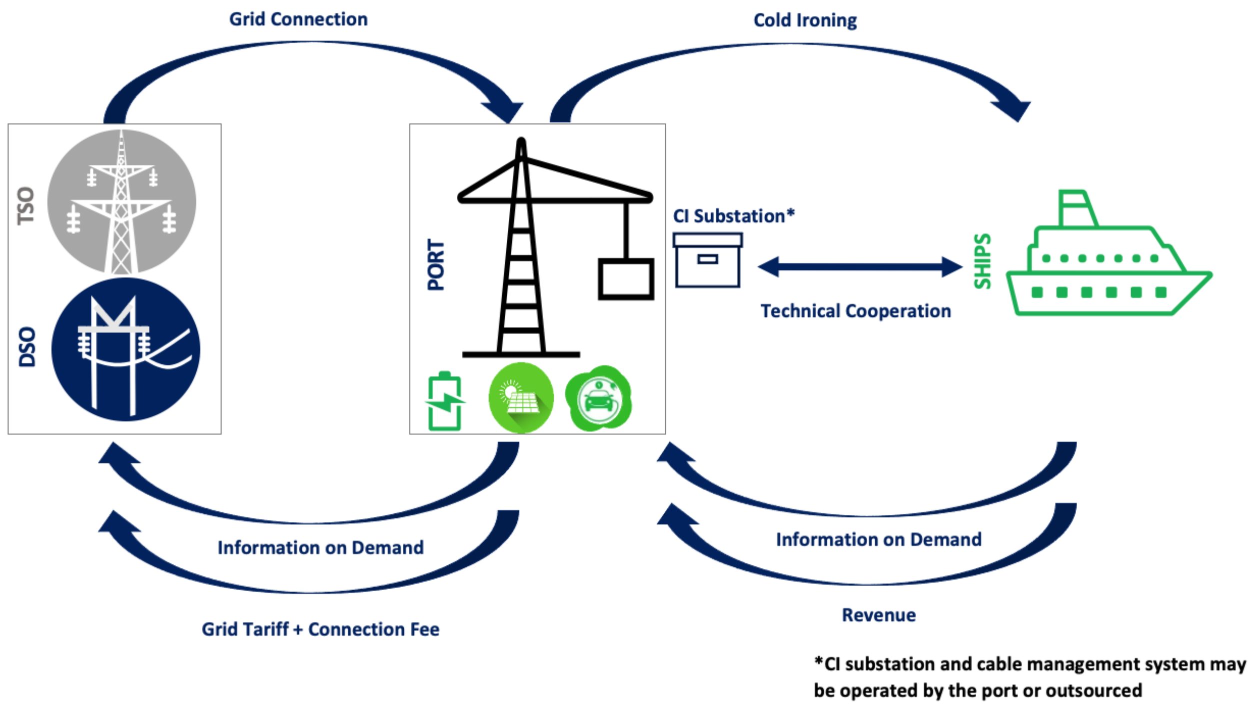
Within Table 1, each core element merits further explanation. *Investment* refers to who pays for the capital expenditure of building a new CI system. Investment may originate from ports, public investment schemes/ EU grants, or even ships paying for the CI system built in ports. In terms of *construction*, ports can construct the CI system themselves, employ external contractors, or engage in a combination of the two. In terms of *scale of operations*, we explored ports in a wide range (from one to eighteen) high voltage CI connections. In terms of the *electricity path*, the port can serve an intermediary, buy electricity and then reselling it to ships. Alternatively, ships can buy electricity directly from suppliers. Regarding *port and ship collaboration*, they may collaborate in the technical connection of ship to shore interface as well as in exchanging information on how much electricity ships will demand and when they will demand it. Furthermore, and regarding *customer segments*, we can distinguish between high and low frequency customers. High frequency customers use the CI system more often (and generally more routinely) than low frequency customers.

We found ports that serve almost exclusively high frequency customers, and ports that serve a mix of high and low frequency customers, but no port that serves only low frequency customers. *Ports and grid operator(s)* share information on electric demand; this includes how much is the port's need for the CI projects, and when it would like to use it (what time of day, for example). The grid operator also communicates with the port how much electricity it can feasibly supply to the port. Grid operators also work with ports to upgrade their grid connections, when necessary. Grid operators can also share data with ports on the grid's capacity to help ports better understand the existing limits and explore where opportunities for investment in grid infrastructure to support CI demand might exist. Regarding *pricing*, we found that ports have three main "buckets" of pricing systems. Fees for operation include flat fees for using CI, monthly payments to help pay for capital expenditure/maintenance, and fees for operation adjusted to how involved connecting the ship to the CI system is. Ports also have the option to charge a margin on electricity, in the cases where they serve as a intermediary (see below) between ships and the grid. Many ports also choose to charge environmental tariffs to all port customers to fund CI systems. Ports can then reduce this tariff for the customers that use CI. Finally, *grid operator's revenue* can derive from the standard grid tariff, from fees for upgrading the connection to the port, and payment for investments in the grid to meet CI demand. The *price determinations* of CI provision can either be set by the port itself or negotiated with customers.

Based on our findings above, we draw a few correlations among these attributes. Larger scale CI operations were more likely to serve a mix of frequent and infrequent customers compared to smaller scale operations. Moreover, larger scale CI operations tend to necessitate closer cooperation with the grid operator. This closer cooperation requires increased revenue for the grid operator to pay for infrastructure and connection upgrades. Finally, we found that the type of customer segments impacts the energy distribution channels as larger customers were able to negotiate buying electricity directly from suppliers. Using these key attributes, and the connections between them, we were able identify three archetypes of CI business models: the standard intermediary, the active intermediary, and the facilitator.

