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How Do Automated Ports Balance Productivity and Sustainability? A Comparative EESG Study of Yangshan Port and Busan Port

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Abstract. This essay examines the automation development of China's Yangshan Port by benchmarking South Korea's Busan Port within the broader context of international maritime trade and port modernization. As global trade continues to expand, ports are increasingly required to improve efficiency, capacity, and technological integration in order to remain competitive.With the development of automation， many companies reduce investment in improving environmental protections and operational transparency. Therefore, in order to pursue long-term efficiency, a more comprehensive evaluating framework is needed. This study argues that port competitiveness is no longer determined solely by throughput or physical scale, but increasingly by the balance between Economic, Environmental, Social, and Governance (EESG) factors.Using a comparative EESG framework, this paper analyzes Yangshan Port and Busan Port across four dimensions: economic automation performance, environmental sustainability, social impact, and governance structure. The study highlights that Yangshan Port has a significant advantage in automation level and productive efficiency, while Busan port is more focused on environmental, social and governance factors. The findings suggest that although Yangshan Port demonstrates superior economic efficiency, Busan Port offers a more balanced EESG performance. Ultimately, we discover that there is a significant trade-off between efficiency and managing social and environmental externalities. Yangshan Port should refer to the Busan regulation and pollution solving model to strengthen environmental, social, governance(ESG) aspects.

Keywords: Automation, Sustainability, Economy, Environment, Government

1. Introduction

Where dockworkers once shouted over engines, silent cranes now move containers by algorithm. With the development of the intelligent economy, global container ports are experiencing a revolutionary transformation through automated technologies and digital governance. Nowadays, the loading capacity is no longer the dominant indicator for port competitiveness and standards. Instead, the core of competitiveness has shifted to port efficiency, social externalities, institutional

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governance, and environmental effects. To address the increasing demand for efficiency, automation has emerged as a double-edged sword. On one hand, automated processes and AI applications have significantly improved operational efficiency and reduced long-term variable costs as the demand for human labor decreases. On the other hand, the automation process also raises new challenges related to carbon emissions, labor substitution, social equality, and transparency in governance. Therefore, the problem faced by automated ports concerns how to increase automation levels and productivity, as well as whether it can balance environmental responsibility, social externalities, and direct governance. This essay compares the performance of Yangshan Port and Busan Port across the Economic, Environmental, Social, and Governance (EESG) factors to highlight the trade-offs and policy implications that global automated ports face in seeking competitiveness and balance across social, environmental, and productivity dimensions.

1.1. Why Yangshan and Busan Ports are a good comparison

Both Yangshan Port and Busan Port are well-known representative ports in Asia, ranking among the busiest ports in the region. Although the two ports operate under different government management and operational systems, their geographic, economic, and technological similarities make Busan Port an ideal candidate for comparison with Yangshan Port. First, both ports are located in East Asia and have access to deep-sea waters, allowing them to operate ultra-large container vessels (ULCVs). In addition, their strategic location connects North America and Europe, making both ports crucial nodes in global maritime trade networks, including the Trans-Pacific and Asia–Europe trade, the Indian Ocean, and the Suez Canal. Moreover, as coastal ports, they both rely less on inland transportation, which increases logistical efficiency. From a technological perspective, both ports share a similar approach to automation. By introducing automated cranes, Automated Guided Vehicles (AGVs), Terminal Operating Systems (TOS), and 5G communication technology, both ports have achieved higher productivity and operational efficiency. Automation also reduced labor dependence while improving consistency in port operations.

2. EESG analysis of Yangshan Port and Busan Port

To consistently and systematically compare Yangshan and Busan Port, this essay applies the EESG framework as its methodology. The EESG framework evaluates port performance across four perspectives: economic, environmental, social, and governance. From an economic perspective, this analysis examines scales, cost structures, and operational efficiency. The environmental part focuses on GHG emissions, green energy use, and ecosystem protection related to port automation. Social analysis considers safety, labor structures, and social impact in the local region. Finally, governance assesses policy frameworks and operational methods. The comparison uses Busan Port as a benchmark, further identifying Yangshan Port's strengths and limitations and offering insights into how it may enhance its sustainability and long-term profitability as an automated port.

