

Regulatory Intermediation and Energy Transition Readiness at the Port of Keelung, Taiwan

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Received: 26 August 2026; **Revised:** 9 Sep 2026; **Accepted:** 21 Sep 2026; **Published Online:** 1 Oct 2026

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ABSTRACT- International maritime environmental regulation is changing port sustainability from a predominantly local environmental-management task into a cross-organisational challenge involving vessels, energy systems, terminal operations, logistics customers, public authorities, and port-city communities. This article examines how the International Maritime Organization's greenhouse-gas framework and the European Union's FuelEU Maritime regime transmit strategic pressure to the non-EU Port of Keelung in Taiwan. The study develops a qualitative, embedded single-port research design that combines regulatory mapping, documentary analysis, official performance evidence, and a transparent Keelung Port Regulatory-Energy Transition Readiness Index (K-RTRI). The index is a diagnostic instrument rather than an emissions inventory. It assesses five dimensions on a 0–4 ordinal scale: regulatory exposure, infrastructure preparedness, governance and disclosure, operational incentives, and just-transition capacity. Evidence indicates that Keelung has moved beyond general aspiration. Its ESG roadmap, EcoPort engagement, smart-port initiatives, carbon-reduction programme, port-city cooperation, and planned high-voltage shore-power system at East Wharf No. 4 show meaningful institutional mobilisation. At the same time, publicly available evidence remains stronger for plans and implementation outputs than for recurring measurements of electricity delivered, actual shore-power connections, fuel displaced, or verified emissions avoided. The conservative overall K-RTRI score is 2.0 out of 4.0, signalling emerging readiness with a significant implementation and verification gap. The article proposes a management framework based on regulatory anticipation, contracted utilisation of clean-energy infrastructure, tiered green-port services, modular investment, verified data architecture, and a just port-city transition. The central argument is that Keelung's competitive advantage will depend less on selecting a single future fuel than on building a governance architecture capable of converting regulatory uncertainty into coordinated investment, measurable environmental performance, and socially legitimate port services.

KEYWORDS- Energy Transition, FuelEU Maritime, Maritime decarbonisation, Port Governance, Port of Keelung.

I. INTRODUCTION

International shipping is entering a period in which environmental regulation, energy transition, commercial contracting, and port management are becoming increasingly interconnected. Historically, environmental management in ports focused primarily on impacts occurring within or immediately adjacent to the port estate, including emissions from auxiliary engines, cargo-handling equipment, trucks, and harbour craft, as well as waste management, dredging, water quality, noise, occupational safety, and land-use conflicts. These responsibilities remain important, but they are now accompanied by a broader set of requirements concerning greenhouse-gas intensity, life-cycle fuel accounting, carbon pricing, energy efficiency, zero-emission operation at berth, emissions disclosure, and supply-chain accountability.

This change expands the environmental-management boundary of the port. Port sustainability can no longer be evaluated solely through the environmental performance of port-authority buildings, vehicles, cranes, and infrastructure. The relevant system increasingly includes vessels, terminal operators, energy suppliers, shipping lines, cargo owners, logistics providers, public authorities, and surrounding communities. Port authorities therefore occupy an increasingly important intermediary position between international regulation and local operations. They translate external regulatory and market requirements into infrastructure decisions, service standards, investment priorities, contractual arrangements, data practices, and stakeholder relationships.

The most important global policy direction is provided by the International Maritime Organization's (IMO) 2023 Strategy on Reduction of Greenhouse Gas Emissions from Ships. The strategy calls for at least a 40% reduction in the carbon intensity of international shipping by 2030 relative to 2008, an uptake of zero- or near-zero-greenhouse-gas technologies, fuels, or energy sources representing at least 5% and striving for 10% of international shipping energy use by 2030, and net-zero greenhouse-gas emissions from international shipping by or around 2050 [1]. The strategy also places greater emphasis on life-cycle emissions and a just and equitable transition.

These global objectives are reinforced by IMO's operational energy-efficiency measures under MARPOL Annex VI. The Energy Efficiency Existing Ship Index (EEXI) and

Carbon Intensity Indicator (CII) place direct compliance responsibilities on shipowners and operators, but their effectiveness is influenced by port-call conditions. Waiting time, congestion, berth duration, cargo-handling efficiency, arrival coordination, and access to lower-emission energy services all affect the operational environment in which vessel carbon performance is managed [2]. Port authorities may therefore influence shipping decarbonization even when the regulatory obligation formally falls on the vessel. A further layer of pressure arises from the European Union. FuelEU Maritime establishes progressively stricter limits on the greenhouse-gas intensity of energy used by ships calling at European ports and applies a well-to-wake accounting approach that includes carbon dioxide, methane, and nitrous oxide [3]. It also introduces requirements for onshore power supply or alternative zero-emission technologies for relevant passenger and container vessels at covered European ports [4]. In parallel, the extension of the European Union Emissions Trading System to maritime transport introduces an explicit carbon-pricing dimension into shipping operations [5].

Although these European measures apply territorially to the European Union, their commercial effects are not necessarily confined to Europe. Maritime transport is organised through interconnected service networks rather than isolated port calls. Shipping lines serving both European and Asian markets may standardise vessel deployment, energy procurement, emissions accounting, and reporting procedures across multiple routes. Cargo owners may demand consistent life-cycle emissions information across an entire logistics chain, while cruise and liner operators may increasingly favour ports capable of providing reliable shore power, transparent energy services, and verifiable environmental information.

This creates what this study terms an extraterritorial commercial transmission channel. A regulation may be geographically limited in legal application while influencing the expectations, investment decisions, and service requirements of firms operating outside the regulated territory.

The Port of Keelung provides an appropriate case through which to examine this phenomenon. Keelung combines commercial cargo, passenger, cruise, urban, and infrastructural functions within a geographically constrained port-city environment. Its energy transition is therefore not simply a question of installing lower-emission equipment. It requires coordination among berth infrastructure, electricity supply, vessel compatibility, service pricing, scheduling, safety management, environmental monitoring, public expectations, and investment decisions made under uncertainty regarding future fuels and technologies.

The case is particularly relevant because different port activities generate different transition requirements. Container services depend strongly on scheduling, logistics integration, and operational efficiency. Cruise vessels may generate substantial hotel-load electricity demand during relatively long urban berthing periods. Harbour craft and cargo-handling equipment contribute to local emissions, while the close interaction between port and city makes air quality, noise, traffic, construction effects, and community acceptance highly visible.

Despite growing policy attention to maritime decarbonisation, three research gaps remain.

Existing literature primarily models maritime environmental regulation as an exogenous operational constraint rather than an institutional catalyst restructuring port governance. Concurrently, prior engineering and economic inquiries into shore-side electricity (OPS) and alternative bunkering disproportionately focus on technical feasibility or capital expenditure, often overlooking operational contracting, metered utilisation, and split-incentive dilemmas. Crucially, academic discourse frequently conflates infrastructure announcements with verified emissions abatement—a methodological vulnerability this study explicitly mitigates.

Accordingly, this study addresses three research questions:

- i) How do current and emerging international marine environmental regulations transmit strategic pressure to a non-EU port such as Keelung?
- ii) What level of regulatory, institutional, and operational readiness can be demonstrated through publicly available evidence concerning the Port of Keelung?
- iii) What management strategies can enable a port to transform regulatory uncertainty into sustainable competitiveness without assuming that a single energy technology or fuel pathway will dominate the maritime transition?