### *3.1 The "Standard Intermediary" Model*

**Figure 1.** The "Standard Intermediary" Business Model



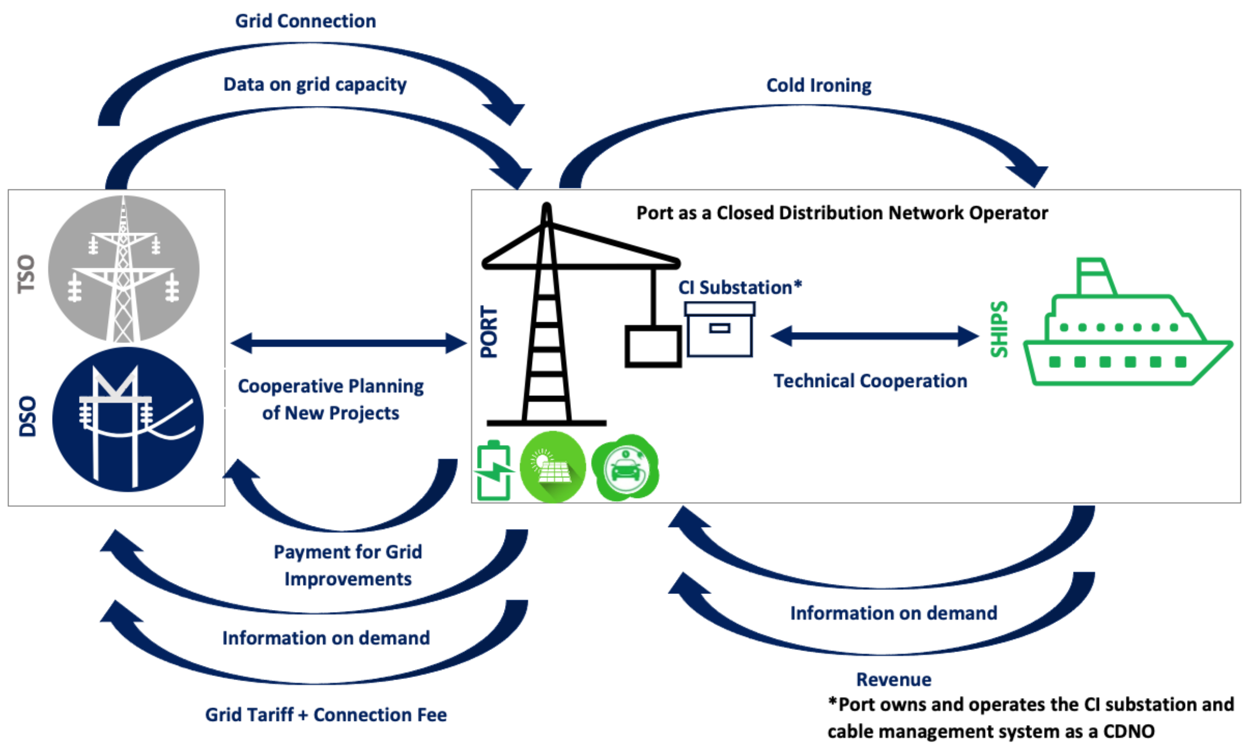

The "Standard Intermediary" business model (see Figure 1) can be reflected in the Port of Helsinki, the Port of Oslo, the Port of Kiel, the Port of Kristiansand, the Port of Gothenburg, the Port of Aarhus, the Port of Copenhagen, the Port of Hamburg, and the Port of Livorno. For this paper, we interviewed the ports of Helsinki and Oslo, while for the rest we conducted desktop research. The ports following the "Standard Intermediary" business model, typically contract out work for building and installing the CI system. In Helsinki, for instance, the port contracted out work on the CI system through a "design-and-build" contract (Port of Helsinki, 2023). In Oslo, the port started contracting both the design and construction phases of projects (Port of Oslo, 2023). As the port gained more expertise in CI, it increasingly did more of this work in-house (Port of Oslo, 2023). Oslo now buys many of its CI systems “off-the-shelf” and only installs it (Port of Oslo, 2023). In all cases we examined in the EU, the port received external funding through a national program. Typically, this covered 30% of the project costs. In Oslo, which has a longer history of CI projects, the state support started at 90% funding for its first project, but, as the technology has matured and CI has become more standard, it now receives 30% of the total investment cost(Port of Oslo, 2023).

In the “Standard Intermediary” business model, the port built the CI system with close collaboration with its long-term customers. In Helsinki, for instance, this included companies that consistently stop at the port while they run ferry services to Tallinn (Port of Helsinki, 2023). These partnerships helped make investment in CI feasible by ensuring that customers would use it. Ports including Kristiansand, Kiel, Oslo, and Copenhagen also have similar partnerships (Eason, 2018; Port of Oslo, 2023; Røyneberg, 2021). CI facilities are open to the public when not in use by one of the larger customers. In this case, the port sets the price unilaterally. For large customers, ports negotiate CI payment structures directly before building the CI system (Port of Helsinki, 2023; Port of Oslo, 2023). The revenue streams include a mix of fixed fees for use, markups on the cost of electricity, fees paid to contractors, and environmental fees. For instance, in both Helsinki and Oslo, the port charges ships a markup on the electricity that passes through the ports to the ships. Publicly available information, which may not fully reflect arrangements made with large customers, shows the use of fees for operation. In Gothenburg, Aarhus, and Kiel, the port charges ship fees for connecting to the CI system as indicated by the publicly announced tariffs. In Kristiansand, the port advertises that it does not charge a margin on electricity, but ships pay fees both to the port and to the contractors who operate the CI.

In the “Standard Intermediary” business model, the port acts as an informational “in-between” on demand between customers and the grid operator. The “Standard Intermediary” ports communicate with ships to find out how much power they will demand and when they will demand it and then relay this information to the grid. Grids receive revenue both through their standard grid operating fee, and fees for upgrading the port’s grid connection. Notably, not every CI project requires an upgraded network connection (Port of Helsinki, 2023; Port of Oslo, 2023). One point of divergence between ports following the “Standard Intermediary” business model was their level of collaboration with the grid operator. In Helsinki, which has four high voltage CI terminals, the grid provided parameters for how much energy they could draw from the grid and the port built their systems within these parameters (Port of Helsinki, 2023). In Oslo, which has nine high voltage CI terminals, the grid similarly provides parameters but has worked with the port to increase this amount over time to enable the port to build more CI terminals (Port of Oslo, 2023). Oslo has a dynamic relationship with the grid operator in which the latter has repeatedly worked with the port to build up the amount of electricity it can supply over time. Ports with low numbers of CI terminals may have less active interactions. In this scenario, the grid operator provides the boundaries for the project and upgrades the port's connection if needed, but there is not a consistent dialogue between the two parties. Thus, the size of the port's demand for CI could determine its relationship with the grid.

### *3.2 The "Active Intermediary" Model*

**Figure 2.** The "Active Intermediary" Business Model




In the "Active Intermediary" business model (see Figure 2) a port-owned company does all the work in maintaining and upgrading the port's closed distribution network (i.e., microgrid). It pays for this investment through a mixture of environmental tariffs and EU funding. Environmental tariffs are levied on all ships, regardless of whether they use CI. Ships that adopt environmental measures receive a discount on the environmental tariff. This is designed to incentivize its customers to adopt environmental measures. This model is found in the Ports of Stockholm, the company that operates the ports of Stockholm, Nynäshamn, Kapellskär and Stockholm Norvik. It has 18 quays that serve ferries, cargo ships, warships, yachts, and cruise ships across its three ports. While most of these were built for frequent, large customers, CI is available to all port customers who want to use it (Port of Kapellskär, 2024). Under the "Active Intermediary" business model, the Ports of Stockholm owns and operates a CDNO, which includes the CI infrastructure. The Ports of Stockholm also consistently receives funding from the EU to support its projects. This typically amounts to 30% of the costs of investment for each project (Port of Kapellskär, 2024).

