sustainability

Article

Coordinated Port–Industry–City Development from a Green Port Perspective: An Empirical Study of Shanghai Port

Jianxun Wang [1], Haiyan Wang [1,2,*] and Fuyou Tan [1]

[1] School of Transportation and Logistics Engineering, Wuhan University of Technology, Wuhan 430063, China; jxwang146@whut.edu.cn (J.W.); fytan@whut.edu.cn (F.T.)
[2] State Key Laboratory of Maritime Technology and Safety, Wuhan University of Technology, Wuhan 430063, China
* Correspondence: hywang777@163.com

Abstract

In the context of China's 'dual carbon' strategy, sustainable port–city integration has become critical for regional transformation. Based on the green development perspective, this study constructed a "port–industry–city" (PIC) coordinated development indicator system, conceptualizing ports, industries, and cities as distinct but interrelated subsystems. An improved coupling coordination degree model and an obstacle degree model were employed to analyze the coordinated development between Shanghai Port and its associated industries and urban areas during the green transformation process from 2014 to 2023. Three key findings were found: (1) The comprehensive development index of Shanghai Port exhibited a W-shaped fluctuation followed by rapid growth, while the overall PIC system showed a continuous upward trajectory, with the overall development level steadily rising. (2) During Shanghai Port's green transformation process, the coordination level of the PIC system improved from moderate imbalance to intermediate coordination, though the overall level still requires improvement. (3) Port green transformation, infrastructure, and urban ecology represent primary obstacles requiring targeted, sustainable interventions. This study enriches the research on port–industry–city coordination and provides both theoretical support and a policy foundation for promoting regional sustainable development led by green port initiatives.

Keywords: Shanghai Port; green port; improved coupling coordination model; port–industry–city coordinated development; lagging factors

check for updates

Academic Editor: Jianming Cai

Received: 9 July 2025
Revised: 23 August 2025
Accepted: 26 August 2025
Published: 28 August 2025

Citation: Wang, J.; Wang, H.; Tan, F. Coordinated Port–Industry–City Development from a Green Port Perspective: An Empirical Study of Shanghai Port. *Sustainability* **2025**, *17*, 7747. https://doi.org/10.3390/su17177747

1. Introduction

Ports, as vital conduits for international trade and key hubs in global supply chains, hold irreplaceable strategic value and exert significant influence on urban economic activity and national development. The relationship between port development and regional economies is deeply interdependent and interactive. A region's financial foundation, policy environment, and market potential shape a port's growth trajectory and competitive advantages. Conversely, a thriving port sector can drive regional economic expansion and promote the upgrading and optimization of industrial structures. This traditional view of the port's economic role is now being supplemented by a sustainability-oriented perspective, fitting within the international 'Blue Economy' framework [1]. This framework emphasizes achieving economic growth through the sustainable use of marine resources. This shift towards sustainability is particularly critical in the port–city interface, where the competition for land is no longer driven solely by traditional industrial and logistical needs but is intensified by new demands from the energy transition, the circular economy, and climate adaptation [2].

In recent years, China has increasingly prioritized the coordinated development of ports and cities. In 2019, nine ministries, including the Ministry of Transport, jointly issued the *Guiding Opinions on Building World-Class Ports.* This high-level strategic framework marked a shift beyond purely technical reforms, explicitly identifying the deep integration of ports, industries, and cities (PICs) as a central objective to be achieved by aligning port development with China's overarching Territorial Spatial Plans. Furthering this agenda, the *Five-Year Action Plan for Accelerating the Construction of a Strong Transportation Nation (2023–2027)* designates green port development as a core strategy for advancing low-carbon transformation in the transport sector. The plan outlines concrete implementation measures in areas such as energy structure optimization, pollution control, and intelligent infrastructure upgrades. In its comprehensive approach, this policy echoes the strategic logic of international initiatives such as the *European Green Deal*, which also links large-scale infrastructure and industrial modernization with sustainability goals [3]. These policies represent a fundamental paradigm shift in PIC coordinated development. The transition moves away from traditional port governance models. A primary example is the 'Landlord Port' model, which focuses on economic and trade-facilitation functions [4]. The new trajectory is instead guided by sustainability, low carbon, and green development. In this emerging paradigm, the port's role shifts to that of a 'societal integrator'. Its governance must now balance economic performance with social well-being and environmental sustainability. The goal is to achieve synergistic coexistence among ports, industries, and cities. This transition is expected to become a defining challenge for port cities seeking to enhance their overall competitiveness during China's high-quality development phase. This challenge is global, with leading ports like Rotterdam focusing on an industry-led energy transition [5], while Singapore emphasizes digitalization and green shipping services to achieve its sustainability goals [6]. The case of Shanghai provides a unique perspective on how these dynamics unfold within the context of China's "dual carbon" strategy.

While a substantial body of the literature exists on port–city interactions, particularly within the fields of Maritime Spatial Planning (MSP) and land–sea integration, specific research gaps remain. Much of the existing research adopts a qualitative or policy-focused approach. There is a less-developed stream of the literature that conducts long-term quantitative assessments of the dynamic evolution of coordination within a comprehensive port–industry–city (PIC) framework. Furthermore, few studies combine this dynamic assessment with an obstacle degree model to precisely diagnose the hindrances to sustainable integration, especially in the context of a major global hub port undergoing a rapid, policy-driven green transformation. While coupling coordination degree models have been widely applied to examine port–city relationships, the recent methodological literature highlights that traditional models possess inherent limitations, particularly in their handling of boundary values and their ability to distinguish nuanced differences in subsystem development [7,8]. Given that large hub ports undergoing green transformation often exhibit the kind of uneven and complex development patterns where these limitations become particularly problematic, a more robust model is required.

To address these research gaps and methodological limitations, this study aims to answer three key questions: How can coordinated port–industry–city development be comprehensively evaluated from a green development perspective? What are the evolutionary patterns and characteristics of coordination during the port green transformation processes? What are the primary obstacles hindering sustainable PIC coordination, and how can they be effectively identified and addressed? Addressing these challenges, this study adopts a green port development perspective to examine the coordinated development of ports, industries, and cities as an integrated system. In this study, this perspective is not merely a theoretical concept but the core operational principle guiding the research design, reflected in two main aspects: First, it guides the construction of the "port–industry–city" (PIC) evaluation framework by integrating green and low-carbon indicators into the subsystems. For instance, the port subsystem is evaluated not only on its throughput but also on its 'Carbon Emissions per Ton of Throughput' and 'Water-to-Water Container Transshipment Ratio'. Second, serving as the main thread of the empirical analysis, this perspective is used not only to interpret the port's development trajectory as a 'green transition' process but also to ultimately diagnose the specific obstacles hindering coordinated development. It is crucial to clarify that the objective is not to measure an abstract state like 'economic welfare' or absolute 'sustainability'. Instead, this study assesses the performance of the sustainability transition, using the coupling coordination degree to quantify the system's progress and synergy. In this context, 'synergy' refers to the condition where the coordinated interaction of the subsystems produces a greater combined effect than the sum of their individual efforts. A high coordination score therefore indicates that the subsystems are advancing towards sustainability goals in a balanced and mutually reinforcing manner, signifying a high-quality transition process. This approach provides a quantitative tool to evaluate progress toward the type of integrated development goals articulated in international consensus frameworks, such as the United Nations' 2030 Agenda (particularly SDG 9 and SDG 11) [9]. Using Shanghai Port as a case study—the world's largest container port with extensive ongoing green transition initiatives—this research evaluates port–industry–city coordination during the green transformation period and identifies primary lagging factors through systematic analysis. The main contributions of this study include the following: (1) developing a comprehensive green-oriented PIC evaluation framework that integrates environmental sustainability indicators with traditional economic and social metrics; (2) employing an improved coupling coordination degree model that addresses methodological limitations through enhanced coupling-coordination distinction, optimized boundary value handling, and improved sensitivity for differentiated subsystem development patterns, combined with obstacle degree model analysis to identify primary lagging factors; (3) providing empirical evidence from a major international hub port during its green transformation period, offering valuable insights for similar port cities pursuing sustainable development pathways.

The remainder of this paper is structured as follows: Section 2 reviews the existing literature on port–industry–city integration and identifies key research gaps. Section 3 provides an overview of Shanghai Port's development status and green innovation practices. Section 4 constructs the analytical models for evaluating port–industry–city coordinated development from a green development perspective. Section 5 presents the empirical analysis of Shanghai Port's coordination development from 2014 to 2023. Section 6 concludes with policy recommendations and research limitations.

2. Literature Review

The concept of "port–industry–city (PIC) integration," first introduced in 1984, refers to the synergistic development and interaction of ports, industries, and cities [10]. Since its inception, it has attracted extensive scholarly attention both in China and abroad. Its central aim is to foster high-quality regional economic growth through the integrated advancement of the three components. Existing research on PIC integration can be broadly categorized into three main strands.

2.1. Port–Industry–City (PIC) Dynamics

The study of the port–city relationship as a dynamic between distinct yet interdependent entities has a long and rich history in urban and transport geography. Foundational concepts such as the 'port–city interface' and Hoyle's classic 'Port–City Evolution Model' provide a strong theoretical basis for analyzing the port and the city as interacting subsystems that evolve through stages, from symbiosis to separation and potential reintegration [11,12]. Ma et al. [13] employed a PSM-DID model to assess the impact of port integration on the green development efficiency of port cities, as well as the corresponding transmission pathways. Their results indicate that port integration significantly improves green development efficiency. Moreover, this positive effect intensifies over time. Zhao et al. [14] investigated the spatiotemporal evolution and spatial spillover effects of PIC integration in the Bohai Rim region. Using empirical analysis, Yu et al. [15] clarified the interrelationships and integration outcomes among China's ports, industries, and cities while identifying the mechanisms by which port reforms drive regional industrial and urban development. From a spatial economics perspective, studies reveal that both government intervention and marketization levels are negatively correlated with the development of the port industry in the Guangdong–Hong Kong–Macao port cluster [16]. One study, which focused on Ningbo Port, further highlights that the interaction between the port and urban development is stage-dependent, with an outward-oriented economy playing a key role in promoting container throughput [17]. This aligns with the broader view of seaports as catalysts for the socioeconomic and spatial development of regions, integrating functions of transport, industry, and logistics while actively shaping the urban and regional form [18]. Zhao et al. [19] applied the Quadratic Assignment Procedure (QAP) to analyze the relationship between port operations and urban competitiveness. Their findings suggest that endogenous factors largely constrain urban competitiveness. Guo et al. [20] developed a dynamic coupling index model for measuring and classifying port–city relationships. The research reveals that the strength and developmental trajectories of port–city relationships are closely associated with the development stages of ports or cities, land–sea interaction, and other underlying factors.