This study makes three contributions:

- i) Conceptually, it develops a regulatory-intermediation perspective in which the port authority is treated as an organisational translator connecting international regulation, commercial demand, infrastructure decisions, and local stakeholders.
- ii) Methodologically, it introduces the Keelung Port Regulatory–Energy Transition Readiness Index (K-RTRI), an ordinal diagnostic framework designed for cases in which detailed continuous energy and emissions data are incomplete.
- iii) Practically, it develops a phased management framework linking regulatory anticipation, infrastructure utilisation, differentiated environmental services, modular investment, data verification, operational integration, and just transition.

Analytically, the diagnostic framework isolates confirmed emissions abatement from preliminary infrastructure commitments to ensure empirical rigor. By categorising documentary evidence into commitments, implementation outputs, and empirical outcomes, this approach systematically avoids mistaking capital project announcements for verified greenhouse gas reductions.

II. LITERATURE REVIEW AND CONCEPTUAL FRAMEWORK

A. From Green-Port Projects To Energy-System Management

The intellectual foundation of green-port research emerged from concern over the environmental externalities created by concentrated maritime and logistics activity. Ports bring together ships, trucks, cargo-handling equipment, rail operations, warehouses, industrial facilities, and energy-intensive infrastructure. Their impacts therefore extend across air pollution, greenhouse-gas emissions, noise, waste, water contamination, ecological disturbance, and neighbouring communities.

Early port-environment research emphasised the need to move beyond reactive pollution control toward integrated prevention. Bailey and Solomon demonstrated that air pollution associated with port activity requires coordinated environmental management rather than isolated technical interventions [6]. This perspective is important because many port environmental impacts originate from multiple interacting sources rather than from a single facility.

The role of the port authority consequently extends beyond conventional infrastructure administration. Acciaro, Ghiara, and Cusano argue that port authorities can assume an active role in coordinating energy generation, consumption, efficiency, and renewable-energy adoption throughout the port system [7]. A port authority may not directly own vessels, terminal equipment, or electricity-generation assets, but it can influence land use, leases, access conditions, tariffs, service standards, infrastructure investment, and relationships with public authorities and private operators. This broader role creates a need for measurable environmental performance. Puig, Wooldridge, and Darbra highlight the importance of systematically identifying and selecting environmental performance indicators for sustainable port development [8]. The implication is that sustainability cannot be demonstrated merely by listing environmental activities; meaningful assessment requires indicators capable of linking management action with observable performance.

Green-port development also has a commercial dimension. Lam and Li show that environmental performance can be incorporated into green-port marketing and become part of a port's value proposition to customers [9]. Sustainability may therefore generate competitive benefits when environmental improvements are credible, visible, and connected to services valued by shipping lines and cargo owners.

Taken together, these studies suggest a shift from pollution control toward energy-system and service management. A green port is not simply a port containing environmentally friendly technologies. It is a port capable of coordinating those technologies, integrating them into operations, measuring their utilisation, and converting environmental performance into reliable services.

B. Regulatory Layering and the Port as Intermediary

Comparative research shows that ports differ substantially in the management instruments they use to achieve environmental objectives. Lam and Notteboom demonstrate that leading ports in Asia and Europe employ a broad range of regulatory, economic, technological, and voluntary tools, rather than relying on a single environmental intervention [10]. This supports the view that port sustainability is fundamentally a management-system problem.

The relationship between port and city further broadens the analytical scope. Lam and Yap emphasise that sustainable port-city development depends on multiple stakeholder relationships and cannot be reduced to environmental performance within the physical port boundary [11]. Port sustainability must account for economic activity, urban development, environmental quality, and the expectations of surrounding communities.

Environmental policy may also generate economic opportunities. Woo, Moon, and Lam argue that environmental regulation can reshape port development and create new opportunities associated with green services,

technology, and infrastructure [12]. Regulation is therefore not necessarily only a compliance cost; its effects depend partly on how port authorities and related firms respond strategically.

This logic extends directly into supply-chain management. Lu, Shang, and Lin show that port managers increasingly understand sustainability through the development of sustainable supply chains rather than through isolated port-level environmental measures [13]. Ports operate as nodes within larger logistics systems, meaning that environmental strategies may affect customers and service providers well beyond the port boundary.

Evidence from Taiwan further supports this network perspective. Yang, Lu, Haider, and Marlow find that green supply-chain management is associated with both environmental performance and firm competitiveness in the container-shipping context [14]. Environmental management can therefore be linked to commercial performance when it becomes embedded within broader operational and supply-chain practices.

The environmental boundary of the port also extends inland. Liao, Tseng, Cullinane, and Lu demonstrate through the case of Taipei Port that changes in port location and inland container transport patterns can significantly influence carbon dioxide emissions [15]. This illustrates why port decarbonisation cannot be assessed solely at the berth or terminal level.

The expansion of port sustainability has encouraged the development of broader evaluation systems. Chen and Pak propose green-performance evaluation indicators for Chinese ports using a Delphi approach, illustrating the need for multidimensional assessment frameworks [16]. Such frameworks are particularly important where environmental performance involves infrastructure, operations, governance, energy use, and stakeholder relationships simultaneously.

Measurement must nevertheless remain grounded in observable evidence. Wooldridge, McMullen, and Howe emphasised at an early stage that environmental policy implementation at ports requires scientific monitoring [17]. This point remains highly relevant to contemporary decarbonisation policy: infrastructure installation or policy adoption cannot by itself demonstrate environmental improvement.

The challenge is particularly significant in emerging economies, where technological ambition must be reconciled with institutional capacity and infrastructure conditions. Le and Nguyen's study of green-port development in Vietnam highlights the interaction between environmental objectives and the practical constraints facing ports in emerging economies [18].

Sustainability implementation also depends on organisational behaviour. Tsai, Lu, and Chang, examining the Eco Port of Kaohsiung, show that organisational green climate influences employees' green behaviour [19]. Port environmental performance therefore depends not only on capital investment and external regulation, but also on internal organisational culture, employee participation, and implementation capacity.

Collectively, this literature suggests that sustainable port development is multidimensional. It includes infrastructure, energy, logistics, supply-chain relationships, organisational behaviour, stakeholder participation, measurement, and commercial strategy. These dimensions provide the

foundation for understanding why isolated “green projects” may be insufficient indicators of transition readiness.

C. Shore-Side Electricity As A Socio-Technical Service

Recent literature places ports more explicitly within the global energy transition. Bielenia, Maziarz, and Dumanska argue that green-port strategies and environmental performance must increasingly be reconsidered in light of changing energy systems and decarbonisation requirements [20]. This shifts attention from environmental improvement within existing systems toward the transformation of the energy systems on which port activity depends.

Low-carbon energy consequently becomes a central element of port sustainability. Inal and Dere connect green-port development with low-carbon energy and broader sustainability objectives, reinforcing the need to assess environmental and energy strategies jointly rather than separately [21].

Renewable-energy deployment also introduces new institutional models. Buonomano and colleagues examine the potential for energy-community frameworks to support renewable-energy integration in seaports [22]. Such approaches highlight the possibility that ports may operate not simply as energy consumers but as coordinators within decentralised systems involving generation, storage, demand management, and multiple participating organisations.

At the same time, climate change is increasing the institutional complexity of port governance. Monios and colleagues conceptualise contemporary port governance as increasingly polycentric, involving public authorities, commercial actors, infrastructure providers, communities, and international regulatory systems [23]. As ports assume greater responsibility for energy infrastructure and climate adaptation, decisions about investment, cost allocation, contractual relationships, and public legitimacy become increasingly interconnected.

This literature leads to an important conclusion: port energy transition is not purely an engineering problem. Technical infrastructure is necessary, but its value depends on demand, utilisation, contracts, data, institutional coordination, and long-term adaptability.