The ports under the "Active Intermediary" business model do not charge a margin on the electricity they provide to CI customers. Instead, they gain revenues in two ways. Customers pay for the electric grid connection fee, pro-rated to the amount of electricity that they use, along with an up-charge on the grid connection fee. In the Port of Kapellskär, one of the Ports of Stockholm, this amounts to a 4-5% up-charge. Customers also pay for maintenance costs through fees for using the CI system, designed to cover maintenance costs but not profit. In the Port of Kapellskär, these fees amount to roughly €5,600 per year. Pricing agreements are directly negotiated with larger customers who consistently use the CI system. For example, in the Port of Kapellskär, the port negotiated directly with Finnlines, which runs a ferry (Port of Kapellskär, 2024).

The ports under the "Active Intermediary" business model maintain a close relationship with both their customers and the grid operator. Also, they coordinate their investments with large customers. For instance, in the Port of Kapellskär, Finnlines (i.e., a large shipping company) wanted to invest in new ships equipped with CI. This led the port to develop CI facilities earlier than they had previously planned. The Ports of Stockholm have coordinated this investment with at least four other large customers. With the development of the IEC/ISO/IEEE 80005-1 technical standards, technical coordination between ships and customers has become easier as both parties build their systems to comply with the standards (Port of Kapellskär, 2024). Furthermore, the Ports of Stockholm communicates information on their customers' electric demand to the grid operator and works closely with them to plan new CI projects in a way that does not affect grid stability. This includes a data-sharing agreement that gives the port information on the grid's capacity and load. This allows the port the ability to plan new projects in collaboration with the grid by seeing where increasing load would be feasible. When the grid's current capacity is not able to support more CI, the port suggests upgrades to the grid operator. Then, the port pays the grid operator the costs of making these upgrades to the grid (incorporated into a higher grid connection tariff). They also pay the grid operator for the cost of upgrading the port's network connection and the standard grid tariff; these payments are negotiated on a case-by-case basis. This model enables the port to factor in the price of grid improvements when considering which CI facilities to build. It also allows them to estimate better how fast they scale CI projects. For example, they might draw a smaller amount of electricity from the grid at the beginning of a project, work with the grid to build up the network, and then draw more power from the grid (Port of Kapellskär, 2024).

### *3.3 The "Facilitator" Model*

**Figure 3.** The "Facilitator" Business Model: Port owns CI infrastructure

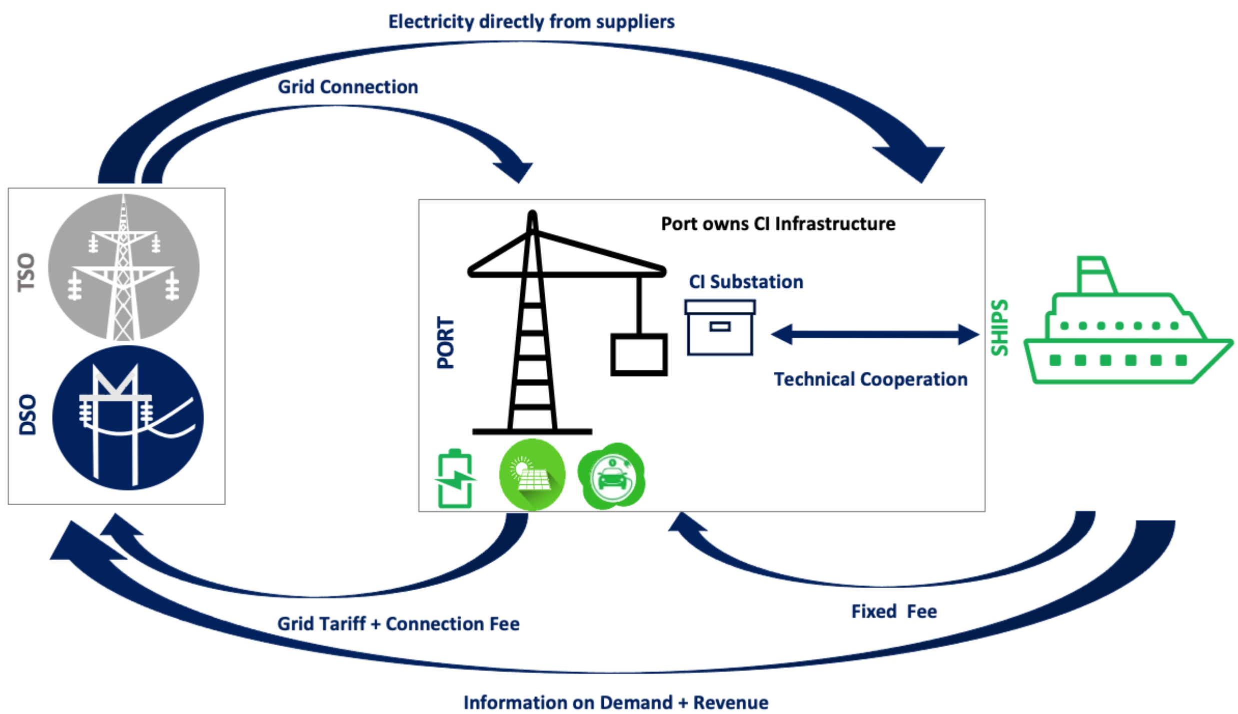
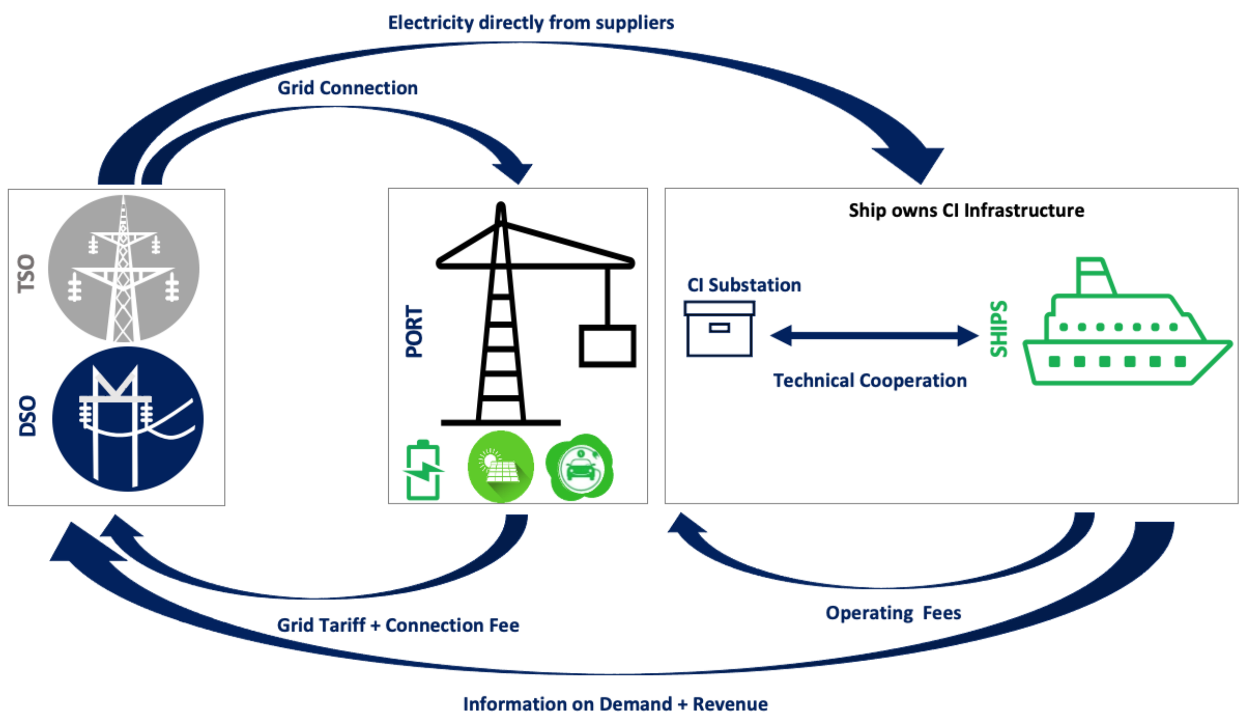