2.2. Impacts of Port Activities on Urban and Industrial Development

Regarding the impact of port activities on urban and industrial development, academic research has primarily focused on evaluating their economic and competitive implications for cities and industries. Qu et al. [21] applied the InVEST model to assess ecosystem service levels across four dimensions, including water supply and climate regulation. Their findings highlight the ecological environment as a fundamental driver of high-quality development for both ports and their associated hinterland cities. Cong et al. [22] developed a regression model to examine the relationship between port throughput and urban economic performance. Their analysis concluded that ports make a significant contribution to the growth of the tertiary sector in port cities. Reinforcing this point, a quantitative analysis of European port regions by Bottasso et al. [23] found that a 10% increase in port throughput can lead to a regional GDP growth of between 6% and 20%. However, this positive view is not universally held. Other researchers, such as Mudronja et al. [24], have questioned the unmitigated benefits of port development, arguing that enhanced transport infrastructure can also expose local producers to intensified competition. Li et al. [25] employed a system dynamics model to quantify the economic contribution of Shanghai Port to the urban economy alongside its environmental constraints. While the port was shown to stimulate regional GDP growth, it also imposes negative externalities such as environmental pollution and resource depletion. Furthermore, the literature highlights that urban waterfront regeneration projects, while often part of port–city integration strategies, can lead to significant social challenges. These projects can trigger gentrification and rising real estate prices, which may displace port workers and original residents, creating new social tensions in the port–city interface [2]. Li et al. [26] found that Jiangsu Province, located on the eastern coast of China along the lower Yangtze River, plays a pivotal role in supporting large-scale industrial development and improving the province's industrial structure. They advocate positioning Jiangsu Province, China, as a leading region for port-adjacent industries. Using Qinzhou Port as a case study, Wang et al. [27] examined the economic linkages between the port and its hinterland industries. Based on their analysis, they proposed targeted strategies to promote port–industry–city integration and support the development of emerging sectors. Additionally, ports can stimulate regional industrialization development by enhancing supply chain efficiency, lowering barriers to market entry, and facilitating the dissemination of commercial information [28]. Chen et al. [29] employed a two-stage Data Envelopment Analysis (DEA) approach to assess the sustainable development performance of various port cities.

2.3. Strategies for Optimizing Coordinated Development of PICs

In terms of strategies for optimizing the coordinated development of ports, cities, and industries, existing research offers a variety of perspectives. A central strategy that has emerged globally is the adoption of the 'green port' concept, which seeks a strategic balance between environmental protection and economic interests in port management systems [30]. Indeed, the principle of sustainable development requires that port strategies be evaluated using numerous interrelated indicators across economic, social, and environmental dimensions [31]. Furthermore, implementing an effective green port policy necessitates deep stakeholder involvement, including collaboration between governments, industry, and local communities [32]. Building on these principles, international case studies reveal diverse pathways. For instance, major hubs like the Port of Rotterdam showcase a strategy of leveraging integrated industrial clusters to facilitate a systemic energy transition [5]. In contrast, the Port of Singapore exemplifies a government-led, technology-driven approach, creating a 'smart port' ecosystem through digitalization [6] and pioneering the transition to low-carbon fuels [33]. Furthermore, other ports focus on specialized technological solutions, such as the large-scale adoption of shore power at the Port of Long Beach to mitigate local air pollution [34] and Copenhagen's efforts to integrate renewable energy into its port operations, aligning with Denmark's national decarbonization goals [35]. These distinct international strategies provide a valuable comparative context for analyzing the specific pathway of Shanghai. Furthermore, some port cities are adopting forward-looking strategies that reshape the port–city interface through economic renewal; for instance, facilitating start-ups in former industrialized port areas can help redevelop vacant land while introducing new, knowledge-based economic orientations for the port and city [36]. Dadashpoor and Taheri [37] traced the historical evolution of the port–city relationship at Bandar Abbas, highlighting the transformative impact of containerization and its national strategic relevance. Schubert [38] analyzed the changing roles of ports and cities in the Hamburg region across three distinct historical phases. Building on this framework, subsequent research further examined shifts in port–city interdependence over time. Zhang et al. [39], evaluating the outcomes of the Yangtze River Economic Belt strategy, found that investment in fixed assets—particularly in transportation, warehousing, and postal services—significantly promotes coordinated development between ports and cities. Furthermore, scholars have advocated reshaping port–city relationships through the introduction of Port–City Underground Logistics Systems (PC-ULSs) to ensure the sustainable development of port cities [40]. Moreover, a strong linkage has been observed between port logistics and the growth of the tertiary sector. Accordingly, scholars emphasize the importance of optimizing industrial structures, facilitating international trade, and expanding investment in logistics infrastructure to align ports with regional economic development [41]. Addressing the insufficient coordination between inland ports along the Yangtze River and their associated industries, Wan et al. [42] proposed several strategies: improving port distribution capacity, expanding economic hinterlands, enhancing connectivity between ports and logistics parks, and strengthening industrial clustering to foster synergy.

2.4. Research Limitations

The preceding review demonstrates that the port–industry–city (PIC) relationship is a rich and well-established field of study. Foundational theories have explained its historical evolution, and a wide range of studies have detailed its economic, social, and environmental impacts, while also exploring diverse governance and greening strategies from an international perspective. However, based on the extensive literature, this study identifies the following areas where further research could provide valuable insights. First, the existing empirical literature relies heavily on cross-sectional or short-term panel data from regional port clusters or small- to medium-sized ports. A clear area for further research is the comprehensive empirical analysis of long-term coordination evolution in large-scale international hub ports, which face unique challenges during their green transformation. Second, while the concept of 'green ports' is gaining traction, many studies addressing the environmental dimensions of port–city coordination remain qualitative or policy-focused. There is a relative scarcity of research that develops a comprehensive evaluation framework to quantitatively assess the coordinated development of the PIC system, specifically from a green development perspective. Third, while some studies have combined coordination analysis with diagnostic tools, they often rely on the traditional coupling coordination model, which possesses inherent limitations (e.g., flawed boundary value handling). Therefore, an opportunity exists to apply an improved coupling coordination model to achieve a more robust and nuanced diagnosis of the specific hindrances to sustainable coordinated development. This study, by focusing on Shanghai Port over a decade and employing an improved, green-oriented quantitative framework, seeks to contribute to these areas.

To address these limitations, this study adopts a comprehensive green port development perspective to construct an integrated "port–industry–city" coordinated development evaluation framework, treating ports, industries, and cities as interconnected subsystems. The research includes an improved coupling coordination degree model that systematically addresses three key limitations of traditional models: inadequate coupling-coordination distinction, flawed boundary value handling, and weak differentiation capacity in accurately reflecting differentiated development among systems. Combined with obstacle degree model analysis, this approach evaluates both the current status and dynamic evolution of coordination during Shanghai Port's green transformation period while identifying primary lagging factors that impede further sustainable coordination.

3. Shanghai Port: Global Hub and Green Transformation

Situated at the forefront of the Yangtze River Delta, Shanghai Port occupies a strategic location at the mouth of the Yangtze River and the midpoint of China's coastline. This position supports a multidimensional transport network that connects the Yangtze River Economic Belt, links the northern and southern coasts, and extends to global trade routes. The port consists of major terminals—Yangshan Deep-Water, Waigaoqiao, Wusongkou, and Luojing—with Yangshan Phase IV recognized as the world's largest fully automated terminal. From 2013 to 2023, the Port of Shanghai consistently led the world in container throughput, demonstrating steady growth, as illustrated in Figure 1. Although the COVID-

19 pandemic slowed this growth in 2020, the port still maintained positive performance, highlighting its strong resilience. With the rebound in international trade after 2021, container volume growth resumed, surpassing 50 million TEUs for the first time in 2024, further reinforcing the port's position as a global container hub. As a key node in the global maritime network, the Port of Shanghai maintains connections with over 700 ports in more than 200 countries and regions. It handles over 3200 liner calls per month, underscoring its central role in global trade.

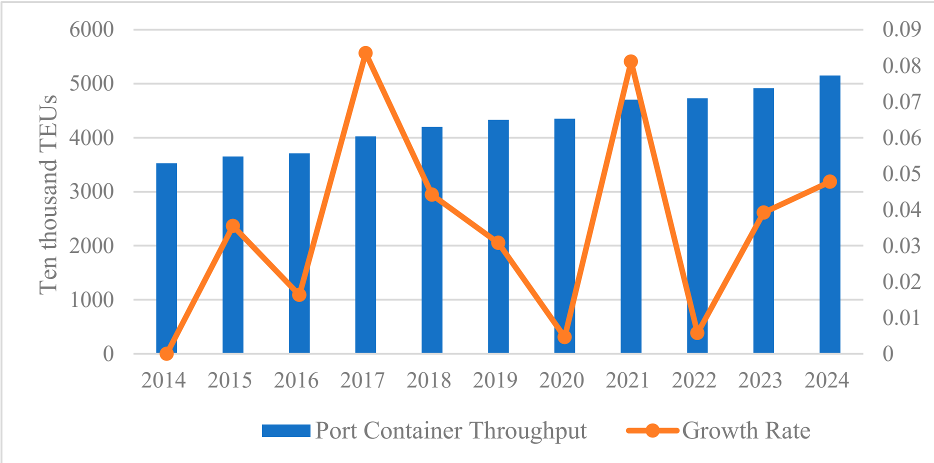

Figure 1. Trend of container throughput at Shanghai Port from 2014 to 2024.

Shanghai Port's green transformation represents a paradigm shift toward sustainable port operations, serving as a critical foundation for examining port–industry–city coordination under green development principles. The 'green transition period' is defined as the timeframe from 2014 to 2023. This period is anchored by the launch of Shanghai's foundational *Shanghai Green Port Three-Year Action Plan (2015–2017)* [43]. This comprehensive plan marked a strategic shift for the port, initiating a wide range of targeted measures in areas such as shore power, clean energy adoption for equipment, and pollution control. Shanghai Port has made significant strides in innovative port development, with the successful launch of Yangshan Phase IV, the world's largest fully automated terminal, marking a substantial breakthrough in automation, featuring cutting-edge systems and equipment that substantially enhance operational efficiency and service quality. Furthermore, the port has advanced in green energy practices, exploring clean fuels and implementing carbon reduction strategies, reflecting its commitment to sustainability. Yangshan Phase IV now operates with zero emissions across critical activities—terminal handling, horizontal transport, and yard operations—also contributing to a notable reduction in ambient noise. Beyond the automated terminal operations, the port has expanded its green initiatives to include shore power facilities for berthed vessels, waste reduction programs, and the exploration of renewable energy integration across its facilities.

These innovations have strengthened Shanghai Port's global competitiveness while establishing a foundation for sustainable development. This green transformation provides a valuable case for examining port–industry–city coordination under sustainable development frameworks, as it catalyzes green industry development and supports technological innovation clusters aligned with Shanghai's broader sustainability objectives.

4. Model Construction for Port–Industry–City Coordinated Development from a Green Development Perspective

The model is not designed to provide a definitive measure of an absolute state of 'sustainability' or 'welfare'. Instead, it serves as a diagnostic tool to assess the system's transition performance. A high coordination score indicates that the port, industry, and city subsystems are developing in a balanced and mutually reinforcing manner in the direction of the established green development goals. A low score, conversely, signals a lack of synergy and points to specific lagging factors that are creating bottlenecks in the sustainability transition.

This model begins by establishing an evaluation index system comprising port, industry, and city subsystems, which include 9 primary and 31 secondary indicators, to capture key dimensions such as logistics scale, infrastructure, green development, industrial upgrading, and urban ecology. The entropy weight method is used to assign weights to the evaluation indicators objectively, ensuring a rational basis for assessment [44]. A comprehensive development index model evaluates the performance of individual subsystems and the integrated system. An enhanced coupling coordination model analyzes inter-subsystem dynamics, and an obstacle degree model identifies critical constraints to coordination. Together, these methods establish a multi-tiered, multidimensional quantitative framework for the green port–industry–city system, supporting future empirical analysis and policy development.