This observation is particularly relevant to shore-side electricity.

Onshore power supply (OPS) is commonly described as a technical substitute for auxiliary-engine operation while a vessel is at berth. In practice, however, OPS functions as a socio-technical service.

Its technical feasibility depends on voltage, frequency, power requirements, connection technology, berth configuration, cable handling, vessel compatibility, and grid capacity.

Its operational feasibility depends on berth duration, scheduling, weather, maintenance, emergency procedures, and trained personnel.

Its commercial feasibility depends on electricity prices, connection charges, capital recovery, vessel contracts, port dues, and the relative cost of marine fuel.

Its environmental performance depends on electricity carbon intensity, the fuel displaced, utilisation rates, and the accounting methodology used to calculate avoided emissions.

These dimensions interact. A technically complete OPS facility may generate little environmental benefit if compatible vessels rarely connect. A favourable emissions

estimate may be misleading if electricity delivery and displaced fuel are not measured. If a project is designed without community communication, construction and electricity-demand concerns—particularly potential voltage fluctuations on Taiwan Power Company’s (Taipower) localized urban distribution feeders during high-demand shore connections—can weaken legitimacy. A low-carbon energy project may also encounter resistance if costs are concentrated on particular users while local benefits remain unclear.

For this reason, port-energy infrastructure should be evaluated as a service system rather than as an installed asset alone.

D. Port-City Sustainability and Just Transition

The Port of Keelung possesses an existing institutional foundation for sustainability governance. Its ESG Implementation Roadmap connects environmental protection, prevention, spatial planning, monitoring, occupational safety, urban revitalisation, cultural value, and port-city relationships [24]. This indicates that the port’s sustainability agenda already extends beyond conventional environmental compliance.

The economic and operational context is also significant. Taiwan International Ports Corporation has reported substantial cargo, container, passenger, and cruise activity across the Port of Keelung subsidiary and has identified the development of high-voltage shore-power infrastructure at Keelung East Wharf No. 4 as part of its recent operational development [25]. These developments make energy-transition questions relevant not only environmentally, but also operationally and commercially.

Official statistical information further provides a basis for evaluating the scale and composition of activity associated with Keelung [26]. Such information is important because the environmental value of infrastructure depends partly on the number and type of vessels served, berth conditions, passenger and cargo patterns, and actual utilisation.

At the same time, Keelung remains embedded within the wider international regulatory system. MARPOL Annex VI provides the principal international framework for regulating ship air pollution and improving ship energy efficiency [27]. Although these obligations are largely directed toward ships and operators, their implementation creates indirect requirements for ports concerning operational efficiency, infrastructure, information, and lower-emission energy services.

Keelung therefore represents a useful case of a medium-sized non-EU port exposed simultaneously to global regulation, commercially transmitted regional regulation, domestic institutional structures, local urban pressures, and emerging energy-transition investment requirements.

Its challenge is not simply whether it can install a particular technology. The more important question is whether it can develop the institutional and operational capabilities needed to evaluate, coordinate, utilise, measure, and adapt energy-transition investments over time.

E. Integrated Conceptual Framework

This article combines the literature into an integrated framework with three analytical stages. The first stage is regulatory exposure. It captures the extent to which international and regional rules, customer requirements, route structures, or market signals may affect the port and

its users. The second stage is transition capability. It captures infrastructure, data, finance, organisational coordination, service design, and workforce capacity. The third stage is sustainable competitiveness. It captures whether the port can preserve or improve commercial performance, environmental outcomes, social legitimacy, and adaptive capacity.

The framework proposes the following causal chain:

Regulatory pressure leads to organisational interpretation; organisational interpretation leads to coordinated investment and service design; coordinated investment and service design lead, when measured and governed effectively, to environmental performance and resilient competitiveness.

The chain is not deterministic. Regulatory pressure may produce investment without utilisation. Investment may produce utilisation without verified environmental benefit. Environmental benefit may be achieved while transition costs are distributed unfairly. The framework therefore treats readiness as multidimensional and distinguishes outputs from outcomes.

The conceptual dimensions, core diagnostic questions, operational port-management mechanisms, and indicative evidence underpinning this analytical architecture are systematically summarized in [Table 1](#).

Table 1: Analytical dimensions of regulatory intermediation

Dimension	Core question	Port-management mechanism	Indicative evidence
Regulatory exposure	Which global, regional, national, and customer requirements may affect the port?	Route mapping, regulatory observatory, scenario planning	IMO targets, MARPOL Annex VI, FuelEU Maritime, EU emissions trading, customer requests
Transition capability	Can the port coordinate lower-emission energy and operational services?	Grid planning, OPS, energy efficiency, fuel readiness, safety systems	Berth equipment, metering, compatibility, renewable-energy procurement, training
Governance and disclosure	Are responsibility, data boundaries, verification, and reporting institutionalized?	ESG governance, assurance, digital data architecture	Roadmaps, EcoPort, sustainability reports, energy statements, audit records
Operational incentives	Do environmental services affect prices, schedules, procurement, or customer value?	Green dues, differentiated tariffs, berth priority, contracts	Verified discounts, service tiers, carrier commitments, green procurement
Just-transition capacity	Are workers, communities, small operators, and public finances included?	Port-city forum, training, monitoring, cost sharing	Training records, public consultation, air-quality data, transition fund

The framework is designed for a medium-sized non-EU port. It does not assume that the port can control the entire maritime value chain or finance every technology. Instead, it focuses on the capabilities that a port authority can develop even when future fuels, carbon prices, and international measures remain uncertain. These capabilities include regulatory interpretation, demand coordination, measurement, service contracting, stakeholder participation, and modular investment. They are the foundation for the empirical assessment that follows.

III. INTERNATIONAL REGULATORY ENVIRONMENT AND STRATEGIC TRANSMISSION

A. IMO 2023 Greenhouse-Gas Strategy

The IMO 2023 GHG Strategy provides the principal global direction for maritime decarbonisation. It calls for lower carbon intensity, increased uptake of zero- or near-zero-emission energy sources, and net-zero greenhouse-gas emissions from international shipping by or around 2050. Its well-to-wake perspective also means that environmental performance cannot be assessed solely through onboard exhaust emissions; upstream fuel production, transport, and distribution must also be considered.

For port authorities, the main implication is that energy infrastructure becomes part of climate governance. Ports may need to support shore-side electricity, renewable-energy procurement, alternative-fuel readiness, efficient

logistics, and transparent emissions information. The key management challenge is not to provide every possible technology, but to identify which services match local traffic, grid, safety, land, and commercial conditions while preserving flexibility under technological uncertainty.

The 2030, 2040, and 2050 milestones also affect current investment planning. Ports must balance the risk of premature technological commitment against the risk of delayed adaptation. Investments in metering, energy efficiency, data systems, safety, and workforce capability therefore have particular value because they remain useful across multiple future energy pathways.

The strategy's just-transition principle further requires attention to employment, public health, affordability, and the distribution of transition costs and benefits. For a port-city such as Keelung, technical feasibility alone is therefore insufficient.

B. MARPOL Annex VI, EEXI, and CII

MARPOL Annex VI establishes international requirements for ship air pollution and energy efficiency. The Energy Efficiency Existing Ship Index (EEXI) addresses technical efficiency, while the Carbon Intensity Indicator (CII) evaluates operational carbon performance. Although direct compliance responsibility lies mainly with shipowners and operators, port-call conditions can influence vessel performance.