**Figure 4.** The "Facilitator" Business Model: Ship owns CI infrastructure




In Helsinki and Oslo, we found cases of a third type of business model in which the port acts as a "Facilitator" between the ships and the grid. The ships buy electricity directly from electricity suppliers, negotiating directly with them over electricity prices instead of the port. In both cases, large customers pushed for this arrangement with ports because they believed that they would be able to buy electricity more cheaply directly from suppliers than if they purchased it through the port. The key difference between these two cases is that in Oslo, the shipper owns the CI facility whereas, in Helsinki, the port owns the CI facility (see Figures 3 and 4; Port of Helsinki, 2023; Port of Oslo, 2023).

In Oslo, one of the port's larger customers (i.e., shipping company) paid for the capital expenditure of the CI infrastructure and owns that infrastructure. Now, the customer pays only the port fees for connection and disconnection, as the port assists them with operating the CI terminal. Roughly 30% of the funding from the project came from Enova, which manages Norway's Climate and Energy Fund (Port of Oslo, 2023). Mixed structures can co-exist within one port, as demonstrated in Oslo, where the port can operate with a facilitator model (e.g., for a large customer that might have its own terminal) and in an intermediary model with other shippers on different terminals. In Helsinki, the CI project received 30% of its funding from the European Union (Port of Helsinki, 2023). Ships in two terminals buy electricity directly from suppliers. In these cases, the port has built and operates the CI terminal. The customers pay the port fixed fees, which are designed to cover their capital expenditures within 15 years. In both ports, these fees were negotiated between the port and customers before the CI terminals were built. The ports agreed to this arrangement because of the customers' size and importance outside of their CI operations (Port of Helsinki, 2023).

### *3.4 Discussion of Best Practices*

In this section, we will try to summarize the key take aways from the three business models identified above (summarized in Table 2). The most important technical feature that alters depending on the business model of the port is the *level of collaboration with the grid operator*. Specifically, in the "Standard Intermediary" model, the port worked collaboratively with the grid operator because of the increased power demand due to CI. That was the case in the Port of Oslo, which has nine terminals and retains a close working partnership with the grid operator. However, the ports under the "Active Intermediary" model require an even more increased collaboration with the grid operator, far beyond the one required in the "Standard Intermediary" model. That is because those ports typically host more terminals (see, for instance, the Port of Stockholm that has eighteen terminals) and thus have much increased power needs that must be accommodated. Compared to ports following the "Standard Intermediary" model, the "Active Intermediary" ports pay the grid operator not only for the connection fees but also for the network upgrades necessary to support demand. Also, in those cases, the grid operator shares data with the ports so they can work collaboratively to figure out how to increase capacity. As such, the "Active Intermediary" business model shows that large scale CI necessitates a deep, collaborative relationship with the grid operator to responsibly scale demand.

**Table 2.** Summary of the Three Business Models of Cold-Ironing

| **Key Characteristics** | **The Three Business Models of Cold-Ironing** | | |
|---|---|---|---|
| | **Standard Intermediary** | **Active Intermediary** | **Facilitator** |
| **Scale of operations** | Small | Large | Medium-Large |
| **Relationship with grid operator** | Grid sets parameters for the port | Active involvement; data sharing; payment to grid operator for network upgrades | Grid allows direct access to electricity suppliers; Large customers negotiate directly with suppliers |
| **Infrastructure Investment** | Port & Public (Grants) | Port & Public (Grants) | Shipping Companies, Port & Public (Grants) |
| **Operator of the CI infrastructure** | Port | Port | Port & Shipping Companies |
| **Competition for sale of electricity** | Closed | Closed | Open |
| **Price for the provision of Cold-Ironing** | Markup on electricity | 5-6% markup on operating costs, prorated to electricity use | Small fee priced to cover operational expenses |
| **Customer Segments** | Predominantly frequent customers | Mix of frequent and infrequent customers | Exclusive use |
| **Sales pathway** | Port as Intermediary | Port as Intermediary | Electric companies sell directly to customers (ships) |