2.1. Economic factor

In the global trade system, container ports are considered the cornerstone of trade efficiency. As competition among major trading ports increases worldwide, economic efficiency has become a key indicator of port competitiveness. The economic factor can be further discussed on four dimensions: scale, cargo volume, capital investment, and operational time.

First, the size of ports determines the number of ships and types of cargo they can handle simultaneously. Scale-related indicators, such as the number of ships and shoreline utilization, are included in port evaluation systems [1]. Yangshan Port benefits from its large offshore location and extensive land area. The *Report on the Cumulative Deepwater Coastline and Bridge Cranes of Yangshan Port in 2025* shows a cumulative deep-water quay line reaching 7,950 m and a network of many automated bridge cranes (e.g., 104 ultra-large intelligent cranes). This geographic advantage allows for longer quay lines, more deep-water berths, and the simultaneous accommodation of large numbers of ULCVs (SIPG, n.d.). Large physical scale increases parallel processing capacity, a key factor in productive efficiency. In comparison, Busan Port is a major regional hub in global trade, but terminal space and berth capacity remain constrained (BPA, n.d.). Busan Port's deep-water containing capacity includes Pier 1 (1,200 m), Pier 2 (2,000 m), Pier 3 (1,100 m), Pier 4 (1,150 m), and Pier 5 (1,400 m), a totally of 6850m, which has a deep-water quay length approximately 100 m shorter than Yangshan Port [2].

Additionally, cargo throughput is a vital indicator. According to the Chinese Ministry of Transport (2025), the growth of port cargo and container throughput effectively supports trade growth, highlighting the importance of cargo volume in reflecting a port's operational efficiency. Regarding cargo volume, Yangshan Port maintains its position as the world's leading container port and core node in global shipping networks (SIPG, n.d.; BPA, n.d.). These data illustrate that Yangshan Port (51.5 million TEUs) handles approximately twice as many TEUs as Busan Port (25 million TEUs). Higher throughput enables Yangshan Port to spread fixed costs across more containers, reduce the average total cost per container, and achieve larger economies of scale than Busan Port.

Besides, capital investment, especially automation technology, is a significant factor in determining long-term dynamic efficiency. More automated machines reduce short-run variable costs, especially labor costs, giving ports a greater advantage in long-term competition. According to the *White Paper on Smart Port Industry*, the large-scale deployment of automated terminals and artificial intelligence scheduling systems has increased port operational efficiency by more than 30%, underscoring that technology investment has become an important component of modern port competitiveness (IIM Information, 2025). In terms of capital, Yangshan Port operates with approximately 26 quay cranes, 120 gantry cranes, and around 130 automated guided vehicles (AGVs). The use of technologies significantly increases productivity and reduces reliance on labor. However, the automation level of Busan Port is still in development (Port Technology International, n.d.).The majority of automated machines at Busan Port operate 9 container cranes (Quay/Ship-to-Shore), 46 transfer cranes, 60 AGVs (Automated Guided Vehicles), 6 Container Cranes (additional installation), and 57 AGVs (Additional Planned Supply). The data illustrates a significant disparity compared to Yangshan Port.

Finally, operational time is a key indicator of port operational efficiency. The World Bank's Container Port Productivity Index uses vessel time in port as a main indicator of port productivity, underscoring its value for comparing port efficiency and global competitiveness [3]. Operational time is reflected in vessel turnaround time. Yangshan completes the loading and unloading of large container ships in approximately 23 hours, while Busan port has an average of 26 hours [4]. The advantage in vessel turnaround time further demonstrates Yangshan's superior economic performance.

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Table 1. Comparative analysis of economic performance and automation capabilities betweenYangshan Port and Busan Port

Economic Factor	Busan Port	Yangshan Port
Scale	Limited land Limited berth capacity 6850m deep-water quay lines	Longer coastline More deep-water berths 7950m deep-water quay lines
Cargo Volume	51.5 million TEUs	25 million TEUs
Capital/Automation	26 Quay Cranes (Ship-to-Shore) 120 Gantry Cranes (Yard Cranes) 130 AGVs (in operation)	9 Quay Cranes (Ship-to-Shore) 46 Transfer (Yard Cranes) 60 AGVs (in operation)
Operation Times	23 hours	26 hours

2.2. Environmental factor

As international ports, the automation process should consider environmental protection. Because of the large vessels and equipment, and the fuel combustion during operation, a large amount of greenhouse gas (GHG) emissions is generated, causing environmental problems and undermining the ecosystem. Therefore, one major challenge automated ports face is balancing automation with environmental protection. In this section, three significant aspects, including GHG emission, green energy usage, and ecosystem protection, are discussed in terms of automation.