Waiting time, poorly coordinated arrivals, cargo-handling delays, and inefficient berth operations can increase fuel use

and emissions. Port authorities can therefore support vessel efficiency through accurate berth information, reduced avoidable waiting, efficient cargo processes, and reliable energy services.

A port should not claim responsibility for a vessel's CII rating. Its role is to identify the operational interfaces it can influence and translate ship-level requirements into port-level actions. For Keelung, these include vessel-call data integration, berth coordination, reduced waiting, and integration of energy-service requirements into cruise and cargo scheduling.

C. FuelEU Maritime and the Extraterritorial Commercial Channel

FuelEU Maritime creates a stronger link between energy intensity, emissions data, and port services. It applies to ships above 5,000 gross tonnage calling at European ports and evaluates onboard energy on a well-to-wake basis. Its progressively stricter greenhouse-gas intensity requirements, together with zero-emission-at-berth provisions for relevant passenger and container vessels, increase the importance of compatible energy infrastructure and verifiable environmental information.

Although Keelung is outside the European Union, the commercial effects of FuelEU Maritime may extend beyond EU territory. Shipping services operate through international networks, and carriers may standardise energy procurement, emissions accounting, and operational practices across multiple routes. Cruise operators may also seek consistent shore-power capability across itineraries.

This creates an extraterritorial commercial transmission channel: a regulation may remain geographically limited in legal scope while influencing commercial expectations and service requirements outside the regulated territory.

For Keelung, the appropriate response is not to claim direct compliance with EU law, but to develop capabilities that reduce friction for customers exposed to those requirements. These capabilities include accurate vessel-call records, energy-delivery data, electricity-source information, compatibility assessments, documented connection procedures, and transparent service charges.

This extraterritorial transmission mechanism and the resulting intermediation requirements are illustrated in Figure 1.

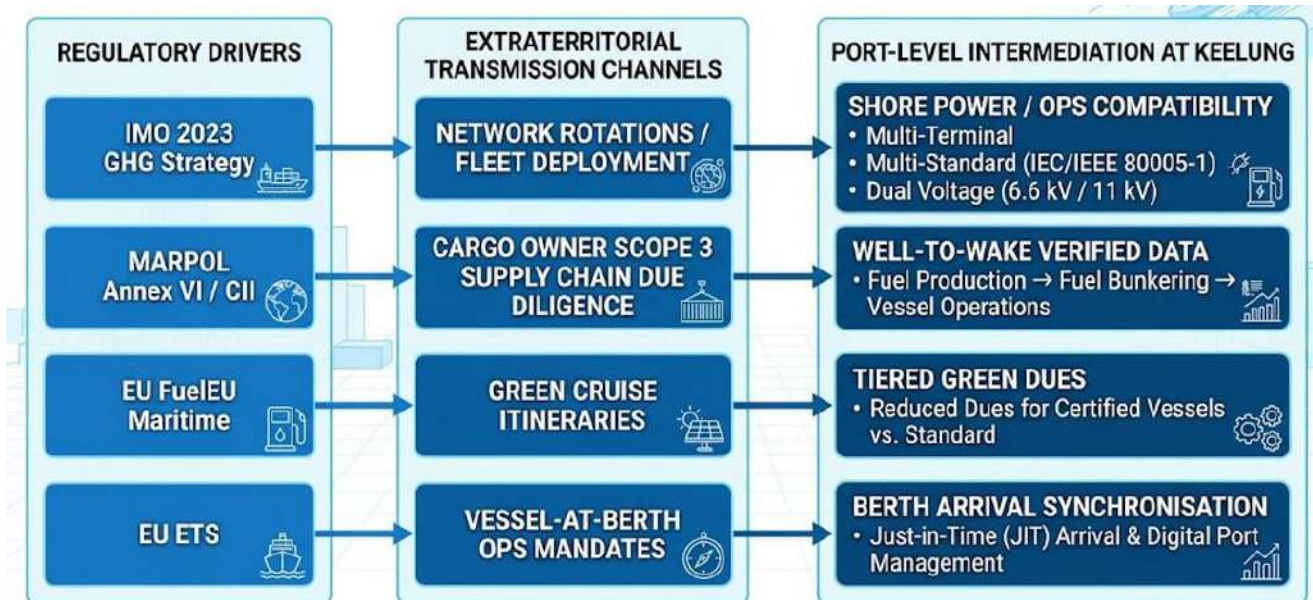


Figure 1: Extraterritorial transmission mechanism of international and regional maritime environmental regulations to non-EU ports

D. Regulatory Comparison and Implications for Keelung

To operationalize the multi-tier regulatory pressures acting upon non-EU ports, Table 2 delineates the specific

regulatory layers, primary duty bearers, time horizons, and their strategic intermediation implications for the Port of Keelung.

Table 2: Regulatory Layers and their Port-Management Implications

Regulatory layer	Main object	Time horizon or status	Primary duty bearer	Strategic implication for Keelung
MARPOL Annex VI, EEXI, and CII	Ship energy efficiency and operational carbon intensity	Operational from 2023 and continuing	Shipowner or ship operator	Reduce avoidable waiting, improve berth coordination, and provide accurate service information
IMO 2023 GHG Strategy	Sector-wide direction toward lower carbon intensity, zero or near-zero energy, and net zero	2030, 2040, and 2050 ambitions	IMO Member States and maritime value chain	Use scenario planning, modular infrastructure, life-cycle accounting, and just-transition principles

FuelEU Maritime	Well-to-wake GHG intensity of onboard energy	Fully applied from 2025; tightening toward 2050	Ships above 5,000 gross tonnage calling at EU ports	Anticipate customer demand for low-carbon energy, verified data, and compatible berth services
EU zero-emission-at-berth provisions	OPS or alternative zero-emission technologies for covered ships	From 2030 in designated ports and from 2035 in other relevant EU ports with OPS capacity	Covered ships and EU port systems	Develop cruise and container service readiness without claiming direct EU legal applicability
EU emissions trading for maritime transport	Market-linked carbon cost for covered maritime activity	From 2024 with progressive implementation	Covered shipping companies and operators	Support fuel-saving operations, reliable schedules, and emissions data that reduce commercial uncertainty
Taiwanese port and environmental governance	Electricity, safety, land, procurement, construction, and local environmental authority	Ongoing	TIPC, central authorities, local government, utilities, and operators	Align international anticipation with domestic legal authority and port-city legitimacy

The comparison reveals a governance gap. International rules define objectives and compliance mechanisms, but they do not automatically tell a port which berth should be electrified first, how a tariff should be calculated, which data should be public, how small operators should be supported, or how local residents should participate. These decisions are managerial and institutional. They are where regulatory intermediation becomes observable.

E. Why Regulatory Anticipation Matters For A Non-EU Port

A non-EU port can respond to regional environmental regulation in three broad ways: wait for direct legal requirements, replicate external rules regardless of local conditions, or selectively anticipate capabilities that are likely to become valuable across maritime networks.

The first approach may reduce short-term expenditure but creates the risk of delayed adaptation. The second may lead to overinvestment or stranded assets. The third preserves flexibility by distinguishing broadly useful capabilities from technology-specific commitments.

For Keelung, broadly useful capabilities include metering, vessel-compatibility records, berth coordination, safety training, data governance, and transparent environmental reporting. More specialized investments, such as large-scale infrastructure dedicated to a particular fuel, should require stronger evidence of demand, safety, supply, certification, and life-cycle performance.

The appropriate strategy is therefore not to delay investment, but to sequence it according to reversibility and strategic option value.