4.1. Construction of the Evaluation Indicator System

This study evaluates the port, industry, and city as three core components of an integrated system. We acknowledge that these are not independent subsystems in reality but are deeply intertwined. In the quantitative analysis of such complex systems, however, an effective approach is to first abstract these entities to measure their individual development [45]. This is achieved by using a set of indicators to first measure the individual state of each component, which serves as the foundation for the subsequent coupling coordination analysis of their interactions. In constructing the indicator system, this study adhered to three core principles: validity (grounding indicator selection in the established literature and official statistics), comparability (relying on standardized data sources), and transparency (providing clear definitions for key indicators within the text).

Drawing on relevant studies by domestic and international scholars [46–49], this study incorporates the influencing factors of the port, industry, and city subsystems while also considering the availability and accessibility of original data. Focusing on the coordinated development of Shanghai's "port–industry–city" (PIC) composite system, this study constructs a comprehensive evaluation index system grounded in green development principles, with ports, industries, and cities treated as interrelated subsystems. The port subsystem includes indicators across three key dimensions: Port Logistics Scale, Port Infrastructure, and Port Greening. The industrial subsystem focuses on the scale of Shanghai's industries and the upgrading of its industrial structure. The urban subsystem is evaluated based on city size, economic performance, and ecological sustainability. The resulting evaluation framework consists of 8 primary indicators and 31 secondary indicators, as detailed in Table 1. Among these indicators, the industrial structure sophistication index is defined as the ratio of value added by the tertiary sector to that of the secondary industry. This indicator serves as a proxy to track the trend of 'servitization,' a key feature of the post-industrial transformation that megacities like Shanghai are experiencing. While not a universal measure of optimality, it is a relevant metric for assessing the structural evolution of a service-dominated economy. The share of emerging industries in the total industrial output above the designated size serves as a proxy for the development of technology-intensive sectors. Water-to-water transshipment refers to the transport of cargo between ports via feeder vessels. The Water-to-Water Container Transshipment Ratio refers to the proportion of container throughput at the port that is transported via water-based transshipment. This metric reflects the port's green and low-carbon performance in its intermodal transport system. Increasing the Water-to-Water Transshipment Ratio can reduce the volume of road-based cargo transport, thereby lowering the port's overall carbon emissions. The 'excellent air quality rate' is the annual percentage of days with a daily average Air Quality Index (AQI) of 100 or less, based on China's official standards.

Table 1. Comprehensive evaluation indicator system for the coordinated development of Shanghai's PIC system.

Subsystem	Primary Indicator	Secondary Indicator	Indicator Attribute
Port Subsystem (P)	Port Logistics Scale	Port Cargo Throughput (100 million tons)	Positive
		Port Container Throughput (10,000 TEUs)	Positive
	Port Infrastructure	Production Berths over 10,000 DWT (units)	Positive
		Number of Dedicated Container Berths (units)	Positive
		Coastal Wharf Length (10,000 m)	Positive
	Port Greening	Carbon Emissions per Ton of Throughput	Negative
		Number of LNG Yard Trucks	Positive
		Annual Environmental Protection Investment (CNY 10,000)	Positive
		Electricity Share in Total Energy Consumption	Positive
		Water-to-Water Container Transshipment Ratio	Positive
Industrial Subsystem (I)	Industrial Scale	Regional GDP (billion CNY)	Positive
		Total Regional Imports and Exports (billion USD)	Positive
		Fixed Asset Investment (billion CNY)	Positive
		Number of Employed Persons (10,000 people)	Positive
		Number of Enterprises above Designated Size (units)	Positive
	Industrial Structure	Proportion of Secondary Industry in GDP	Negative
		Proportion of Tertiary Industry in GDP	Positive
		Share of Emerging Industries in Total Output of Large Industrial Enterprises [1]	Positive
		Industrial Structure Sophistication Index	Positive
Urban Subsystem (C)	Urban Economy	GDP per Capita (CNY/person)	Positive
		Per Capita Disposable Income of Urban Residents (CNY)	Positive
		Local General Public Budget Revenue (billion CNY)	Positive
		Total Retail Sales of Consumer Goods (billion CNY)	Positive
	Urban Scale	Permanent Population (10,000 persons)	Positive
		Urban Road Length (km)	Positive
		Built-up Area (square km)	Positive
	Urban Ecology	Green Coverage Rate in Built-up Areas	Positive
		Per Capita Park Green Space (square m/person)	Positive
		Excellent Air Quality Rate (%) [2]	Positive
		Ratio of Environmental Investment to GDP	Positive
		Daily Sewage Treatment Capacity of Urban Treatment Plants (10,000 m^3)	Positive

[1] In the context of Chinese industrial statistics, 'above the designated size' refers to industrial enterprises with an annual main business revenue of CNY 20 million or more, a standard set by the National Bureau of Statistics. [2] It should be noted that China's national AQI is a comprehensive index calculated from six pollutants (SO_2, NO_2, PM_{10}, $PM_{2.5}$, CO, and O_3), which differs from the WHO's approach of setting specific health-based guideline values for individual pollutants.

4.2. Entropy Weight Method

The entropy weight method is an objective weighting approach grounded in information entropy theory. It determines indicator weights by calculating the entropy of each indicator's data distribution. When an indicator exhibits significant variability across evaluation units, it conveys more valuable information, indicating higher importance and, therefore, deserves a greater weight in the composite evaluation system. Conversely, if an indicator shows minimal variation and its entropy approaches the maximum value, it contributes relatively little information and should be assigned a lower weight.

Step 1: Data Standardization

First, depending on whether each indicator is positive or negative, the data are standardized accordingly to eliminate differences in measurement units. The resulting dimensionless standardized values are denoted as X'_{ij}.

For positive indicators, the formula is

$$X'_{ij} = \frac{x_{ij} - \min\{x_i\}}{\max\{x_i\} - \min\{x_i\}} \tag{1}$$

For negative indicators, the formula is

$$X'_{ij} = \frac{\max\{x_i\} - x_{ij}}{\max\{x_i\} - \min\{x_i\}} \tag{2}$$

Step 2: Calculation of Information Entropy

The proportion f_{ij} of the j-th indicator for the i-th object is computed as E_j:

$$f_{ij} = \frac{X'_{ij}}{\sum\limits_{j=1}^{m} X'_{ij}} \tag{3}$$

$$E_j = -\frac{1}{\ln n} \sum_{i=1}^{n} f_{ij} \ln f_{ij} \tag{4}$$

Step 3: Calculation of Indicator Weights

Based on the entropy values, the weight w_j of each secondary indicator is determined as follows:

$$w_j = \frac{1 - E_j}{\sum\limits_{j=1}^{m} (1 - E_j)} \tag{5}$$

4.3. System Comprehensive Development Index Model

The development level of the port–industry–city (PIC) composite system reflects the integrated performance of multiple dimensions, making it challenging for any single indicator to capture the system's overall state entirely. Therefore, a comprehensive evaluation index must be constructed to assess system development quantitatively. The System Comprehensive Development Index (SCDI) model achieves a scientifically grounded assessment of PIC development by integrating a multi-level indicator system through weighted aggregation. It also provides foundational data for subsequent coupling coordination analysis.

This model adopts a two-stage computational framework. In the first stage, the development scores for the port, industry, and city subsystems are calculated based on the weighted values of their respective indicators. In the second stage, these subsystem scores are aggregated through weighted integration to generate the overall System Comprehensive Development Index. The specific calculation formulas are as follows:

$$Q_i(P) = \sum_{i=1}^{n} w_{\mathrm{ij}} X'_{ij} \tag{6}$$

$$T_0 = aQ_i(P) + bQ_i(I) + cQ_i(C) \tag{7}$$

where $Q_i(P)$, $Q_i(I)$, and $Q_i(C)$ represent the comprehensive evaluation scores for the port, industry, and city subsystems, respectively; all three subsystems use the same calculation formula. T_0 denotes the overall development index of the integrated system. X'_{ij} represents the standardized value of each secondary indicator and w_{ij} indicates the corresponding weight of each indicator. The coefficients a, b, and c reflect the relative importance of each subsystem within the overall evaluation framework. Since the port, industry, and city subsystems are assumed to be equally important in this framework, each coefficient is set to 1/3.

4.4. Improved Coupling Coordination Degree Model

The term "coupling" originates from physics, describing the phenomenon where two or more systems or modes of motion interact with each other through mutual influence. In the context of complex systems, it is now widely used to quantify the degree of interaction among subsystems during system development. To explain this intuitively, the port–industry–city (PIC) system can be seen as three interconnected gears. The coupling coordination degree model assesses their systemic harmony in two steps: First, the coupling degree (C) measures the strength of their interaction, essentially quantifying the consistency among the development scores of the three subsystems; a high value means they are developing in close step. Second, the coupling coordination degree (D) provides a more comprehensive assessment by combining this harmony (C) with the overall development level of the entire system (T_0). In essence, a high 'D' value indicates that the three subsystems are not only strongly interconnected but are also developing together at a high level.

The coupling coordination degree model is a widely used tool for assessing systemic harmony. The traditional model is typically formulated as follows (n = 3):

$$C = 3 \times \frac{\sqrt[3]{Q_1 \times Q_2 \times Q_3}}{Q_1 + Q_2 + Q_3} \tag{8}$$

$$D = \sqrt{C \times T_0} \tag{9}$$

However, as noted in the Introduction, the traditional coupling coordination model has several limitations. A systematic critique by Fan et al. [50] identifies three specific flaws when the model is applied to complex social science systems:

(1) A lack of clear distinction between coupling and coordination, where the formula for coupling degree often conflates the two concepts.
(2) Unreasonable handling of boundary values, where if any single subsystem's score is zero, the model outputs a coupling degree of zero, failing to differentiate between vastly different scenarios of imbalance.
(3) Insufficient discriminatory capability making it difficult to distinguish nuanced differences in subsystem development.

To overcome these issues, this study adopts an improved coupling coordination degree model based on the work of Fan et al. [50]. The specific calculation formulas for the improved model are as follows:

$$C == 1 - 2\sqrt{\frac{n \cdot \sum_{i=1}^{n} Q_i^2 - \left(\sum_{i=1}^{n} Q_i\right)^2}{n^2}} \tag{10}$$

$$D = \sqrt{C \times T_0} \tag{11}$$

These improvements primarily benefit from the new formulas' construction. Unlike the traditional model, which uses a multiplicative form, the improved formula for the coupling degree (C) is based on the normalized geometric distance among the subsystem scores. This revised structure directly leads to the three main advantages: (1) It ensures that C purely measures the degree of deviation (harmony), cleanly separating it from the overall development level (T_0). (2) It resolves the boundary value problem because the formula no longer collapses to zero when a single subsystem is zero. (3) This distance-based measure provides a more linear and sensitive response across the entire range of values, thus enhancing the model's discriminatory capability.

n represents the number of subsystems, and Q_i represents the comprehensive evaluation score of each subsystem. C represents the overall coupling degree of the system, while D denotes the system's overall coupling coordination degree. T_0 represents the integrated development index of the three subsystems. The coupling degree C quantifies the strength of interaction among subsystems: the higher its value is, the more strongly the subsystems influence one another. The coupling coordination degree$D$ measures the level of coordinated development within the port–industry–city (PIC) composite system: a higher value reflects stronger internal coordination and higher overall development quality. This D value, therefore, serves as the ultimate measure of a 'balanced, mutually reinforcing growth pattern', as it synthetically combines the 'balance' between subsystems (measured by C) and their overall 'mutually reinforcing' upward trajectory (measured by T_0).