The international shipping industry is a significant contributor to global greenhouse gases. In 2018, the global shipping industry emitted 1,076 tons of CO2, accounting for about 2.9% of global carbon emissions from human activities (European Commission). Therefore, international ports also need to reduce emissions as automation levels increase. Despite the lack of official data in its report, an academic study shows that the automation process results in a reduction of more than 7500 tons of carbon emissions per year, approximately 10% from 2020 to 2023 [5]. This significant reduction reflects the consistent efforts Yangshan Port has made to achieve its goal of becoming carbon neutral by 2060 [6]. The automation process increases the use of electrical equipment and optimizes energy management, leading to lower carbon emissions. In comparison, Busan Port serves as a benchmark for the GHG reduction level. According to its 2025 sustainability report, the port achieved a 20.5% reduction in GHG emissions [7]. This higher reduction rate reflects a greater focus on GHG reduction at Busan Port, illustrating its efforts to strike a balance between automation and carbon emissions.

To further promote environmental protection, ports need to transform from energy consumers to energy generators. Given the appeal of sustainable development, ports are seeking a way to shift to green energy [8]. Yangshan Port has made an effort to adopt cleaner energy sources, including electricity and renewable energy. In 2025, Yangshan Port had already covered all container terminals with shore power, which supplies energy to ships instead of using their engines, with +25% YoY vessel connections and 28+ million kWh supplied [9]. This adaptation to shore power increases electricity use and reduces emissions from ship engines, demonstrating that Yangshan Port is trying to replace traditional energy sources with electricity, which generates fewer negative externalities. In Busan Port, similar actions are also being taken to shift to green energy sources. Piezoelectric technology, which converts mechanical pressure to electricity, is used at port gates to generate renewable energy from cargo truck vibrations and pressure (WPSP). The use of piezoelectric

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technology is expected to generate 2,115 MWh annually, enough to power 705 households. This result also demonstrates that Busan Port is moving toward energy sources that generate fewer emissions and pollution, helping protect the environment during its automation process.

Ports are closely linked with the ecosystem. Traditional ports can produce pollution that might deteriorate the environment. Therefore, port automation with a focus on ecosystem protection is also an issue worldwide. In this area, Yangshan Port provides an outstanding example. After the operation of Yangshan Port, the levels of a toxic pollutant, polycyclic aromatic hydrocarbons (PAHs), decrease sharply [10]. This reduction in pollutant bioavailability (the proportion of a drug or other substance that enters the circulation when introduced into the body and is thus able to exert an active effect) underscores Yangshan Port's emphasis on maritime ecosystem protection and highlights the significant effects of automation. However, the situation at Busan Port may differ. According to data up to 2020, suspended solids (SS) in water, which are critical drivers of water quality degradation, reducing light penetration, transporting nutrients, and promoting eutrophication, peaked at 92 mg/L, frequently exceeding 10 mg/L, especially near enclosed port areas with limited water circulation [11]. This high concentration indicates that Busan Port is facing a serious water pollution problem caused by operations, which may worsen the marine ecosystem and further deteriorate the environment.

In conclusion, the Yangshan port saw significant improvements in environmental protection through automation. Its reduced GHG emissions, adoption of clean energy, and lower water pollutant concentrations illustrate a shift from traditional polluters to an environmental protector. Compared to Busan port, its higher automation level and larger scale protect the maritime ecosystem but also make reducing emissions and adopting green energy more challenging.

2.3. Social factor

Different operation models and geographical conditions contribute to disparate social outcomes. Yangshan Port and Busan Port, as mega ports within their respective regions, employ different management structures and labor conditions. In addition, varied interactions with surrounding regions shape different social impacts. Social factors are analyzed by examining the labor structure, strategies aimed at displaced workers due to automation, and their broader impact on the local community.