IV. RESEARCH DESIGN AND METHODS

A. Case Selection And Research Logic

The Port of Keelung is selected as a critical case for examining regulatory intermediation under maritime energy transition. It is legally outside the European Union but remains connected to international shipping networks with potential European exposure, allowing the study to examine how regional regulation creates commercial pressure beyond its territorial scope. Keelung also combines cargo, passenger, cruise, and urban functions, producing diverse

operational and stakeholder requirements. Its relatively rich public record further enables documentary triangulation while revealing gaps in publicly available evidence.

The study adopts an embedded single-case design. The principal case is the Port of Keelung within the TIPC port group, examined through five analytical units: regulatory environment, infrastructure and energy services, governance and disclosure, operational incentives, and port-city transition capacity. The study period is 2023–2026, covering the current IMO greenhouse-gas framework and the latest publicly available TIPC evidence concerning high-voltage shore power at East Wharf No. 4.

B. Data Sources And Documentary Boundaries

The evidence base includes four source categories: official IMO regulatory materials; European Commission and European Union legal documents; TIPC and Port of Keelung announcements, statistics, ESG disclosures, and infrastructure information; and scholarly literature on port sustainability, energy management, governance, and transition.

Official sources are used for claims concerning regulation, projects, and reported performance, while academic literature supports conceptual interpretation. No confidential carrier records, proprietary electricity data, vessel fuel logs, interviews, or personally identifiable information were used. The study therefore assesses publicly evidenced readiness rather than undisclosed operational performance.

Each source was examined for four questions: what obligation or capability it establishes; which actors are responsible; what port-level capability is required; and what public evidence shows that Keelung has planned, implemented, measured, or verified that capability.

C. Evidence-level Classification

To distinguish project announcements from demonstrated environmental performance, evidence is classified into three levels.

Level 1, verified outcome, refers to measured environmental performance supported by a defined methodology, boundary, and recurring data.

Level 2, implementation output, refers to a completed or formally documented project, certification, operational policy, management system, or infrastructure installation. Level 3, commitment or planned action, refers to a target, roadmap, announcement, proposed investment, or future action not yet publicly demonstrated as operational. The classification is deliberately conservative. Commitments are not treated as achieved performance, and implementation outputs are not treated as proof of utilisation or emissions reduction. The highest level assigned is therefore limited to what the documentary evidence directly supports. This distinction is especially important for shore power, where installed capacity does not necessarily imply actual connection, electricity delivery, or verified emissions reduction.

D. Development of the K-RTRI

The Keelung Port Regulatory–Energy Transition Readiness Index (K-RTRI) is an ordinal diagnostic instrument designed to assess whether the institutional and operational conditions for regulatory response are in place. It is not an emissions inventory, decarbonisation pathway, or comparative port ranking.

The index contains five dimensions:

Regulatory exposure – recognition of global, regional, national, and customer requirements.

Infrastructure preparedness – ability to provide or coordinate lower-emission energy services.

Governance and disclosure – institutionalization of responsibility, reporting, verification, and accountability.

Operational incentives – linkage between environmental performance and tariffs, scheduling, procurement, contracts, or customer value.

Just-transition capacity – inclusion of workers, communities, smaller operators, public authorities, and transition costs.

Each dimension is scored from 0 to 4: 0 indicates no relevant public evidence; 1 a general commitment; 2 a formal policy or planning instrument; 3 a documented implementation output or external verification; and 4 a recurring verified outcome supported by reproducible data. The overall K-RTRI score is the unweighted average of the five dimensions.

Equal weighting is used because the index is diagnostic, no superior weighting scheme is supported by the available evidence, and equal weights improve transparency and reproducibility.

Scores are accompanied by confidence labels. High confidence requires official implementation evidence or external verification; medium confidence applies where formal policy or project evidence exists but recurring outcome data are limited; and low confidence applies where assessment depends mainly on general commitments or incomplete disclosure. Where evidence supports two possible levels, the lower score is assigned. The scoring criteria are summarized in Table 3.

Table 3: K-RTRI Scoring Protocol

Score	Evidence condition	Interpretation for port management
0	No relevant public evidence	Capability is not publicly demonstrated

1	General commitment, aspiration, or broad ESG language	Intent exists, but no specified instrument is evident
2	Formal plan, roadmap, policy, or defined planning instrument	Capability is being organized or prepared
3	Project, certification, implementation output, or external verification	Capability has entered implementation, although outcome may remain unverified
4	Recurring measured outcome with defined method and verification	Capability is institutionalized and performance is demonstrable

E. Coding procedure and validity safeguards

The qualitative evidence was systematically coded by a single researcher according to issuing institution, date, policy domain, geographic relevance, responsible actor, evidence level, and K-RTRI dimension. To safeguard analytical rigor, structured coding rubrics, explicit operational definitions, and multi-round iterative cross-document verification were strictly maintained. Nevertheless, this single-coder procedure is transparently acknowledged as a methodological limitation, as inter-coder reliability metrics could not be statistically calculated.

Three safeguards were applied. First, legal and regulatory claims rely on official IMO, EU, and equivalent sources, while port-specific performance claims rely on TIPC, Port of Keelung, or recognized port-sustainability sources. Second, the analysis distinguishes Keelung-specific evidence from data applying to the wider TIPC subsidiary, including Taipei and Suao. Third, the absence of a public metric is treated as a disclosure limitation rather than proof that no internal system exists.

The K-RTRI has construct validity as a readiness instrument because its dimensions reflect the sequence through which regulation becomes operational. Its criterion validity is more limited because the study lacks a complete independent emissions inventory. The index is therefore used as a diagnostic tool rather than a performance ranking.

F. Analytical model and propositions

The empirical analysis follows the sequence:

Regulatory exposure → institutional interpretation → capability development → service utilisation → verified outcome → resilient competitiveness.

The transitions are not automatic. A gap at any stage may prevent progress to the next, such as infrastructure without utilisation or utilisation without verification.

The model yields three propositions for future comparative testing:

- Proposition 1: The sustainable competitiveness of a non-EU port is positively associated with its ability to anticipate extraterritorial regulatory requirements affecting its customers and network services.
- Proposition 2: The environmental value of port energy infrastructure is positively associated with contracted demand, transparent utilisation metrics, and integration with berth and vessel scheduling.
- Proposition 3: The durability of port decarbonisation investment is positively associated with institutionalized

cost-sharing, worker transition, and port-city participation.

These propositions are not statistically tested in this study but guide interpretation of the Keelung case and provide a basis for future comparative research.

V. EMPIRICAL RESULTS: KEELUNG'S READINESS UNDER REGULATORY PRESSURE

A. Commercial and Institutional Context

Keelung is a historic port with cargo, passenger, cruise, and urban functions and is managed within the broader TIPC port group. This creates both an opportunity for integrated governance and an analytical constraint: group-level statistics should not be interpreted as Keelung-only energy or emissions performance.

TIPC reported strong operational activity in 2025, including 143.36 million revenue tons of cargo, 3.06 million TEU, 1.11 million passengers, and NT\$5.635 billion in operating revenue. The subsidiary's container yards handled 594,000 TEU, while international cruise activity reached 993,000 passengers. These figures indicate that energy transition must be pursued while maintaining commercially important cargo and passenger services.

The port's cargo-cruise mix creates different transition requirements. Container services emphasize scheduling and logistics coordination, while cruise vessels may create substantial hotel-load demand during longer urban berths. TIPC has also reported smart-port initiatives, sustainability certifications, and EcoPort recertification, indicating institutional and digital capacity relevant to transition. These outputs, however, represent implementation evidence rather than verified emissions outcomes.

The 2022 ESG Implementation Roadmap further connects technology, monitoring, port-city relations, safety, urban development, and cultural preservation, providing an institutional basis for linking energy transition with broader social and urban objectives.