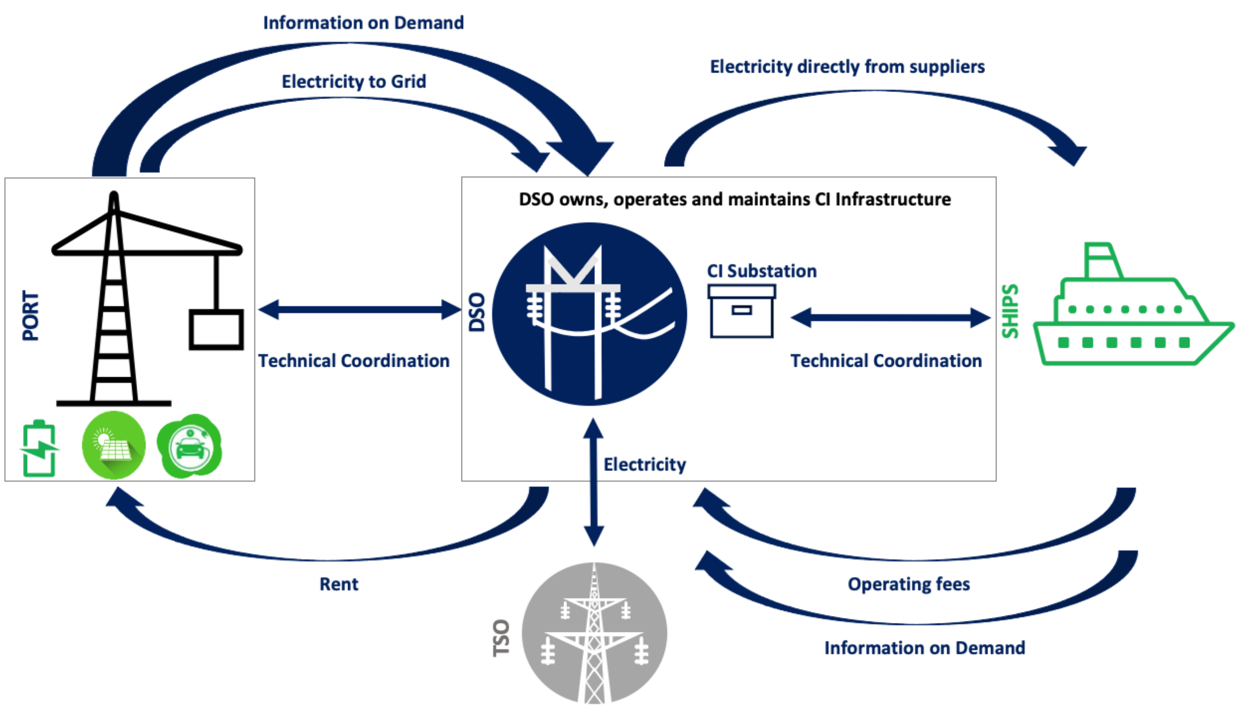
Compared to "Standard Intermediary" and "Active Intermediary", the "Facilitator" business model presents a fundamentally different arrangement for CI that could solve some of the challenges in CI implementation. In the case where shipping companies pay the capital expenditure for the CI infrastructure they use, this could help alleviate funding challenges for ports. This is particularly relevant given recent research that suggests that paying the capital expenditure for CI is a challenge for small and medium-sized ports (Bullock et al., 2023). In addition, the port no longer acts as an informational relay between customers and the grid operator on how much electricity they demand as the ship's connection is an extension of the grid directly to the customer, without the port as an intermediary. This arrangement could potentially help to provide information on CI demand more effectively to the grid operator and reduce the investment costs for ports.

Second, our analysis showed that *while port CI infrastructure is primarily operated by ports, it doesn't have to be*. This finding contrasts with the literature on technical implementation of CI (Lyridis et al., 2023; Manos et al., 2023) that attributes a predominant influence to ports in the operation of CI. Our findings suggest that many ports have already contracted out the construction of CI infrastructure and, in some of them, the contractors also operate the CI system for a predefined period of time. This arrangement along with differential fee structures provide flexibility for sharing revenue among parties (e.g., fees, markup on electricity). Third, our analysis indicates that *ports will gain more bargaining power over ships* with the recently enforced EU regulations (i.e., FuelEU and AFIR). Prior to the regulations, and especially the FuelEU that mandates CI adoption by ships, the possibility for container and passenger ships to self-generate constrained the ability of monopolist suppliers of in-port electricity to exert their market power. After the application of the regulations, the possibility of bypassing the port-supplied electricity is eliminated except for stored energy power, or zero-emissions technologies for use within the port, such as solar or wind on the ship, or on-board fuel cells with no emissions. In the two examples of the "Facilitator" model that we investigated, customers negotiated to buy electricity directly from suppliers because they believed they could get a better price on the competitive marketplace (Port of Helsinki, 2023; Port of Oslo, 2023). In both models though, ports charged a fee based on the amount of electricity consumed. Notably, the Port of Stockholm, which was not allowed to charge a margin on electricity, charged a margin on the grid connection fee (Port of Kapellskär, 2024). Specifically, it prorated the amount of this fee each customer paid to the amount of electricity used (Port of Kapellskär, 2024), effectively amounting to a margin on electricity. Thus, even in "Facilitator" business model, the ports exercised their power towards ships by implementing extra fees and charges to their own benefit (i.e., implement a monopoly market model in contrast to the European market rules both for energy provision as well as other port services, (2017/352 Regulation and 2019/944 Directive).

### *3.5 "Extension-to-Grid": A new Business Model of Cold-Ironing*

To tackle the limitations identified in the three CI business models currently in place, we suggest a fourth configuration that puts grid operator(s) at the heart of CI (see Figure 5). Specifically, we propose the "Extension-to-Grid" business model where the grid operator is the stakeholder responsible for contracting out the CI infrastructure development and takes over (or oversees) its operation. In that case, the grid operator connects electricity supplier(s) with customers (i.e., ships) and enables effective communication over the load placed on grids. Hence, ports are no longer informational intermediaries between the seller and the customers, and information asymmetries are minimized. Also, by bundling the grid and CI infrastructure, the joint grid/CI owner internalizes negative affect on the network, ensuring responsible implementation of CI in the short time limits posed by the EU regulations. Third, by assigning grid operator the role of connecting ships to the competitive energy marketplace, the "Extension-to-Grid" model stops ports from raising electricity hidden costs (such those presented in the "Facilitator" business model) and balances their increasing power due to recently enforced EU regulations. Furthermore, the "Extension-to-Grid" business model ensures that the technical expertise needed for the implementation of the CI will be easily accessible and that the common oversight of the entire system will eliminate coordination challenges. Finally, implementation of CI is often limited by access to capital, particularly for small and medium size ports. The EU mandatory regulation affects EU comprehensive ports, which are mainly small and medium sized. The "Extension-to-Grid" business model could provide an opportunity for grid operators to invest in developing CI infrastructure in those ports and, thus, help enable projects that otherwise would not be built or would be delayed.