Yangshan Port, as the main port in Shanghai, is largely automated. However, the limited transparency of public information on labor, safety, and workforce transitions makes it difficult to verify the company's social performance fully. The port employs around 300 workers and handles approximately 6 million TEU per year. Operating with high labor efficiency, however, leads to massive labor displacement. Demand for manual labor decreased significantly, with overall labor reductions of 70% in 2023 [12]. For example, traditionally, standard rail-mounted gantry cranes had a 1:1 operator-to-crane ratio, but were reduced to 1 operator per 11.9 cranes after automation [13].

Yangshan Port, as a key state-owned port under the Shanghai International Port Group (SIPG), has a similar structure to Bianzhi labor (meaning state-affiliated) as other Chinese public companies do. Yangshan port's labor is composed of 90% Bianzhi workers, with stable contracts, and 10% non-Bianzhi labor. Bianzhi workers are considered critical to port efficiency and safety. They form the stable pillar of the workforce, while non-Bianzhi labor serves as dispatched labor with limited transition flexibility, fixed-term contracts, and fewer benefits in the Yangshan port.

Yangshan Port has a strong safety record due to automation. However, heavy reliance on technology creates long-term maintenance and resilience problems. The port's social impact is largely symbolic and strategic, representing China's technological and infrastructural advancement

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as a national project, operating under government-led projects. The port plays a strong political role, integrating with the Belt and Road Initiative, and serves as a public relations tool for soft power. For example, Chancay Port in Peru linked Yangshan's governance model to the success of the Belt and Road in 2024. Yangshan port prioritizes international influence and national fame over the local labor community.

By comparison, Busan Port has adopted partial automation at a lower rate than Yangshan Port, with a greater focus on local labor, community welfare, and transparency. Busan port focuses on reskilling and retention for workforce development, particularly for workers at risk of automation. In 2025, Busan Port achieved 100% employment retention through retraining workers [14]. This number demonstrates that Busan port prioritizes labor protection, maintaining a mix of human and automated labor rather than replacing labor. The labor structure at Busan Port includes both formal and outsourced workers, who are protected by the Busan Port Transport Workers' Union (BPTWU). The union provides institutional protection, labor' labor-management, and a formal voice for workers during automation transitions. For example, BPTWU negotiated collective bargaining agreements for the 22nd consecutive year, including on working conditions and responses to automation, demonstrating stable labor negotiations. Joint signing of a Human Rights Management Charter between the port authority and the union further highlights labor's workplace rights and protections [15].

Busan Port's social impact is community and labor-centered. Its contribution reduces local inequality and minimizes the negative externalities of automation. Busan employment rates reached 59%, the highest on record for the city [16]. According to Statistics Korea (2025) reported by the Busan Metropolitan Government, the number of regular workers in Busan increased from about 856,000 in early 2023 to over 1,003,000 by June 2025, marking its highest level on record. Moreover, Busan port contributes to a better community welfare. Busan port participates in volunteer programs, such as donating to children's protection facilities in Seoul at the end of each year. In addition, for three years, it has continuously achieved the highest grade in the 2025 Regional Community Contribution Evaluation. Forming a culture of sustained financial support in social engagement. Furthermore, BPA was recognized as the top institution in disaster management, reinforcing the safety of its employees and the surrounding community and reflecting a social responsibility that considers both welfare and safety [17]. These achievements demonstrate that Busan port functions not primarily as a trading hub but as an institution that grows harmoniously with local communities while pursuing social and economic sustainability.

Yangshan Port emphasizes automation efficiency, scale, and national strategy and global influence, while Busan Port prioritizes equity, labor protection, workplace safety, and local social stability. Structurally, Yangshan uses the Bianzhi labor system, whereas Busan relies on union-regulated employment. Overall, Busan demonstrates a more human-centered, locally embedded automation model. At the same time, Yangshan represents a state-driven, technology-first model, where social impact is framed primarily through global soft power rather than local community integration.

2.4. Governance factor

To compare governance differences between Yangshan Port and Busan Port, we focus on labor outsourcing and the transition after the ports' automation. The Yangshan Port chooses structural divestment. Specifically, the managers of Yangshan Port have established a more high-tech area for workers to control automation. Additionally, the transition in Yangshan is not an evolution of the existing workforce but rather a start from a clean slate. According to the report, the number of

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factory workers had fallen from 3,500 to about 1,800. However, productivity has boomed. The CEO of Yangshan port predicted that the company will need only about 800 production workers [18].