B. Regulatory Exposure

Keelung has high strategic exposure to maritime environmental regulation despite limited direct territorial exposure to EU law. Its customers operate within global shipping networks, and IMO and FuelEU developments may influence fleet deployment, energy procurement, reporting, and berth-service expectations.

Public evidence demonstrates regulatory awareness and sustainability engagement, but no public route-level exposure map identifies EU-linked services, vessel eligibility, or customer demand for well-to-wake information. Such a system would improve operational prioritization.

Regulatory exposure is therefore scored at 3, with medium confidence.

C. Infrastructure Preparedness

The strongest visible evidence is the high-voltage shore-power system at East Wharf No. 4, planned for cruise vessels and designed to international high-voltage shore-connection standards. The project provides a basis for electricity metering, vessel compatibility, safety procedures, maintenance, and customer contracting.

However, public evidence does not establish actual connection frequency, electricity delivered, reliability, cost recovery, grid emission factors, or verified emissions avoided. Evidence of wider renewable-energy, storage, alternative-fuel, and microgrid capability also remains limited.

Infrastructure preparedness is therefore scored at 2, with medium confidence.

D. Governance and Disclosure

Keelung's governance evidence is stronger than its public energy-outcome evidence. The ESG roadmap, EcoPort engagement, smart-port projects, sustainability communication, and port-city cooperation indicate that environmental management is embedded within institutional activity.

However, public reporting does not yet provide a complete verification architecture covering organizational boundaries, electricity sources, consistent time-series data, uncertainty, double-counting rules, and independent assurance.

Governance and disclosure are therefore scored at 3, with medium-to-high confidence.

E. Operational Incentives

Public evidence of differentiated green dues, berth priority, connection contracts, procurement criteria, or other performance-linked incentives is limited. Without explicit benefits, technically compatible vessels may have little commercial reason to use shore power.

A stronger incentive system would link benefits progressively to verified planning, actual OPS use, and independently verified emissions reduction.

Operational incentives are therefore scored at 1, with low-to-medium confidence.

F. Just-transition Capacity

Public evidence concerning worker training, small-operator support, community monitoring, and explicit port-city cost-sharing remains limited. Existing ESG and port-city cooperation provide an institutional basis, but they do not yet demonstrate a dedicated operational transition mechanism.

This gap matters because energy-transition projects can distribute benefits and costs unevenly among workers, contractors, businesses, residents, and public agencies.

Just-transition capacity is therefore scored at 1, with low confidence.

G. K-RTRI Results

The documentary assessment is summarized in [Table 4](#) and visually illustrated in the radar profile in [Figure 2](#). The overall score is the unweighted average of the five dimensions. It should not be read as a performance ranking or as an emissions estimate. Its purpose is to make the implementation pattern visible.

Table 4: K-RTRI assessment for the Port of Keelung

K-RTRI dimension	Score (0–4)	Confidence	Evidence-based interpretation
Regulatory exposure	3	Medium	Global IMO direction, EU network effects, and sustainability engagement are identifiable; a public route-level exposure map is not evident
Infrastructure preparedness	2	Medium	HVSPS at East Wharf No. 4 is publicly announced for cruise vessels; broader multi-fuel, renewable-energy, and grid-readiness evidence is incomplete
Governance and disclosure	3	Medium–high	ESG roadmap, EcoPort engagement, smart management, and sustainability outputs exist; public energy time series and assurance require strengthening
Operational incentives	1	Low–medium	Public evidence of differentiated green dues, berth priority, connection contracts, or customer-linked energy incentives is limited
Just-transition capacity	1	Low	Port-city cooperation is visible, but worker training, small-operator support, community metrics, and cost-sharing are not publicly institutionalized
Overall K-RTRI	2.0	Medium	Emerging readiness with a clear implementation, utilisation, and verification gap

Note: Reported commercial statistics refer to the relevant TIPC subsidiary/group reporting scope (including Keelung, Taipei, and Suao ports) and should not be interpreted as Keelung-only energy or emissions performance

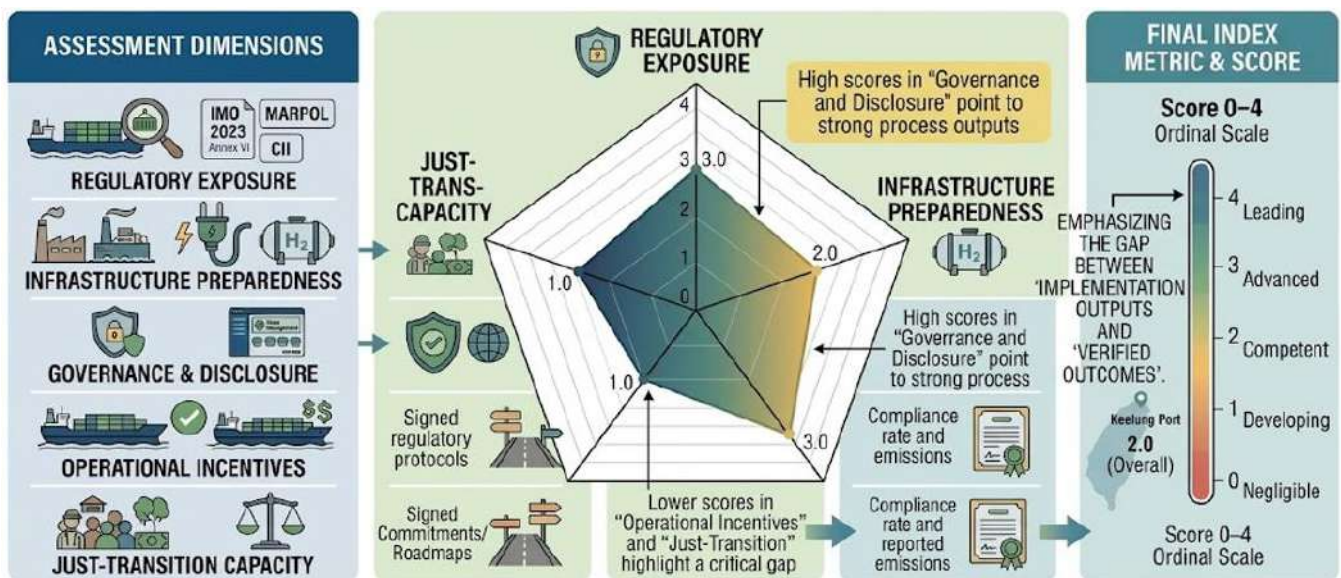


Figure 2: K-RTRI readiness profile across five diagnostic dimensions for the Port of Keelung (Overall Score: 2.0/4.0).

The profile shows stronger regulatory awareness and governance mobilisation, moderate infrastructure preparedness, and weaker operational incentives and just-transition capacity. Five implementation barriers help explain this pattern: fragmented data limit verification and investment comparison; uncertain OPS demand may lead to underutilised capacity; regulatory and technological uncertainty increases the risk of premature fuel-specific investment; Keelung's urban setting makes social legitimacy important; and fragmented organisational responsibilities can weaken accountability for metering, tariffs, verification, and stakeholder communication. Overall, Keelung has begun organizing the transition but has

not yet completed the link from regulation and investment to utilisation, verification, and equitable implementation.

VI. STRATEGIC FRAMEWORK FOR SUSTAINABLE PORT MANAGEMENT

To address the implementation, utilisation, and verification gaps identified by the K-RTRI assessment, this study proposes six interconnected strategies linking regulatory anticipation, infrastructure utilisation, service incentives, modular investment, port-city participation, and verified data governance. The integrated framework is illustrated in Figure 3.