The superiority of this improved model becomes particularly evident when considering the boundary value problem. For example, under the traditional model, a system with subsystem scores of (0.9, 0.9, 0) would yield the same coupling degree (C = 0) as a system with scores of (0.9, 0, 0). This is an unrealistic result, as the former system is more coupled than the latter. Our improved model can accurately differentiate between these two scenarios, providing a more realistic assessment.

Based on prior research findings [51–53], this study establishes a classification framework for evaluating the degree of coupling coordination. The framework categorizes development status into four broad stages and ten specific levels, providing a scientific basis for quantitatively assessing the system's coordination status. The detailed classification criteria are presented in Table 2.

Table 2. Classification of coupling coordination stages.

***D* Range**	**Coordination Level**	**Coupling Development Stage**	***D* Range**	**Coordination Level**	**Coupling Development Stage**
0–0.09	Extreme Imbalance	Low-level Stage	0.50–0.59	Basic Imbalance	Running-in Stage
0.10–0.19	Severe Imbalance	Low-level Stage	0.60–0.69	Primary Coordination	Running-in Stage
0.20–0.29	Moderate Imbalance	Low-level Stage	0.70–0.79	Intermediate Coordination	Running-in Stage
0.30–0.39	Mild Imbalance	Turbulent Stage	0.80–0.89	Good Coordination	High-level Stage
0.40–0.49	Near Imbalance	Turbulent Stage	0.90–1.00	Excellent Coordination	High-level Stage

4.5. Obstacle Degree Model

The obstacle degree model is a diagnostic tool used to quantitatively identify the key factors, or 'obstacles,' that most significantly hinder a system's overall development [54]. By calculating an 'obstacle degree' for each indicator, it allows researchers to rank and pinpoint the primary constraints to coordinated development. Using this model, we can accurately identify the primary obstacles to coupling and coordinated development among the port, industry, and city subsystems in Shanghai and further analyze the internal factors underlying these obstacles. The specific formulation of the model is as follows:

$$H_{ij} = \frac{(1 - X'_{ij}) \times w_{ij} \times 100\%}{\sum (1 - X'_{ij}) \times w_{ij}} \quad (12)$$

$$H_i = \sum H_{ij} \quad (13)$$

H_{ij} represents the obstacle degree of the j-th secondary indicator under the i-th primary indicator within the port, industry, or city subsystems, and the variable H_i represents the overall obstacle degree of the i-th primary indicator. $X_{ij}{}'$ refers to the standardized value of the j-th secondary indicator after normalization, and w_{ij} indicates the weight of the j-th secondary indicator under the i-th primary indicator.

5. Empirical Analysis

5.1. Data Sources and Processing

The original data used in this study were primarily obtained from the *Shanghai Statistical Yearbook* (2014–2023) [55], the Annual Reports of Shanghai International Port Group (SIPG) [56], and the *SIPG Sustainability Reports* [57]. In addition, specific indicator data for Shanghai were sourced from the Zhongjing Database [58]. The historical carbon emissions of Shanghai Port were calculated based on annual fuel and electricity consumption data disclosed in the *SIPG Sustainability Reports*, using corresponding carbon emission factors from the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* [59]. For missing indicator data in certain years, interpolation methods such as the arithmetic mean were applied to complete the dataset. The entropy weight method was employed to determine the weights of all secondary indicators. The detailed weight assignments are presented in Table 3. The complete dataset compiled for this study is provided in the Supplementary Materials (Table S1).

Table 3. Weights of the comprehensive evaluation indicators for the coordinated development of Shanghai's PIC system.

Subsystem	Primary Indicator	Secondary Indicator	Weight
Port Subsystem (P)	Port Logistics Scale	Port Cargo Throughput (100 million tons)	0.0434
		Port Container Throughput (10,000 TEUs)	0.0301
	Port Infrastructure	Production Berths over 10,000 DWT (units)	0.0147
		Number of Dedicated Container Berths (units)	0.0579
		Coastal Wharf Length (10,000 m)	0.0755
	Port Greening	Carbon Emissions per Ton of Throughput	0.0235
		Number of LNG Yard Trucks	0.0163
		Annual Environmental Protection Investment (CNY 10,000)	0.0520
		Electricity Share in Total Energy Consumption	0.0240
		Water-to-Water Container Transshipment Ratio	0.0564
Industrial Subsystem (I)	Industrial Scale	Regional GDP (billion CNY)	0.0288
		Total Regional Imports and Exports (billion USD)	0.0372
		Fixed Asset Investment (billion CNY)	0.0314
		Number of Employed Persons (10,000 people)	0.0228
		Number of Enterprises above Designated Size (units)	0.0332

Table 3. *Cont.*

Subsystem	Primary Indicator	Secondary Indicator	Weight
Industrial Subsystem (I)	Industrial Structure	Proportion of Secondary Industry in GDP	0.0165
		Proportion of Tertiary Industry in GDP	0.0165
		Share of Emerging Industries in Total Output of Large Industrial Enterprises	0.0481
		Industrial Structure Sophistication Index	0.0186
Urban Subsystem (C)	Urban Economy	GDP per Capita (CNY/person)	0.0296
		Per Capita Disposable Income of Urban Residents (CNY)	0.0311
		Local General Public Budget Revenue (billion CNY)	0.0171
		Total Retail Sales of Consumer Goods (billion CNY)	0.0248
	Urban Scale	Permanent Population (10,000 persons)	0.0236
		Urban Road Length (km)	0.0279
		Built-up Area (square km)	0.0550
	Urban Ecology	Green Coverage Rate in Built-up Areas	0.0192
		Per Capita Park Green Space (square m/person)	0.0249
		Excellent Air Quality Rate (%)	0.0239
		Ratio of Environmental Investment to GDP	0.0278
		Daily Sewage Treatment Capacity of Urban Treatment Plants (10,000 m^3)	0.0481

5.2. Evolution Trend of Shanghai's Port–Industry–City Integrated Development Index

By substituting the data into the System Comprehensive Development Index model, the comprehensive development indices for Shanghai Port's port subsystem, Shanghai's industrial subsystem, and urban subsystem from 2013 to 2023 were calculated, as shown in Table 4. To analyze the evolutionary trends of the port, industry, and city subsystems, a line chart was generated to illustrate their dynamic changes over time, as presented in Figure 2.

Table 4. Comprehensive development indexes of each subsystem in Shanghai (2014–2023).

Year	Port System	Industry System	City System	PIC System
2014	0.1465	0.0545	0.0519	0.0843
2015	0.1590	0.0559	0.0531	0.0893
2016	0.1063	0.0618	0.0965	0.0882
2017	0.1077	0.0870	0.1241	0.1063
2018	0.1626	0.1042	0.1892	0.1520
2019	0.1452	0.1372	0.2159	0.1661
2020	0.1302	0.1684	0.2350	0.1779
2021	0.1822	0.2134	0.2692	0.2216
2022	0.2134	0.2136	0.2572	0.2281
2023	0.2938	0.2212	0.3100	0.2750

5.2.1. Evolution Trend of Shanghai Port Development

Between 2014 and 2023, the comprehensive development index of Shanghai Port's subsystem followed a W-shaped fluctuation pattern. The index fell from 0.1590 in 2015 to 0.1077 in 2017, rebounded to 0.1626 in 2018, and began rising again after 2020. This fluctuation pattern corresponds to Shanghai Port's green transformation process.

In 2015, amid tightening environmental regulations, Shanghai Port launched its *Three-Year Action Plan for Green Port Development*, allocating nearly CNY 900 million to green initiatives, which initially boosted the development index. However, by 2017, as the plan drew to a close and investment waned, the development index declined accordingly. The decline from 2015 to 2017 highlights the features of early-stage green port development:

high initial investment, delayed benefits, and short-term operational pressures under stricter regulations. Since 2018, the commissioning and operation of the Yangshan Phase IV Automated Terminal, the rollout of LNG-powered trucks, and the implementation of full shore power coverage have signaled significant progress in green and smart port upgrades. Shanghai Port's green transition has entered the benefit realization phase, with sustained investments steadily enhancing its overall competitiveness. The COVID-19 outbreak in early 2020 severely disrupted global trade and logistics, temporarily affecting Shanghai Port. From 2021 to 2023, as the global economy recovered, cargo and container throughput at Shanghai Port surged, driving rapid growth in the development index.

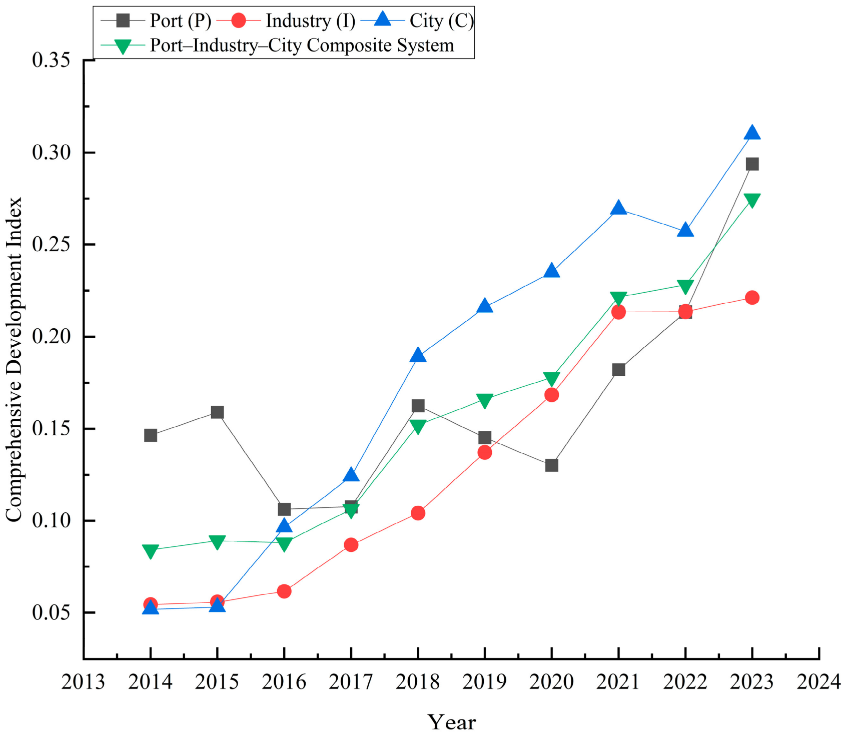

Figure 2. Comprehensive development trends of each subsystem in Shanghai (2014–2023).

Overall, Shanghai Port's development followed a path of "transformation pains–strategic adjustment–benefit realization," illustrating the typical course of green transition in large hub ports.

5.2.2. Evolution Trend of Shanghai's Port–Industry–City System Development

Between 2014 and 2023, the comprehensive development index of Shanghai's port–industry–city (PIC) system steadily rose from 0.0843 to 0.2750. The system's development can be divided into two phases: a fluctuation-adjustment phase (2014–2019) and an accelerated growth phase (2019–2023). During the fluctuation-adjustment phase (2014–2019), the urban subsystem was the primary driver of growth, with its index increasing from 0.0531 in 2015 to 0.2159 in 2019. However, volatility in the port subsystem and the industrial subsystem's lagging development limited the overall growth of the composite system.