**Figure 5.** The "Extension-to-Grid" Business Model




While the "Extension-to-Grid" business model limits information asymmetries, enables effective coordination between involved parties, and protects consumers, it does not come without limitations. A key limitation of the suggested model is that it requires large investments by the grid operators both for the development of the CI infrastructure as well as for the upgrade of their network reaching to ports (e.g., medium/high voltage substations upgrades, new power lines dedicated to CI). Of course, like in current CI implementations, grid operators can access EU funding schemes (e.g., decarbonization fund, Connecting Europe Facility) to support the CI infrastructure development. Second, the suggested business model may need to overcome legal barriers. For instance, the CI system is typically placed within ports' limits some of which are fully or partly privatized. Hence, the necessary legal requirements need to be carefully considered so that they allow grid operators to "own and operate" the CI systems which are placed in ports. Third, such an "Extension-to-Grid" business model may demotivate ports from the quick implementation of the CI, as their revenues from the provision of electricity to ships will be capped. However, it will enable them to reach their sustainability/environmental goals as emissions at berths will be minimized.

In conclusion, our analysis extends the literature on the technical implementation of CI ports (Lyridis et al., 2023; Manos et al., 2023) by identifying and analyzing the agency relationships between the stakeholders of CI (Jensen & Meckling, 1976; Ross, 1973). First, by utilizing extensive fieldwork and the BMC tool, it defines the ten core elements of the business models of CI. Second, and based on those core elements, it presents three distinct business models (i.e., the "Standard Intermediary", the "Active Intermediary" and the "Facilitator") that ports currently follow in the implementation of CI and draws their similarities and key differences. We argue that a missing business model would alleviate the challenges identified in the following dimensions: the port-grid operator collaboration intensity, the operational capacity for CI, and the market power that ports may gain from the recently enforced EU regulations (i.e., FuelEU and AFIR). Thus, we now proceed to explore in more detail the market power and port-grid collaborator questions in more detail. These illustrate that the benefits to customers and grid stability of the "Extension-to-Grid" business model will be large in some instances, and that the model may be more important for some types of customers and for some types of grid constraints.

### *3.6 Customer Protection under the "Extension-to-Grid" Business Model*

A key reason why we suggested a missing business model (i.e., "Extension-to-Grid") is because the literature on technical implementation of CI has provided a disproportionate attention to ports in the provision of electricity to ships (Lyridis et al., 2023; Manos et al., 2023). However, the recently enforced requirement of the article 6.1 of the FuelEU (2023/1805/EU) could further enhance ports' market power as electricity pricing is heavily dependent on ports' decisions (see also how ports under the "Facilitator" business models adapted their pricing policies), especially if there is no regulatory oversight (Biggar, 2022; Wang, Si, & Hu, 2023). Additionally, while the 2017/352/EU Regulation on port services requires at least 2 energy providers within ports, our research revealed that it does not practically apply so far. The regulation also prevents ships from running their engines to self-generate electricity as of 2025. This self-generation possibility always created a second option for ships if they found CI prices too high, which constrained the ability of monopolist suppliers of in-port electricity to exert their market power. After the application of the regulation, the possibility of bypassing the port supplied electricity is eliminated except for stored energy power, or zero-emissions technologies for use within the port, such as solar or wind on the ship, or on-board fuel cells with no emissions. In practice, many of these options will be more feasible for new, purpose-designed ships to implement than existing ships. The possibility of price increases from lack of alternatives to ships exists most obviously in ports that are privately owned, but can equally exist in state-owned ports, to the extent that state-owned ports may choose to exert their market power[8].

The importance of considering the impacts of potential use of market power in a regime with no alternative source generation that creates emissions in the port can be illustrated by considering the effect of profit maximization in a standard monopoly model with linear demand. Figure 6 illustrates that, for a given level of price and demand prior to the creation of market power for ports, price impacts will be relatively modest in a highly elastic demand ($D_1$), with a price $p^m{}_1$ that is close to the cost to the monopolist of energy c, while less elastic demand ($D_2$) yields a substantially higher price $p^m{}_2$ and a highly inelastic demand ($D_3$) yields a very much higher price, of $p^m{}_3$. The welfare costs to ship owners of exercise of monopoly power can be very substantial in the case of inelastic demand. This is because the lack of a self-generation alternative to ships after the regulation takes force has an automatic effect of making demand more inelastic.

**Figure 6.** Demand Slope Implications for Margins and Welfare

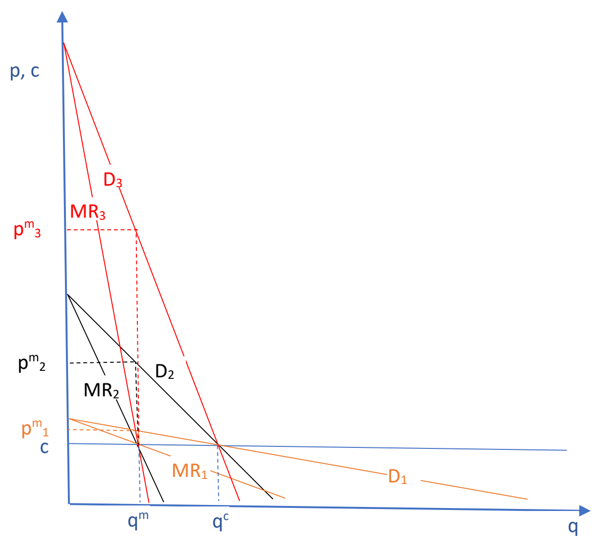



**Table 3.** Demand Elasticity Impact on Pricing by Ports that Fully Use Market Power

[8] One analogy with ports is publicly run hospitals. Simpson and Shin (1998)find that in systems where hospitals set their own prices, publicly run hospitals do set higher prices when they have market power.

| Hypothetical cost of electricity to port (Eurocents per KwH) | Slope of demand | Port Price When Monopoly Power Fully Exercised (Eurocents per KwH) | Ship welfare loss as ratio to cost of energy purchased by ship |
|---|---|---|---|
| 10 | -0.1 | 12 | 0.2 |
| 10 | -0.25 | 15 | 0.5 |
| 10 | -0.5 | 20 | 1 |
| 10 | -0.75 | 25 | 1.5 |
| 10 | -1.0 | 30 | 2 |
| 10 | -2.5 | 60 | 5 |
| 10 | -5.0 | 110 | 10 |
| 10 | -7.5 | 160 | 15 |
| 10 | -10.0 | 210 | 20 |

*Note: Figures for excess costs calculated compared to initial starting point of ships receiving energy at constant marginal cost. Two part tariffs may aid CI constructors to recover their cost of construction in a regulated environment aimed at keeping variable prices close to variable costs.*

The possible scale of price impacts for different slopes of a linear demand curve is provided in Table 3. This table strongly suggests that shipping, which has particularly inelastic demand, can be subjected to substantial market power. The inelastic demand may originate, within a ship, from the limited capacity to have solar and wind generation on the ship generating needed power, combined with a constraint on the installation of batteries, e.g. due to full space utilization on existing ships and limited ability to repurpose space with existing uses. Based on these criteria, we hypothesize that container and freight shipping would have moderate elasticity of demand for energy from CI while cruise ships would have highly inelastic demand, due to the limited ability to reduce usage on a ship while satisfying its cruise customers and due to the full utilization of existing space that prevents the installation of large battery sources that would be needed for in-port self-provision of electricity.