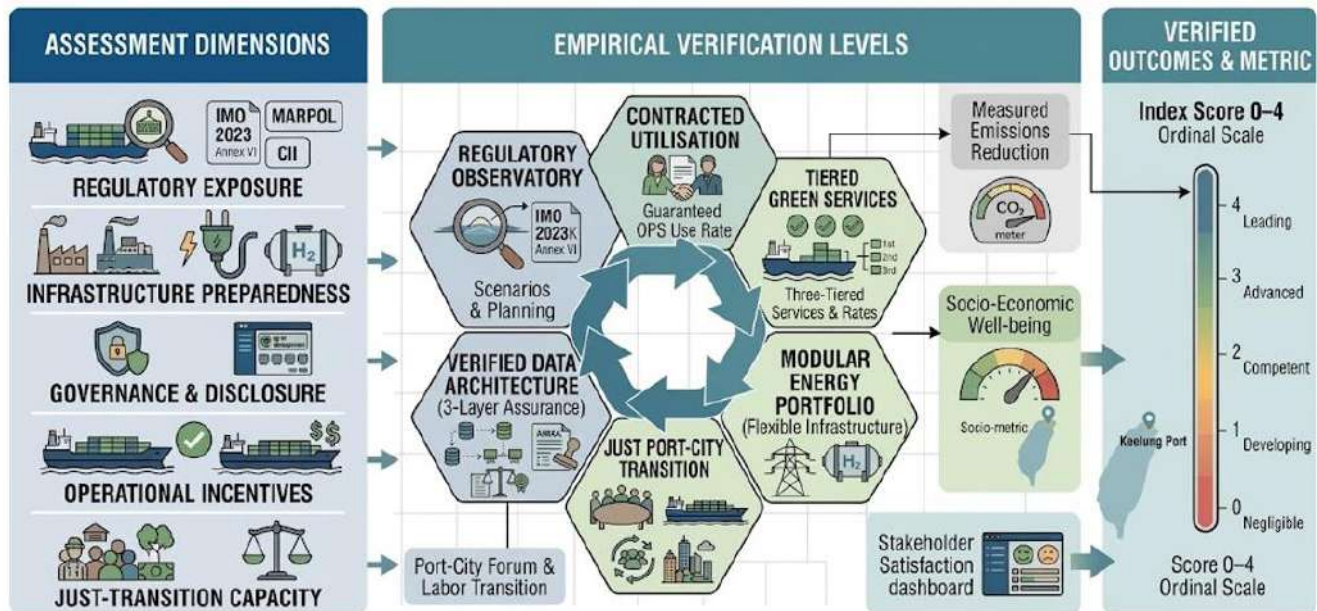


Figure 3: Integrated Strategic Management Framework for Port Decarbonisation and Energy Transition.

A. Strategy 1: Establish a regulatory anticipation and investment observatory

TIPC should establish a Maritime Environmental Regulation Observatory to translate IMO, MARPOL, FuelEU Maritime, EU emissions-trading developments, Taiwanese policies, customer requirements, and technical standards into an operational investment matrix. The matrix should classify vessel services by regulatory exposure, OPS compatibility, energy demand, operational characteristics, and investment priority.

The observatory should maintain a periodic regulatory dashboard and distinguish between no-regret, option-preserving, and high-commitment investments. Investments tied to a single fuel or technology should require stronger evidence of demand, safety, supply, certification, and life-cycle performance.

B. Strategy 2: Move from installed capacity to contracted utilisation

The environmental and financial value of shore power depends on actual use rather than installation alone. Keelung should therefore develop contracted-utilisation arrangements with carriers, terminal operators, electricity providers, and relevant authorities, including targets for OPS-ready calls, connection rates, transparent charges, and risk-sharing during early deployment.

A pilot programme should collect data on actual connections, electricity delivered, fuel displaced, service reliability, and emissions avoided. Public reporting should distinguish measured values from estimates and clearly define accounting boundaries to avoid double counting.

C. Strategy 3: Introduce tiered and verified green-port services

Keelung should link environmental benefits to verifiable service performance through a tiered green-port programme. Lower tiers may recognize documented readiness and vessel compatibility, while higher tiers should reward actual OPS use, certified low-emission energy, or independently verified emissions reductions.

Incentives may include service discounts, scheduling advantages, technical support, or longer-term agreements, but eligibility should be based on transparent evidence rather than environmental claims alone. This approach can reduce greenwashing while keeping participation accessible to smaller operators.

D. Strategy 4: Adopt a modular port energy-transition portfolio

Keelung should avoid dependence on a single fuel or technology and instead pursue a modular portfolio combining shore-side electricity, renewable energy, efficiency measures, digital scheduling, grid resilience, and alternative-fuel readiness.

Common infrastructure such as metering, communication systems, safety protocols, training, and data systems should be prioritized because it remains useful across multiple future fuel pathways. More specialized infrastructure should proceed only when supported by sufficient evidence of demand, safety, and regulatory compatibility.

E. Strategy 5: Institutionalize a just port-city transition

TIPC and the Keelung City Government should establish a Port-City Energy Transition Forum involving port users, workers, utilities, local businesses, communities, and public authorities. The forum should address local environmental benefits, construction impacts, workforce requirements, safety, and the distribution of transition costs and benefits. Worker training, support for smaller operators, community monitoring, and transparent reporting should be integrated into investment planning rather than treated as secondary measures after infrastructure decisions have been made.

F. Strategy 6: Create a verified sustainability data architecture

Keelung should establish an annual Port Energy and Maritime Emissions Statement defining reporting boundaries, energy sources, activity data, emission factors, uncertainty, verification procedures, and double-counting rules.

A standardized data architecture should record key indicators such as OPS-ready calls, actual connections, electricity supplied, estimated fuel displacement, verified emissions reductions, workforce transition, and community co-benefits. Data should progress from operational recording to port-level validation and, where appropriate, external assurance.

Reliable data governance would support customer contracts, investment decisions, regulatory anticipation, and credible evaluation of environmental performance.

VII. DISCUSSION

A. From Regulatory Compliance To Regulatory Intermediation

The findings support a reinterpretation of port sustainability under international regulatory pressure. Regulation is not merely a constraint imposed on a port. It can become a coordination opportunity when shipowners, cargo owners, energy suppliers, terminals, public authorities, and communities face a shared future requirement. A port authority that maps the requirement, aggregates demand, standardizes data, and designs transparent services can reduce transaction costs across the network.

This perspective extends the green-port literature in two ways. First, it moves the unit of analysis from the port estate to the networked port service. Environmental performance depends on the relation among the vessel, berth, energy system, terminal, route, customer, and city. Second, it treats institutional readiness as a meaningful intermediate outcome. A port may not yet demonstrate a large measured emission reduction, but it may possess capabilities that make future reduction more likely. Conversely, a port may have a strong environmental narrative while lacking the contracts, meters, incentives, and verification required for operational change.

The K-RTRI makes this distinction visible. Keelung's overall score of 2.0 suggests emerging readiness rather than maturity. The profile is uneven: regulatory exposure and governance mobilisation are stronger than operational incentives and just-transition capacity. The HVSPS project indicates movement toward implementation, but the absence of public utilisation data prevents a conclusion about actual environmental impact. This is a more cautious and useful conclusion than either celebrating the project as completed decarbonisation or dismissing the port as unprepared.