Urban development was particularly notable, as rising consumer spending and increasing per capita income enhanced the foundational role of consumption in economic growth. Shanghai promoted platforms such as cross-border e-commerce and the China International Import Expo, boosting retail sales and integrating domestic and international trade. Industrial transformation showed early results, though challenges persisted. The tertiary sector grew steadily, with finance, trade, and shipping contributing over 50% of GDP. Emerging sectors such as AI and integrated circuits grew by up to 15%. Shanghai has strengthened industrial chains in these and related areas, such as new energy vehicles, with clustering effects that support sustainable development. However, traditional sectors, such as steel and petrochemicals, still account for approximately 60% of total energy consumption. The adoption rate of green technologies remained low, and growth in emerging sectors was modest.

During the accelerated growth phase (2019–2023), the comprehensive development index of Shanghai's port–industry–city (PIC) system rose rapidly from 0.1661 to 0.2750. All three subsystems experienced marked improvement in their respective indices. The port's green and smart transformation significantly boosted operational efficiency. In 2020, the Yangshan Phase IV Fully Automated Terminal was commissioned, contributing to a container throughput exceeding 47.3 million TEUs by 2023 and reducing terminal carbon emissions by approximately 15%. The widespread adoption of green shipping technologies also played a crucial role: LNG bunkering services covered 80% of international routes, and shore power availability reached 85%, establishing Shanghai Port as one of the top three global hubs for green marine fuel.

At the urban level, Shanghai's GDP grew steadily between 2019 and 2023, with enhanced economic resilience and vitality. The city's spatial structure continued to improve, reinforcing its comprehensive competitiveness. Industrially, modern services consolidated their dominant position as the primary engine of growth. By 2023, the total output of three leading sectors—integrated circuits, biomedicine, and artificial intelligence—reached CNY 1.6 trillion, becoming key pillars of high-quality development. Collectively, the enhanced coordination among the port, industry, and city subsystems was a key driver for the PIC system's trajectory toward more integrated and sustainable growth.

5.3. Coupling Coordination Dynamics of Shanghai's Port–Industry–City System

Using the improved coupling coordination degree model, this study calculated the annual coupling degree (C) and coordination degree (D) of Shanghai's port–industry–city (PIC) system from 2014 to 2023. The results (Table 5 and Figure 3) show that the coupling degree remained consistently above 0.9 throughout the period, indicating a highly coupled state. Such a highly coupled state indicates close interaction and mutual reinforcement among the port, industry, and city subsystems, reflecting the typical interdependence found in major international hub ports and their urban–industrial systems.

Table 5. Coupling coordination status of Shanghai's PIC system.

Year	Coupling Degree (C)	Coupling Type	Coordination Degree (D)	Coordination Level	Coupling Development Stage
2014	0.9120	High Coupling	0.2773	Moderate Imbalance	Low-level Stage
2015	0.9014	High Coupling	0.2838	Moderate Imbalance	Low-level Stage
2016	0.9618	High Coupling	0.2913	Moderate Imbalance	Low-level Stage
2017	0.9696	High Coupling	0.3210	Mild Imbalance	Turbulent Stage
2018	0.9672	High Coupling	0.3757	Mild Imbalance	Turbulent Stage
2019	0.9293	High Coupling	0.3929	Near Imbalance	Turbulent Stage
2020	0.9134	High Coupling	0.4031	Basic Imbalance	Running-in Stage
2021	0.9302	High Coupling	0.4535	Primary Coordination	Running-in Stage
2022	0.9588	High Coupling	0.4676	Primary Coordination	Running-in Stage
2023	0.9227	High Coupling	0.5037	Intermediate Coordination	Running-in Stage

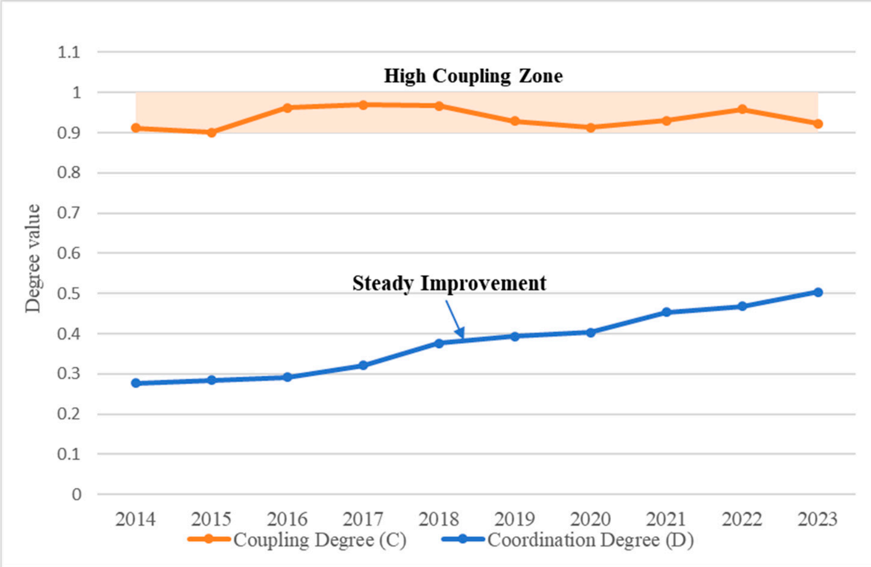

Figure 3. Coupling and coordination trends of Shanghai Port's PIC system (2014–2023).

Although the coupling level was high, the overall coordination remained relatively low in the early years, reaching only "intermediate coordination" by 2023. Initially, the system exhibited a typical "high coupling but low coordination" pattern, indicating that the subsystems were closely linked but not well synchronized in their development. Indeed, the analysis of the subsystems' development indices confirms this observation, showing that the steady growth of the urban subsystem often acted as the primary stabilizing and driving force for the overall system, particularly during the port's more volatile green transformation phase. However, the coordination level steadily improved over time. As shown in Figure 3, D increased from 0.2773 in 2014 to 0.5037 in 2023. Accordingly, the coordination stage advanced from "moderate imbalance" to "intermediate coordination," while the development phase shifted from the low-level stage to the "running-in" stage (as shown in Figure 4).

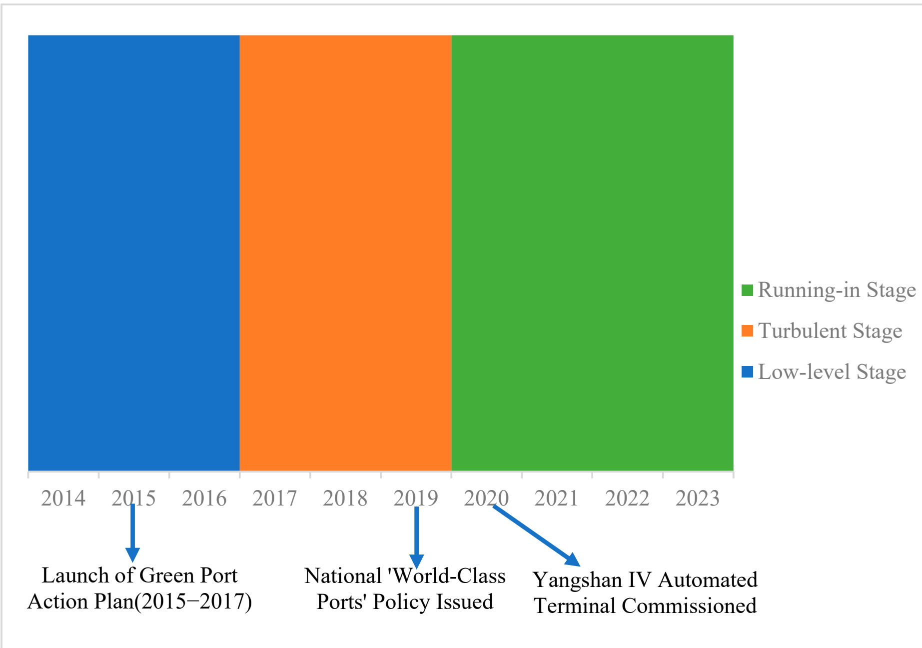

Figure 4. Evolution of coordination stages in PIC system (2014–2023).

Low-level Stage (2014–2016): During this stage, the development of the three subsystems had not yet formed a well-coordinated mechanism. There were deficiencies in resource allocation and policy coordination, resulting in uneven growth and limited overall effectiveness. Port management primarily followed a traditional "port–city separation" model, leading to a certain degree of disconnection between port expansion and urban spatial planning. The pilot Free Trade Zone was still in its initial phase, and the benefits of institutional innovation had yet to materialize. Although Shanghai promoted industrial restructuring, the alignment between the industrial layout and the port and city development was still insufficient.

Turbulent Stage (2017–2019): During this period, the three subsystems underwent frequent adjustments in their interactions due to rapid development, causing fluctuations in coordination. Although the coordination degree improved somewhat, the system remained in a state of imbalance, indicating that the mechanisms for synchronized development were still underdeveloped. Shanghai Port has made progress in its intelligent and green transformation, but the results have not been fully realized. Linkages between the city, industry, and port remained inadequate, particularly in terms of supporting infrastructure, transportation networks, and environmental protection.

Running-in Stage (2020–2023): From 2020 to 2023, the system entered the running-in stage. The relationships among the three subsystems became more stable, and coordination gradually improved. The coordination degree continued to rise, reaching an intermediate level by 2023. This improvement indicated substantial progress in resource allocation, policy alignment, and functional complementarity, forming a more coordinated and sustainable development pattern. The establishment of the Lin-gang Special Area provided new opportunities for coordinated PIC development in Shanghai. Lin-gang is a modern new city and a special economic zone. It is geographically located near the core terminals of Shanghai Port. Its functional position is to be a hub for high-end manufacturing, international trade, and institutional innovation. This combination of geographical proximity and strategic purpose fosters tighter industrial and service chains. This is evidenced by the entry of numerous high-end industries and enterprises into Lin-gang, which has created new market demands for Shanghai Port and supported its transformation toward high-value-added logistics services.

Meanwhile, the green transition of Shanghai Port achieved preliminary results, injecting new momentum into its sustainable development. Green fuel bunkering services have emerged as a new growth point, attracting international shipping vessels to the Yangshan Port Area and generating new demand for this type of service. The steady rise in the proportion of water-to-water container transhipment contributed to both cost savings in road transport and carbon reduction. The synergy among port, industry, and city in terms of planning, policy, and function improved significantly.

5.4. Identification of Lagging Factors in Shanghai's Port–Industry–City System

To further investigate the lagging factors affecting the coordinated development of Shanghai's port–industry–city (PIC) system, this study employed the obstacle degree model to quantitatively assess both primary and secondary indicators, aiming to identify key constraints to systemic coordination accurately.

According to the analysis results presented in Table 6, from 2014 to 2023, the main obstacles to the coordinated development of the PIC system were concentrated in three primary indicators: Port Infrastructure, Port Greening, and Urban Ecology. A closer examination reveals a significant overlap effect between Port Greening and Urban Ecology, underscoring the central role of environmental sustainability in the coordinated development between ports and cities. Notably, Port Greening and Port Infrastructure alternated as the top obstacle indicators over the study period. In recent years, Port Greening has emerged as the primary constraint, followed by Port Infrastructure. This trend reflects the 'one-time investment with long-term benefits' nature of infrastructure and highlights the critical importance of green port transformation in advancing PIC coordination in Shanghai. Additionally, Urban Scale and Industrial Scale appeared as obstacle factors primarily in the early years of the study, with a relatively low frequency. The infrequent appearance of the Urban Scale and Industrial Scale as obstacle factors suggests that Shanghai has established a relatively stable foundation in industrial and urban development, which supports the long-term coordinated evolution of the city's PIC system.