These figures and price simulations suggest that, particularly where ports have a higher likelihood of exercising market power, e.g. due to their private ownership, innovative approaches to the provision of electricity may be needed that would constrain the port monopolist incentives. These possibilities can be considered within the broader regime of EU regulatory change for innovation. They show that prices for marginal usage can vary from close to the cost, if purchasers are highly elastic, to about 20 times the cost, if demand is highly inelastic. The figures illustrate that shipowners' welfare loss as a share of the true costs of what it uses (and port profit) can vary by a factor of 100 for demand curve slopes varying between -.1 and 10. The idea that pricing is potentially a variable of revenue generation for ports can be seen from comparing the limited information that we could find from the authors gathering information from European ports that already have CI. In this exercise, we found that prices as of the first half of 2024 ranged as below in Table 4.

**Table 4.** Prices for electricity in European ports with CI, March 2024

| Port | Price per KWh (euros) | Public or Private | Connection fee/ other (euros) |
|---|---|---|---|
| **Kiel** | 0.52 | Public | 29.00 |
| **Kristiansand** | 0.32 | Private | 461.55 - 1075.51 connection/disconnection |
| **Stockholm** | 0.17 | Public | 17.06 - 86.18 per day fee for use<br>Connection fee priced to cover port's costs of connection/disconnection |
| **Gothenburg** | 0.13 | Public | 75.54 - 235.49 for connection/disconnection |
| **Antwerp** | 0.27 | Public | |
| **Bergen** | 0.52 | Public | 881.03 per call |
| **Alesund** | 0.33 | Public | 1762.06 |
| **Marseilles** | 1.02 | Public | |
| **Cuxhaven** | 0.41 | Private | |

With enhanced market power from regulation, the level of electricity pricing by ports, and subsequent ship welfare loss could differ by shipping type. We can find suggestive evidence of relative elasticities of different types of electricity utilization by analogy with land-based uses, due to lack of focused demand elasticity estimates for ships in ports. We hypothesize that cargo and container vessels may have demands for electricity that are comparable to long-run industrial customers on land. This is because they have high control over the nature of devices and use of electricity on board and will have a business reason to pay attention to prices. Recent estimates of long-run elasticity for industrial electricity customers have varied in a range from -0.75 to -1.01.[9] In contrast, due to the nature of cruise ships, with usage being highly independent of price and determined largely by individual users who are not paying the costs of the electricity they use, elasticity may be much more inelastic, comparable to short-term residential elasticities for electricity, or even lower due to the user non-payment for electricity. These have been estimated in the range of -0.07 to -0.33.[10] Applying these estimates to our pricing and welfare loss estimates, in the presence of monopolist pricing, for the case of cargo vessels, one might expect a welfare loss on the order of the level of cost of electricity and for cruise ships, the welfare loss could easily be on the order of 10-20 times the cost (or even more).

Where the risks of market power and coordination and off-port investment are important, the business model we suggest has important advantages over more traditional models. Up until now, most CI has occurred in a voluntary context via contracting with an outside option (even if discouraged) for the shipowners to create energy by self-generating while in port. This own-source option is no longer present for pre-existing ships with implementation of the new CI regulation in the EU. The scenarios for electricity pricing to shipowners are summarized in Table 5. This shows that when the contracting nexus for electricity via mandated CI is via privately owned ports, there is a high risk of monopoly pricing, while when the nexus is with publicly managed ports, the outcome need not be monopoly pricing (but could be). In contrast, if Extension-to-Grid business models are adopted, the risks of market power exercise are limited due to existing regulatory oversight of distributors. We hypothesize that contractual patterns observed so far in the case studies are more in the bottom left corner of Table 5, but that another desirable alternative, particularly when ports are privately operated, is in the upper right-hand side with distributor contracting to the ship.

**Table 5.** Electricity Pricing to Shipowners

| | **Port** | **Distributor** |
|---|---|---|
| **For profit** | Monopoly pricing | Cost recovery |
| **Non-profit** | Ranging from cost recovery to monopoly pricing | Cost recovery |

The potential for such market power can reduce shipowner willingness to enter into CI contracts in ports where market power is exercised. The self-generation constraint disappears under our reading of Section 6 of the new FuelEU regulation. This is not to suggest that regulation to encourage CI is not needed. EU regulation helps to foster innovation as it defines the parameters for a new market, incentivizes innovation

[9] See Csereklyei (2020) for survey results and Burke and Csereklyei (2016)for an estimate of -0.88.
[10] See Csereklyei (2020) and (Espey & Espey, 2004), respectively.

through taxes and subsidies, and coordinates standards. These regulations help create pressure that solves the "chicken-and-the-egg" problem of coordinating investment in CI shoreside and shipside. Thus, the effect of this regulation is pro-innovation. Nonetheless, the same regulation has effects that both promote innovation and can still lead to a suppression of innovation adoption, due to potential market power effects. How can these effects be separated?

Our examination of the business models of CI may provide a solution. The "Facilitator" model enables ships to buy electricity directly from suppliers. By removing the port as the "de-facto" intermediary, the facilitator model eliminates their market power. In fact, even providing the option for ships to use the facilitator model could act as a competitive constraint on ports. To enable this, policymakers should consider granting grid operators the right to build CI infrastructure within ports and the right to connect electricity suppliers with grid as an extension of their normal operations. In the previous section, we analytically discussed the importance of the "Extension-to-Grid" business model, that places grid operators at the center of CI implementation, its merits, and potential drawbacks. While we did not see any example of this practice, we did see that, in Helsinki, the port operates via a "Facilitator" model but does not own the CI system. Indeed, many ports such as Kristiansand already contract out their CI system operation (Port of Kristiansand, 2024). Enabling third parties to compete in the CI market with the "Extension-to-Grid" model would help to prevent the market power abuses potential of other models, due to distributors already operating within a regulated revenue context. Application of the model could also help ameliorate the constraint of high capital costs, given that distributors often have large capital availability for investment. Given that CI investment is often prohibitively expensive for smaller ports (Bullock et al., 2023), the option to bringing in grid operators and/or electricity suppliers to invest directly in CI infrastructure would help capitalize otherwise unfunded projects and facilitate CI adoption.