B. Infrastructure Value Depends On Utilisation And Verification

The case demonstrates why the installed-capacity metric is insufficient. A shore-power system has value only when compatible vessels connect, electricity is delivered reliably, fuel use is displaced, and the result is measured against a defensible baseline. Utilisation also determines financial sustainability. If the system is rarely used, maintenance and capital costs may be difficult to recover, and customers may not perceive the service as dependable. If demand is contracted and reported, the infrastructure can become a competitive service.

This finding is consistent with energy-management research that treats ports as participants in supply-demand coordination. It also supports the governance argument that commercial relationships need to share future costs and

benefits more explicitly. For Keelung, the implication is that an engineering completion certificate should be followed by a service-development phase. The performance question should move from whether the equipment exists to how often it is used, by which vessel types, under what electricity conditions, with what operational reliability, and with what local and life-cycle outcomes.

Verification is equally important. A port should distinguish local combustion reduction from well-to-wake greenhouse-gas reduction. It should distinguish measured electricity from estimated fuel displacement. It should state whether avoided emissions are attributed to the port, the vessel, the cargo owner, or a shared value-chain account. Such discipline may initially make claims appear smaller, but it increases credibility and supports durable customer relationships.

C. The Value Of Modularity Under Regulatory Uncertainty

The regulatory environment favours ports that manage uncertainty rather than pretend to eliminate it. The IMO's long-term direction is clear, but the detailed design and timing of future mid-term measures may evolve. FuelEU Maritime is more specific, yet its application, verification, and infrastructure effects continue to develop through guidance and implementing measures. Alternative fuels carry uncertainty about supply, safety, certification, and life-cycle emissions.

A rigid port strategy may become obsolete if it commits capital to a technology that does not achieve sufficient demand or regulatory recognition. A modular strategy preserves option value. Metering, data governance, digital scheduling, energy efficiency, grid resilience, safety training, and port-city institutions remain useful under multiple scenarios. Fuel-specific infrastructure can be staged behind demand and safety gates. This is not an argument for slow action. It is an argument for action that creates future choices.

Modularity also improves management learning. A pilot can reveal connection rates, maintenance needs, customer behaviour, local benefits, and cost structures before a larger commitment is made. The port can update the investment matrix as evidence improves. Such iterative governance is appropriate for a transition in which regulation, technology, and markets co-evolve.

D. Port-City Integration as Competitive Capability

Keelung's urban context is often described as a constraint because land is limited, stakeholders are close, and construction impacts are visible. The case suggests a more balanced interpretation. Port-city integration can be a source of legitimacy and innovation when local benefits are measurable and public participation is institutionalized. Cruise-related shore power, local air-quality monitoring, transparent construction communication, and workforce development can make decarbonisation visible to residents. The ESG roadmap's Protect, Prevent, and Preserve structure is valuable because it already links environmental, social, and cultural objectives. The challenge is to connect that narrative with energy-transition indicators. A port-city forum, community monitoring, and transition fund would turn broad cooperation into a management mechanism. The result could improve public acceptance, identify operational

problems earlier, and create a stronger social case for investment.

This aspect highlights the vital nexus between engineering design and governance management. Engineering choices directly shape public outcomes, while management structures determine whether technical solutions are successfully utilized, maintained, financed, and socially accepted. Port energy transition is therefore an interdisciplinary engineering-management problem. Its performance cannot be judged only by equipment specifications or only by financial return.

VIII. CONCLUSIONS, LIMITATIONS, AND FUTURE SCOPE

This article examined how international marine environmental regulation affects the sustainable management and energy-transition readiness of the Port of Keelung. The analysis showed that the IMO 2023 GHG Strategy and MARPOL Annex VI create a global direction toward lower carbon intensity, zero- and near-zero-emission energy, life-cycle accounting, and eventual net zero. FuelEU Maritime adds a regional but commercially transmissible layer by regulating well-to-wake energy intensity and requiring OPS or alternative zero-emission technologies for relevant ships at covered European ports. Together, these instruments make port energy governance strategically important even when a port is not directly within the European Union legal territory.

Keelung has established an emerging readiness base. Its ESG Implementation Roadmap, EcoPort engagement, smart-port initiatives, carbon-reduction activities, port-city cooperation, and high-voltage shore-power project at East Wharf No. 4 demonstrate institutional mobilisation. Its commercial and passenger activity creates both a need and an opportunity for transition. Cruise vessels, container services, terminal operations, harbour craft, and urban interfaces require different service solutions and different evidence.

The public record is not yet sufficient to claim mature energy-transition performance or verified greenhouse-gas reductions. The strongest evidence concerns governance and implementation outputs. The weakest evidence concerns actual OPS utilisation, electricity delivered, fuel displaced, verified emissions avoided, performance-linked incentives, worker transition, and explicit port-city cost-sharing. The conservative K-RTRI score of 2.0 out of 4.0 therefore indicates emerging readiness with a clear implementation, utilisation, and verification gap.

The policy and management implications are practical. TIPC should establish a regulatory anticipation and investment observatory, construct a route-and-service exposure map, convert shore-power capacity into contracted utilisation, introduce tiered and verified green-port services, maintain a modular energy portfolio, integrate energy with berth and logistics operations, institutionalize a Port-City Energy Transition Forum, and publish a verified annual Port Energy and Maritime Emissions Statement. These actions would move Keelung from project-based sustainability toward outcome-based regulatory governance.

The study has five principal limitations. First, public evidence does not provide a complete time series of port-wide electricity consumption, OPS connections, electricity delivered, vessel fuel displacement, or direct and value-

chain emissions. Second, the TIPC commercial figures used in the case context apply to the Port of Keelung subsidiary covering Keelung, Taipei, and Suao, and should not be interpreted as Keelung-only energy performance. Third, the K-RTRI is an ordinal readiness tool and its equal weighting has not been validated through expert elicitation or comparative cases. Fourth, the analysis does not contain interviews or proprietary carrier and utility data, so it cannot observe internal decision-making or confidential contracts. Fifth, the international regulatory environment is dynamic, and future IMO mid-term measures, EU implementing guidance, fuel standards, and accounting methodologies may alter investment priorities.

Future research should combine documentary analysis with vessel-call data, metered energy information, interviews, stakeholder surveys, cost-benefit analysis, and life-cycle assessment. It should test whether contracted OPS demand improves utilisation, whether green-port incentives change behaviour, how electricity carbon intensity affects climate benefits, and whether port-city participation improves project durability. It should also compare ports of different sizes, governance models, and degrees of European Union network exposure.

Ultimately, Keelung's maritime energy transition should not be treated as a competition to select a single future fuel or technology. The more important challenge is to build institutional capacity for regulatory anticipation, coordinated investment, reliable energy-service utilisation, transparent verification, and port-city participation. By strengthening these capabilities, Keelung can respond more effectively to changing international environmental requirements while improving the durability, credibility, and commercial value of its decarbonisation strategy.

DECLARATIONS

Funding: No external funding was received for this research.

Conflict of Interest: The author declares that there is no conflict of interest.

Data availability: The analysis relies on publicly accessible regulatory and institutional documents listed in the references. The K-RTRI coding sheet and evidence matrix can be made available upon reasonable request.

Ethics Approval: This documentary research did not involve human participants, personal data, or interventions; ethics approval was not required.

Originality: The manuscript is prepared as an original research article and is not under consideration elsewhere. The author has reviewed and approved the final submitted manuscript.

ACKNOWLEDGMENT

The author acknowledges the International Maritime Organization, the European Commission, Taiwan International Ports Corporation, the Port of Keelung, and the World Port Sustainability Program for making the regulatory and institutional materials used in this documentary research publicly available. No organization cited in the article was asked to endorse the interpretation or recommendations.

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