Table 6. Top three lagging factors of Shanghai's PIC system—primary indicators.

Year	Obstacle Degree (%)		
	Rank 1	**Rank 2**	**Rank 3**
2014	Port Greening (18.04%)	Urban Economy (13.80%)	Urban Scale (13.42%)
2015	Industrial Scale (15.70%)	Urban Ecology (14.83%)	Urban Scale (14.49%)
2016	Port Infrastructure (17.85%)	Industrial Scale (16.90%)	Urban Scale (12.93%)
2017	Port Infrastructure (20.61%)	Port Greening (17.53%)	Industrial Scale (15.68%)
2018	Port Greening (20.08%)	Port Infrastructure (18.78%)	Industrial Scale (16.40%)
2019	Port Greening (27.25%)	Port Infrastructure (16.73%)	Urban Ecology (15.26%)
2020	Port Greening (22.65%)	Port Infrastructure (19.79%)	Urban Ecology (15.86%)
2021	Port Greening (29.59%)	Port Infrastructure (20.90%)	Urban Ecology (20.24%)
2022	Port Greening (22.68%)	Urban Ecology (20.36%)	Port Infrastructure (19.09%)
2023	Port Infrastructure (29.21%)	Port Greening (28.35%)	Urban Ecology (19.01%)

Based on the analysis of secondary evaluation indicators in Table 7, the lagging factors hindering the coordinated development of Shanghai's port–industry–city (PIC) system exhibit a diversified pattern. Among them, 'Coastal Wharf Length' was the most frequently identified secondary indicator and consistently ranked among the top in obstacle degree. The consistently high ranking was primarily due to significant fluctuations in this indicator's data, which peaked at 126,900 m between 2014 and 2015 but declined to between 105,800 and 109,300 m in subsequent years. Moreover, this indicator ranked within the top 5% in terms of weight among all indicators. Since 'Coastal Wharf Length' is a positive indicator within the 'Port Infrastructure' dimension, this decline resulted in a lower score, causing the model to identify it as a significant obstacle to the port subsystem's development. It is important to note that Shanghai has limited coastline resources, and the available deep-water shoreline in the port's core areas is nearing full utilization. Constructing new terminals involves high costs and strict regulatory review. Therefore, Shanghai Port has opted to integrate existing wharf resources and enhance berth efficiency through smart upgrades rather than expanding shoreline length. This statistical decrease in total length is a direct result of three key actions: (1) the functional redevelopment of old, inefficient inner-city terminals for urban use [60]; (2) the strategic consolidation of smaller, scattered berths into fewer, but larger and more efficient ones [61]; (3) a clear prioritization of centralized, deep-water facilities in key port areas under jurisdiction, such as Yangshan and Waigaoqiao [62]. This trade-off—sacrificing shoreline quantity for operational quality and efficiency—is precisely what the obstacle degree model effectively captures.

Table 7. Top five lagging factors of Shanghai's PIC system—secondary indicators.

Year	Obstacle Degree (%)				
	Rank 1	Rank 2	Rank 3	Rank 4	Rank 5
2014	Number of Dedicated Container Berths (7.79%)	Built-up Area (7.40%)	Water-to-Water Container Transshipment Ratio (7.11%)	Daily Sewage Treatment Capacity of Urban Treatment Plants (6.47%)	Share of Emerging Industries in Total Output of Large Industrial Enterprises (6.47%)
2015	Number of Dedicated Container Berths (8.13%)	Water-to-Water Container Transshipment Ratio (7.92%)	Daily Sewage Treatment Capacity of Urban Treatment Plants (7.72%)	Water-to-Water Container Transshipment Ratio (6.75%)	Share of Emerging Industries in Total Output of Large Industrial Enterprises (6.53%)
2016	Coastal Wharf Length (8.81%)	Number of Dedicated Container Berths (8.05%)	Built-up Area (7.65%)	Water-to-Water Container Transshipment Ratio (6.93%)	Share of Emerging Industries in Total Output of Large Industrial Enterprises (6.43%)
2017	Coastal Wharf Length (11.00%)	Number of Dedicated Container Berths (8.56%)	Built-up Area (8.13%)	Annual Environmental Protection Investment (7.68%)	Water-to-Water Container Transshipment Ratio (7.23%)
2018	Coastal Wharf Length (12.94%)	Water-to-Water Container Transshipment Ratio (9.14%)	Daily Sewage Treatment Capacity of Urban Treatment Plants (7.68%)	Annual Environmental Protection Investment (7.46%)	Share of Emerging Industries in Total Output of Large Industrial Enterprises (6.56%)
2019	Coastal Wharf Length (13.50%)	Water-to-Water Container Transshipment Ratio (9.27%)	Annual Environmental Protection Investment (8.87%)	Daily Sewage Treatment Capacity of Urban Treatment Plants (7.28%)	Share of Emerging Industries in Total Output of Large Industrial Enterprises (5.86%)
2020	Coastal Wharf Length (16.15%)	Annual Environmental Protection Investment (10.53%)	Water-to-Water Container Transshipment Ratio (10.37%)	Port Cargo Throughput (9.29%)	Daily Sewage Treatment Capacity of Urban Treatment Plants (7.95%)
2021	Coastal Wharf Length (19.61%)	Annual Environmental Protection Investment (14.10%)	Water-to-Water Container Transshipment Ratio (11.19%)	Daily Sewage Treatment Capacity of Urban Treatment Plants (10.44%)	Port Cargo Throughput (6.23%)
2022	Coastal Wharf Length (19.09%)	Port Cargo Throughput (12.13%)	Ratio of Environmental Investment to GDP (8.38%)	Annual Environmental Protection Investment (7.82%)	Daily Sewage Treatment Capacity of Urban Treatment Plants (7.74%)
2023	Coastal Wharf Length (29.21%)	Annual Environmental Protection Investment (14.92%)	Ratio of Environmental Investment to GDP (12.90%)	Electricity Share in Total Energy Consumption (11.12%)	Number of Employed Persons (10.59%)

Additionally, several Port Greening indicators—such as the Water-to-Water Container Transshipment Ratio and Annual Environmental Protection Investment—repeatedly appeared as key lagging factors, indicating that the green transformation of Shanghai Port still faces numerous challenges. In the industrial subsystem, during the early years of the study, the 'Share of Emerging Industries in Total Output of Large Industrial Enterprises' appeared frequently as a significant obstacle. The focus on emerging industries aligns closely with Shanghai's strategic push for industrial upgrading and its shift from traditional manufacturing to high-value-added industrial sectors. For the urban subsystem, indicators reflecting ecological and environmental quality—such as 'Daily Sewage Treatment Capacity of Urban Treatment Plants' and 'Ratio of Environmental Investment to GDP'—also emerged repeatedly as significant lagging factors.

This study systematically examines the obstacle degree percentages of each subsystem and their primary indicators, as illustrated in Figures 5 and 6, revealing the dynamic evolution of key lagging factors across different years. This analytical approach is instrumental in identifying critical constraints to coordinated development within each subsystem, as well as their temporal trends. The comprehensive analysis points to specific strategic directions for targeted improvements within each subsystem. For the port subsystem, continuous focus should be placed on advancing green port construction and optimizing infrastructure. The industrial subsystem should prioritize the deepening of industrial structural adjustments. Meanwhile, the urban subsystem needs to concentrate on enhancing ecological and environmental governance. These findings offer scientific guidance for the formulation of targeted policy measures, ultimately facilitating the coordinated and sustainable development of the port–industry–city (PIC) system.

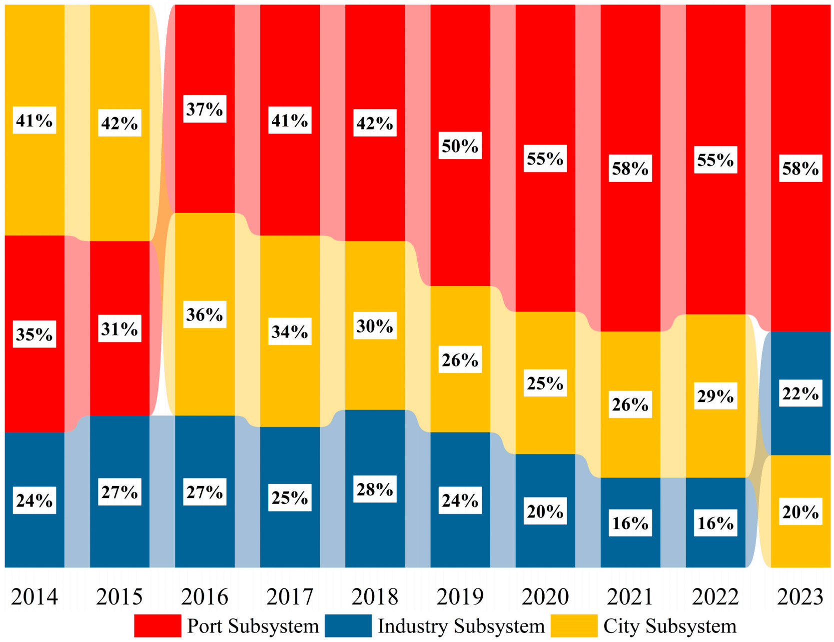

Figure 5. Cumulative percentage Sankey diagram of lagging factors in each subsystem.

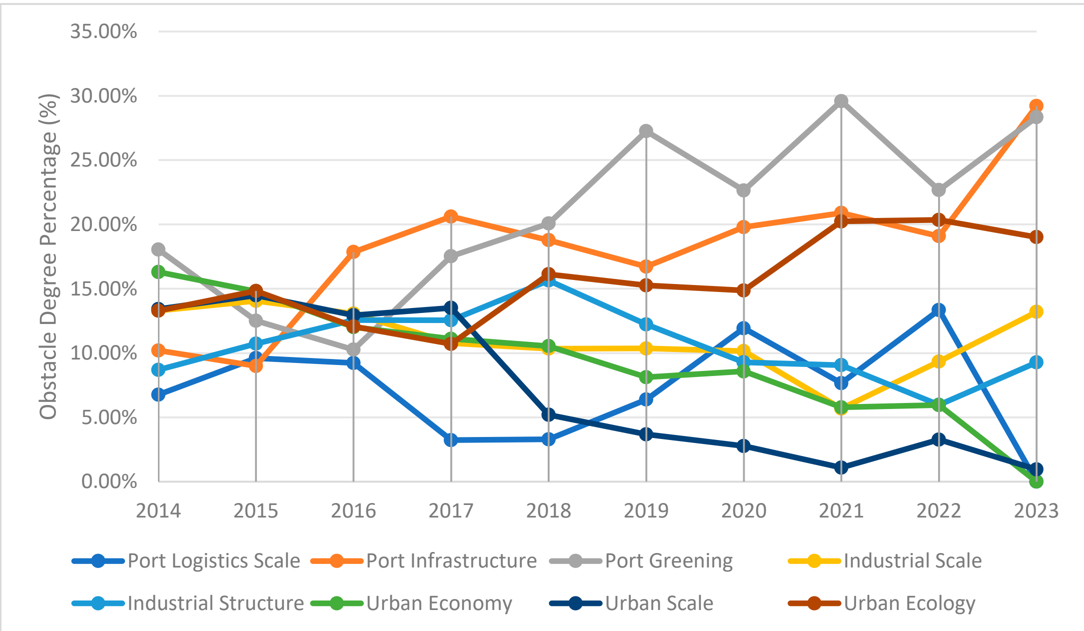

Figure 6. Temporal trends in obstacle degree percentages of primary indicators in Shanghai's PIC system.