### *3.7 Small Ports and Island Provisions under the "Extension-to-Grid" Business Model*

The ultimate organizational challenge for the delivery of CI is over the contracting structure for delivery of the product (Estache & Wren-Lewis, 2009; Laffont, 2005) combined with the technical constraint for the constant network balance. One of the challenges for the product is that in smaller electricity markets, such as islands and smaller ports (Innes & Monios, 2018), the port is unlikely to generate its own energy and so would need to draw electricity from the general usage grid (in any case non interconnected islands are exempt from the AFIR regulation). The volume of electricity at stake in a large cruise ship is like that of a small town. Thus, when a large ship draws electricity, this can challenge the provision capacity and network stability of the non-port electricity network, unless there is close coordination with the generation facilities and the overall network balancing task.

Absent the upgrading of surrounding infrastructure when it has been built to pre-existing need, the risk of brownouts and blackouts from CI on small islands is present, due to the relative electricity demand of small islands and large cruise ships. As a technical matter, avoiding brownouts and blackouts requires the installation of additional distribution and potentially transmission and generation facilities. Moreover, the connection of a large user, like a cruise ship, to the distribution network creates a coordination challenge for additional energy supply simultaneously to achieve constant network balance. The grid-port-ship coordination challenge can be greater in the presence of vertical contracting than with vertical integration, suggesting that for smaller networks, there is more reason for vertical integration of CI port facilities with grid operation and electricity provision (Williamson, 1985). The relative importance of these additional investments for networks and information sharing (for increased level of production) is much larger on small ports and islands than in urban conglomerations. Whatever solution is found for coordination, the cost of building the additional infrastructure arises as a result of the network's need to satisfy a particular type of client at a particular location. As a result, the question arises of how to ensure the outside-the-port costs of infrastructure upgrading are borne by the actual users and not by the general population, particularly as the general population is not using the cruise ships. There is a high risk that investments carried out specifically because of the demand challenges posed by CI are borne by users in general, due to the difficulty of separating out costs for ports from other costs and due to a potential inability to charge the ships for the outside the port upgrades necessary for their CI.

Suppose the contracting between the ships and "electricity supplier" is with the port. Then the incentives of the port must be examined. Private ports may have different profit incentives from municipally or state-run ports (Arlt & Astier, 2023). These profit incentives would suggest that a private port may wish to charge a profit-maximizing price for electricity connections. Some customers may have other alternatives, such as ships with wind or solar power. If ships have no other reasonable choice of supply and have a high need, the port will technically lie in a monopoly position, which permits monopoly pricing. The port will not have fully aligned incentives with the social ones to ensure that the non-port electricity network has balanced electricity suppliers, and thus to avoid brown outs or blackouts. In contrast, if the port is a public operator, owned and run for the benefit of the state, it will not have as large an incentive to act as a profit maximiser towards berthing ships over the pricing of electricity supply. The port will still not have fully aligned incentives to ensure that the non-port electricity network has balanced electricity supply at all times, and thus will leave small communities around a port more exposed to brownouts or blackouts than large population basins. If the ship contracts for electricity supply via the distributor, it will then have access to supply options that are in line with those overseen by the distributor and its regulator. The distributor will have well-aligned incentives to ensure network balance and will be in a position to ensure the coordination needed between ship connection and disconnection and network stability.

For small islands that are unconnected to a national grid, the network cost per Mw of usage for CI is likely to lie at a higher level than for the same quantity of land-based users, because the infrastructure costs for both building in the port and upgrading outside the port will be spread over a relatively small amount of hours of usage compared to a constant land-based user. The principal of cost recovery for costs caused by a new connection will dictate that the network connection costs for CI will be higher. These observations suggest that the contracting scenarios have different implications for both pricing to shipowners and for stability of electricity supply. We further showed earlier that the difference between monopoly pricing and cost recovery can be quite large for shipping, particularly for cruise ships due to their highly inelastic demand (comparable or lower than residential demand in cities). The scenarios for electricity supply stability for the port and outside the port areas are shown in Table 6.

**Table 6.** Stability of Supply Risks

| Size of network | High network coordination | Low network coordination |
|---|---|---|
| **Small** | Stable supply | Blackouts |
| **Urban** | Stable supply | Brownouts |

The scenarios for electricity supply in small markets are here shown to be different depending on the extent of network coordination and outside port network investment that takes place. In particular, the importance of outside the port coordination is emphasized in this model for small markets. Most of the experience with CI in the EU, based on existing case studies, has so far occurred in geographies that are urban. This means the complexities of network configuration in small islands with large ship arrivals in port have so far not been featured in many operating configurations. We conclude that contracting model experimentation is needed for conditions that will have either private ports or small electricity markets. The modelling above suggests the one logical experimentation is to ensure the incentives for network coordination are handled fully by the distributor, which has both a regulated cost recovery oversight that can prevent monopolistic exploitation of the shipowners, and where the distributors have the normal responsibility of network balancing. Thus, we suggest novel regulatory and contractual arrangements for CI are well justified in the particular conditions of small ports and islands.

## 4. CONCLUSION

The decarbonization of maritime transport through CI presents both a regulatory mandate and a strategic opportunity for innovation. This paper examined how ports across Europe are responding to these new requirements, revealing three distinct business models that reflect different approaches to investment, pricing, and stakeholder coordination. While these models demonstrate early adaptation, they also expose important risks: market power in electricity pricing, uneven cost burdens, and fragile grid integration, particularly in smaller ports and island settings. In response, we propose a new business model coined as "Extension-to-Grid" that shifts the primary responsibility for cold-ironing infrastructure from ports to grid operators. This model offers several advantages: it reduces information asymmetries, curbs monopoly pricing, and facilitates better coordination between electricity supply and demand. It also enables more equitable access to infrastructure for smaller or less capital-rich ports, helping to prevent a two-speed transition. More broadly, our findings contribute to the growing literature on how regulation drives business model experimentation in energy and infrastructure sectors. They also point to the importance of regulatory design in aligning commercial incentives with long-term regulatory goals. As investment in CI accelerates, getting its governance right will be just as important as the technology.

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