6. Conclusions and Limitations

This study integrates green port development within the port–industry–city (PIC) framework and constructs a comprehensive evaluation system that encompasses green, economic, and ecological dimensions. This integrated approach offers a novel analytical framework for theoretical research on the sustainable development of port cities. By systematically analyzing the dynamic relationships and coordination mechanisms among the port, industry, and city subsystems, it provides empirical support for studies on inter-system linkages.

6.1. Key Research Findings

This study, from a green development perspective, constructed a comprehensive development index model and a coupling coordination model using Shanghai's port, industry, and city as subsystems. It revealed the evolution of, interaction mechanisms of, and key obstacles to their coordinated development during the port's green transformation from 2014 to 2023.

(1) The port's green transformation has been unstable and faces internal bottlenecks. Although the overall port–industry–city (PIC) system showed steady upward growth, the port subsystem itself experienced a volatile "W-shaped" development trajectory, reflecting the impacts of fluctuating investments and external shocks. This indicates that the port's green development is not yet resilient and requires targeted policies to ensure consistent progress. Furthermore, the obstacle degree model identified "Port Greening" and "Port Infrastructure" as the most significant internal challenges hindering the system's coordination.

(2) A lagging industrial subsystem is the primary bottleneck for system-wide coordination. The study found that while the PIC system is highly coupled, its coordination level remains relatively low, having only improved to "intermediate coordination". The empirical analysis explicitly points to the "industrial subsystem's lagging development" as a primary cause. This has created a structural mismatch where the city's industrial structure is not keeping pace with the port's advanced and green logistics needs. However, the analysis also notes that the establishment of the Lin-gang Special Area has already created new opportunities for port–industry synergy, highlighting a successful pathway that can be leveraged.

(3) Poor urban ecology acts as a persistent constraint on port–city integration. The obstacle degree analysis consistently ranked "Urban Ecology" as a primary lagging factor, particularly in recent years. Specific indicators such as "Daily Sewage Treatment Capacity" and the "Ratio of Environmental Investment to GDP" were identified as significant recurring obstacles. This finding underscores that the city's environmental quality and management mechanisms are insufficient to support a truly sustainable and integrated port–city relationship.

6.2. Policy Recommendations

The findings suggest that green port development has evolved beyond traditional technological upgrades and environmental protection, becoming a complex engineering system that requires coordinated advancement across the port, industry, and city subsystems. This transition is deeply intertwined with an evolving global maritime governance agenda. Two principal frameworks are setting the pace for decarbonization: the International Maritime Organization (IMO)'s 2023 GHG Strategy [63], which sets ambitious emission reduction targets for the global shipping fleet, and the European Green Deal, which, through its 'Fit for 55' package and FuelEU Maritime initiative, establishes some of the world's most stringent standards for vessel emissions and the use of sustainable marine fuels in European ports [64]. Our finding that "Port Greening" is a primary obstacle for Shanghai highlights a crucial point: green port development is a prerequisite for fulfilling these international mandates. Global shipping now faces stringent environmental regulations from both the IMO and the EU. To meet these standards, vessels require access to green infrastructure. Major hubs like Shanghai fulfill this need by providing facilities for alternative fuel bunkering (e.g., LNG, methanol) and shore power, thus enabling shipping lines to achieve compliance. Accordingly, future research on PIC integration should move beyond a narrow focus on economic efficiency. The new priority must be to integrate sustainable development principles into a unified framework for ports, industries, and cities, offering guidance for both regional theory and practice.

Based on the above findings and analysis of lagging factors, the following policy recommendations are proposed:

(1) Strengthen green port development: (1) Establish a dedicated fund for green port development to support environmental technology R&D and clean energy infrastructure, for instance, by allocating a percentage of port fees or creating a public–private partnership (PPP) investment vehicle. (2) Promote water-to-water container transhipment and other environmentally friendly transport models, such as by implementing preferential berth allocation and reduced port dues for feeder services over road transport. (3) Collaborate with the Yangtze River Delta to develop a regional green port cluster, specifically by harmonizing standards for shore power and alternative fuels to ensure interoperability across the region.

(2) Deepen port–industry coordination: Utilize the Lin-gang area as a pilot zone to establish a green supply chain demonstration park, which could showcase technologies like end-to-end carbon footprint tracking and low-carbon automated warehousing. And foster emerging clusters, such as green shipping and smart logistics.

(3) Promote port–city ecological integration: (1) Enhance sewage treatment and urban greening capacities, with a particular focus on treating port-related industrial runoff and creating green spaces adjacent to logistics parks. (2) Establish a joint port–city environmental investment mechanism, which could be formalized as a 'port–city Eco-Fund' with structured contributions from both port revenue and municipal budgets. (3) Develop ecological buffer zones between port operational areas and residential communities to mitigate noise and air pollution.

6.3. Research Limitations and Future Prospects

This study has the following limitations: First, it primarily relies on quantitative analysis, with limited exploration of qualitative factors such as policy shifts and institutional innovations. Second, the research focuses on a single city case, lacking comparative analysis across regions, which may constrain the generalizability of its findings. Third, although the constructed PIC evaluation system covers multiple dimensions, some aspects still require further refinement.

Future research can be expanded in several ways: (1) Broaden the data scope by incorporating more diverse indicators, such as sociocultural factors, institutional safeguards, and carbon reduction performance, to achieve a more holistic assessment of PIC coordination. (2) From a global perspective, conduct comparative studies across different countries and regions to explore the diverse integration models and mechanisms in green transformation. While the model's core logic is adaptable, its application requires customizing the indicator system to fit diverse socioeconomic contexts. For instance, for a mature hub port in a developed economy like Rotterdam, where the focus is on advanced topics like the energy transition and digitalization, the indicators would need to capture these themes (e.g., adoption rate of alternative fuels, share of circular economy industries). Conversely, for a port in a developing nation, where primary challenges might be infrastructure deficits and fostering industrial growth, the evaluation would prioritize more foundational indicators, such as hinterland connectivity and port-driven job creation. (3) Combine qualitative research methods to investigate how policy changes and institutional innovations impact PIC coordination and development. Through continued in-depth research on green ports and urban coordination, this study aims to provide broader theoretical insights and practical references for the sustainable transformation of global port cities.

Supplementary Materials: The following supporting information can be downloaded at https://www.mdpi.com/article/10.3390/su17177747/s1. Table S1: Indicator dataset for the coordinated port–industry–city development study.

Author Contributions: Conceptualization, H.W.; methodology, J.W.; investigation, F.T.; writing—original draft preparation, J.W.; writing—review and editing, J.W. and F.T. All authors have read and agreed to the published version of the manuscript.

Funding: This research was supported by the Science and Technology Innovation and Demonstration Project of Department of Transport of Yunnan Province (Grant number: YNZC2024-G3-04393-YNZZ-0391).

Data Availability Statement: The original contributions presented in this study are included in the article/Supplementary Materials. Further inquiries can be directed to the corresponding author.

Conflicts of Interest: The authors declare no conflicts of interest.

Abbreviations

The following abbreviations are used in this manuscript:

PIC	Port–Industry–City
COVID-19	Coronavirus Disease 2019
SIPG	Shanghai International Port Group

References

1. World Bank; United Nations Department of Economic and Social Affairs. *The Potential of the Blue Economy: Increasing Long-Term Benefits of the Sustainable Use of Marine Resources for Small Island Developing States and Coastal Least Developed Countries*; World Bank: Washington, DC, USA, 2017.
2. Witte, P.; Wiegmans, B.; Louw, E. More claims than land: Multi-facetted land use challenges in the port-city interface. *J. Transp. Geogr.* **2025**, *124*, 104181. [CrossRef]
3. Fetting, C. *The European Green Deal*; ESDN Office: Vienna, Austria, 2020.
4. Lacoste, R.; Douet, M. The Adaptation of the Landlord Port Model to France's Major Seaports: A Critical Analysis of Local Solutions. *Marit. Policy Manag.* **2013**, *40*, 27–47. [CrossRef]
5. Hentschel, M.; Ketter, W.; Collins, J. Renewable Energy Cooperatives: Facilitating the Energy Transition at the Port of Rotterdam. *Energy Policy* **2018**, *121*, 61–69. [CrossRef]
6. Chen, P.S.-L.; Fan, H.; Enshaei, H.; Zhang, W.; Shi, W.; Abdussamie, N.; Miwa, T.; Qu, Z.; Yang, Z. A Review on Ports' Readiness to Facilitate International Hydrogen Trade. *Int. J. Hydrogen Energy* **2023**, *48*, 17351–17369. [CrossRef]
7. Wang, S.; Kong, W.; Ren, L.; Zhi, D.; Dai, B. Misconceptions and Corrections of the Coupling Coordination Degree Model in China. *J. Nat. Resour.* **2021**, *36*, 793–810.
8. Cong, X. Expression and Mathematical Property of Coupling Model, and Its Misuse in Geographical Science. *Econ. Geogr.* **2019**, *39*, 18–25. [CrossRef]
9. Ettorre, B.; Daldanise, G.; Giovene di Girasole, E.; Clemente, M. Co-Planning Port-City 2030: The InterACT Approach as a Booster for Port-City Sustainable Development. *Sustainability* **2023**, *15*, 15641. [CrossRef]
10. Ma, C.; Mo, L.; Wang, S. The Coordinated Development and Evolutionary Characteristics of "Port-Industry-City" System in Fangchenggang City of Western China. *City Built Environ.* **2025**, *3*, 1. [CrossRef]
11. Hayuth, Y. The Port-Urban Interface: An Area in Transition. *Area* **1982**, *14*, 219–224.
12. Hoyle, B.S. The Port–City Interface: Trends, Problems and Examples. *Geoforum* **1989**, *20*, 429–435. [CrossRef]
13. Ma, Q.; Li, S.; Jia, P.; Kuang, H. Is Port Integration a Panacea for Regions Green Development: An Empirical Study of China Port City. *Transp. Policy* **2025**, *160*, 15–28. [CrossRef]
14. Zhao, D.; Dongmei, X.; Wei, D. Research on Port-Industry-City Integration and Its Spatial Spillover Effects: Empirical Evidence from the Bohai Sea Rim Region. *Appl. Spatial Anal. Policy* **2024**, *17*, 1653–1679. [CrossRef]
15. Yu, T.; Li, H.; Zhou, T.; Zhao, N.; Yang, Z. Evaluation and Strategy Development of Port-Industry-City Integration: A China' s Case. *Res. Transp. Bus. Manag.* **2025**, *60*, 101375. [CrossRef]
16. Liu, L.; Ping, H. Study of the Influencing Factors on Development of Ports in Guangdong, Hong Kong, and Macao from the Perspective of Spatial Economics. *Math. Probl. Eng.* **2020**, *2020*, 1–12. [CrossRef]
17. Ke, L.; Oh, Y.-S. The Relationship between Port and City Growth: The Case of Ningbo. *J. Korea. Trade.* **2023**, *19*, 165–177. [CrossRef]

18. Bocheński, T.; Palmowski, T.; Studzieniecki, T. The Development of Major Seaports in the Context of National Maritime Policy. The Case Study of Poland. *Sustainability* **2021**, *13*, 12883. [CrossRef]
19. Zhao, Q.; Xu, H.; Wall, R.S.; Stavropoulos, S. Building a Bridge between Port and City: Improving the Urban Competitiveness of Port Cities. *J. Transp. Geogr.* **2017**, *59*, 120–133. [CrossRef]
20. Guo, J.; Qin, Y.; Du, X.; Han, Z. Dynamic Measurements and Mechanisms of Coastal Port - City Relationships Based on the DCI Model: Empirical Evidence from China. *Cities* **2020**, *96*, 102440. [CrossRef]
21. Youyou, Q.; You, K.; Zhen, L.; Enyan, Z. Pursue the Coordinated Development of Port-City Economic Construction and Ecological Environment: A Case of the Eight Major Ports in China. *Ocean Coastal Manag.* **2023**, *242*, 106694.
22. Cong, L.; Zhang, D.; Wang, M.; Xu, H.; Li, L. The Role of Ports in the Economic Development of Port Cities: Panel Evidence from China. *Transp. Policy* **2020**, *90*, 13–21. [CrossRef]
23. Bottasso, A.; Conti, M.; Ferrari, C.; Tei, A. Ports and regional development: A spatial analysis on a panel of European regions. Transp. *Res. Part A Policy Pract.* **2014**, *65*, 44–55. [CrossRef]
24. Mudronja, G.; Jugovic, A.; Škalamera-Alilović, D. Seaports and Economic Growth: Panel Data Analysis of EU Port Regions. *J. Mar. Sci. Eng.* **2020**, *8*, 1017. [CrossRef]
25. Li, Y.; Zhang, X.; Lin, K.; Huang, Q. The Analysis of a Simulation of a Port - City Green Cooperative Development, Based on System Dynamics: A Case Study of Shanghai Port, China. *Sustainability* **2019**, *11*, 5948. [CrossRef]
26. Li, X.; Wu, H.; Sun, L. Research on the Current Status and Countermeasures of Jiangsu Port Services for Port - Proximate Industrial Development. *China Water Transp.* **2024**, *23*, 20–22. [CrossRef]
27. Wang, R.; Li, M.; He, D. A Study on the Economic Interaction between Port and City in Qinzhou Port, Guangxi, Based on Sea-Rail Intermodal Transport. *Bus. Econ.* **2024**, *11*, 75–80. [CrossRef]
28. In, Y.J.; Sojung, H.; Bogang, J. Ports as Catalysts: Spillover Effects of Neighbouring Ports on Regional Industrial Diversification and Economic Resilience. *Reg. Stud.* **2023**, *58*, 981–998. [CrossRef]
29. Chen, C.; Lam, J.S.L. Sustainability and Interactivity between Cities and Ports: A Two-Stage Data Envelopment Analysis (DEA) Approach. *Marit. Policy Manag.* **2018**, *45*, 944–961. [CrossRef]
30. Martiz, A.; Shieh, C.J.; Yeh, S.P. Innovation and success factors in the construction of green ports. *J. Environ. Prot. Ecol.* **2014**, *15*, 1255–1263.
31. Hossain, T.; Adams, M.; Walker, T.R. Role of sustainability in global seaports. *Ocean Coast. Manag.* **2021**, *202*, 105435. [CrossRef]
32. Lam, J.; Van De Voorde, E. Green port strategy for sustainable growth and development. In Proceedings of the International Forum on Shipping, Ports and Airports (IFSPA), Hong Kong, China, 27 May 2012; pp. 417–427.
33. Zhang, Z.; Song, C.; Zhang, J.; Chen, Z.; Liu, M.; Aziz, F.; Kurniawan, T.A.; Yap, P.S. Digitalization and Innovation in Green Ports: A Review of Current Issues, Contributions and the Way Forward in Promoting Sustainable Ports and Maritime Logistics. *Sci. Total Environ.* **2024**, *912*, 169075. [CrossRef]
34. He, Z.; Lam, J.S.L.; Liang, M. Impact of Disruption on Ship Emissions in Port: Case of Pandemic in Long Beach. *Sustainability* **2023**, *15*, 7215. [CrossRef]
35. Christensen, L. Renewable Energy Adoption and Carbon Emission Reductions in Copenhagen, Denmark. *Int. J. Commun. Syst.* **2024**, *3*, 26–38. [CrossRef]
36. Witte, P.; Slack, B.; Keesman, M.; Jugie, J.H.; Wiegmans, B. Facilitating start-ups in port-city innovation ecosystems: A case study of Montreal and Rotterdam. *J. Transp. Geogr.* **2018**, *71*, 224–234. [CrossRef]
37. Dadashpoor, H.; Taheri, E. Port-City Interface Dynamics for the Bandar-Abbas Port, Iran. *GeoJournal* **2023**, *88*, 4645–4670. [CrossRef]
38. Schubert, D. Spatial restructuring of port cities: Periods from inclusion to fragmentation and re-integration of city and port in Hamburg. In *European Port Cities in Transition: Moving Towards More Sustainable Sea Transport Hubs*; Springer: Berlin, Germany, 2020; pp. 109–126.
39. Zhang, J.Q.; Woo, S.H.; Li, K.X. Port-City Synergism and Regional Development Policy: Evidence from the Yangtze River Region. *Transp. Res. Part E Logist. Transp. Rev.* **2024**, *192*, 103817. [CrossRef]
40. Hou, L.; Xu, Y.; Dong, J.; Chong, H.-Y.; Ren, R.; Chen, Z. Reshaping Port-City Relationships through Underground Logistics System: A Mixed Qualitative Approach. *Cities* **2024**, *154*, 105395. [CrossRef]
41. Dai, P. Grey Correlation Analysis of the Relationship between Port Logistics and Regional Economic Development in Tangshan City. *J. World Econ.* **2023**, *2*, 61–67. [CrossRef]
42. Wan, Y.; Huang, C.; Zhou, W.; Liu, M. Evaluation of the Coupling Synergy Degree of Inland Ports and Industries along the Yangtze River. *Sustainability* **2023**, *15*, 15578. [CrossRef]
43. General Office of Shanghai Municipal People's Government. Notice on Forwarding the Shanghai Green Port Three-Year Action Plan (2015–2017). Available online: https://jtw.sh.gov.cn/ghjh1/20180605/0010-107.html (accessed on 6 August 2025).
44. Zou, T.; Guo, P.; Wu, Q. Applying an Entropy-Weighted TOPSIS Method to Evaluate Energy Green Consumption Revolution Progressing of China. *Environ. Sci. Pollut. Res.* **2023**, *30*, 42267–42281. [CrossRef]

45. Dong, L.; Liang, L.; Wang, Z.; Chen, L.; Zhang, F. Exploration of Coupling Effects in the Economy–Society–Environment System in Urban Areas: Case Study of the Yangtze River Delta Urban Agglomeration. *Ecol. Indic.* **2021**, *128*, 107858. [CrossRef]
46. Hua, C.; Chen, J.; Wan, Z.; Xu, L.; Bai, Y.; Zheng, T.; Fei, Y. Evaluation and Governance of Green Development Practice of Port: A Sea Port Case of China. *J. Cleaner Prod.* **2020**, *249*, 119434. [CrossRef]
47. Dong, Y.; Li, Y.; Zhang, L.; Yan, M.; Shao, W.; Zhang, Q.; Ji, C.; Mahmood, R.; Wang, P. Improved Urbanization-Vegetation Cover Coordination Associated with Economic Level in Port Cities along the Maritime Silk Road. *Ecol. Indic.* **2024**, *163*, 11211. [CrossRef]
48. Su, J.; Liu, J.; Zhang, A. Promoting Regional Coordinated and Sustainable Development of Port, Economy, and Environment in Archipelago-a Case Study of Zhoushan Port in China. *Ocean Coast. Manag.* **2024**, *257*, 107324. [CrossRef]
49. He, K.; Li, M. Study on the synergy development degree of regional port logistics and economy. In Proceedings of the International Conference on Statistics, Data Science, and Computational Intelligence (CSDSCI 2022), Qingdao, China, 19–21 August 2022.
50. Fan, D.; Ke, H.; Cao, R. Modification and Improvement of Coupling Coordination Degree Model. *Stat. Decis.* **2024**, *40*, 41–46. [CrossRef]
51. Wang, M.; Lan, Y.; Li, H.; Jing, X.; Lu, S.; Deng, K. Spatial—Temporal Differentiation and Trend Prediction of Coupling Coordination Degree of Port Environmental Efficiency and Urban Economy: A Case Study of the Yangtze River Delta. *Land* **2024**, *13*, 374. [CrossRef]
52. Fu, L.; Ren, Y.; Lu, L.; Zhang, H. Study on Integration Development and Evolutionary Features of Nantong City's "Port–Industry–City". *Mod. Urban Res.* **2021**, *6*, 60–66.
53. Chen, J.; Zhang, W.; Song, L.; Wang, Y. The Coupling Effect between Economic Development and the Urban Ecological Environment in Shanghai Port. *Sci. Total Environ.* **2022**, *841*, 156734. [CrossRef]
54. Yang, J.; Wang, T.; Zhang, M.; Hu, Y.; Liu, X. The Coordinated Development and Identification of Obstacles in the Manufacturing Industry Based on Economy-Society-Resource-Environment Goals. *Systems* **2025**, *13*, 78. [CrossRef]
55. Shanghai Statistical Yearbook. Available online: https://tjj.sh.gov.cn/tjnj/ (accessed on 6 August 2025).
56. Shanghai International Port Group (SIPG) Annual Reports. Available online: https://data.eastmoney.com/notices/stock/600018.html (accessed on 6 August 2025).
57. Shanghai International Port Group (SIPG) Sustainability Reports. Available online: https://www.portshanghai.com.cn/xxpl/index.jhtml?index=3 (accessed on 6 August 2025).
58. Zhongjing Database. Available online: https://ceidata.cei.cn/ (accessed on 6 August 2025).
59. Paustian, K.; Ravindranath, N.H.; van Amstel, A. *2006 IPCC Guidelines for National Greenhouse Gas Inventories*; International Panel on Climate Change: Geneva, Switzerland, 2006.
60. Shanghai Municipal People's Government. *Shanghai Municipal Gazette 2016, No. 19 (Serial No. 379)*; Shanghai Municipal People's Government General Office: Shanghai, China, 2016. Available online: https://www.shanghai.gov.cn/newshanghai2018/zfgb/201619/ZFGB1619.pdf (accessed on 27 August 2025).
61. Liu, C.; Yan, X.; Qu, S. Vulnerability Assessment of Port Logistics System Based on Set Pair Analysis. *Nav. China* **2024**, *47*, 293–302.
62. Tencent News. North Xiaoyangshan to Host Shanghai Port's Largest Single Automated Terminal. Available online: https://news.qq.com/rain/a/20250514A025AJ00 (accessed on 6 August 2025).
63. International Maritime Organization. *2023 IMO Strategy on Reduction of GHG Emissions from Ships*; Resolution MEPC. 377 (80); IMO: London, UK, 2023; Available online: https://www.imo.org/en/MediaCentre/HotTopics/Pages/Cutting-GHG-emissions.aspx (accessed on 17 August 2025).
64. European Commission. *Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions: 'Fit for 55': Delivering the EU's 2030 Climate Target on the Way to Climate Neutrality*; COM (2021) 550 Final; European Commission: Brussels, Belgium, 2021.