Because the automation in Yangshan has developed rapidly and uses high-level AI and Digital Twin technology (upgrading efficiency by 5.37% in 2025) to manage Phase IV [19]. The public message is supremacy - showing that the state has the most advanced "Smart Brain" to move cargo faster than anyone else. Consequently, Yangshan Port reduces its labor costs by up to 70%. It employs only highly skilled laborers to operate automated vehicles and artificial intelligence, rather than relying on low-skilled workers for manual labor or on machines. Hence, with the transformation of traditional terminals towards automation, the demand for outsourcing has disappeared, reflecting the logic of state-driven industrial upgrading. The focus of Yangshan is on "Industry 4.0" and "Smart Port", and its governance emphasis is on the accumulation of technological capital rather than the placement of the social labor force. The laborers who were replaced by automation choose to work in roles such as delivering takeout and express packages [18], widening the gap between workers and putting pressure on governments to address unemployment.

Unlike Yangshan Port, Busan Port mostly uses subsidiary-based hiring to absorb outside labor. For instance, the Busan Port Authority (BPA) (2025) established specialized subsidiaries to hire workers previously outsourced directly. This policy focuses on converting "indirect" and "irregular" employees into regular employees to reduce employment uncertainty and provide long-term career security. From the BPA's perspective, subsidiaries can achieve employment succession, reduce the risk of employee strikes caused by job uncertainty, and ensure worker safety by adopting the same management standards. Compared with outsourcing contracts that are concealed, subsidiaries' financial and personnel systems are more transparent, meeting the requirements of global investors for ESG governance. In 2024-2025, BPA achieved a 100% retention rate for 598 port workers at Jaseongdae Pier by ensuring their "employment succession" when the terminal operator changed . The subsidiaries' goals also align with the Korean government's "Zero Non-Regular Workers" policy, a public-sector initiative aimed at eliminating the "dual labor market". This market covers both regular and irregular workers who do the same job for different pay [20]. In addition, the Korean Public Service and Transport Workers' Union (KPTU) is highly influential in the Korean labor market. It treats automation not as a purely technical shift but as a "Social Risk" that must be managed, and that provides security for laborers. Therefore, the BPA and KPTU not only reduce the inequality gap among workers but also provide employees with a regular status, high benefits, and safety assurance.

Finally, Busan Port offers a better solution for workers experiencing technological unemployment. The Yangshan Port's success is more dependent on its efficiency in increasing TEU, whereas Busan Port's success depends on measurable social value data.

2.5. Key findings

The comparison between Yangshan Port and Busan Port illustrates the difference between a national-level port and a more private port. Yangshan Port, due to its greater scale, has a larger capacity and higher efficiency through automation. In contrast, Busan port focuses more on interaction with society and the environment, aiming for greater transparency in its operations.

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Table 2. Summary of key EESG findings between Yangshan Port and Busan Port

	Yangshan Port	Busan Port	Key Findings
Economy	Greater scale; Larger cargo capacity; Higher automation level; Greater efficiency	Smaller scale; Lower cargo capacity; Partially automated; Longer ship turnaround time	Yangshan Port has greater development potential due to its larger scale, but it may face challenges with automation because of its overly large scale.
Environment	Lower percentage of GHG emission cut; Shore power coverage; Higher water quality	Absolute GHG percentage cut; Piezoelectric technology; High suspended solids concentration	Busan Port has a greater focus on environmental protection, while some water quality indicators affect the effectiveness of its protection efforts.
Society	Bianzhi structure	Labor union; More human-centered	Yangshan Port has a clearer and more direct employment institution; Busan Port focuses more on labor replacement and its interactions with society.
Government	Lack of data in certain parts; Widening gap between workers	More transparency; Fewer replacements for workers	Busan Port has greater transparency in its operations, which facilitates friendly interaction with diverse social groups.

3. Suggested reforms

3.1. More transparent public relations

Yangshan Port needs to improve transparency in public communication. Good public communication can first increase transparency during the labor transition. Busan Port performs better in its "Inclusive Growth" narrative. BPA proactively communicates how it manages the workforce during automation. While achieving a 70% reduction in personnel through automation, Yangshan Port's public relations focus almost entirely on the technology. By communicating specific re-employment pathways or technical upskilling for the displaced 70%, Yangshan can shift its image from "labor-replacing" to "labor-evolving."

However, opening public communication also has a disadvantage. Since public opinion may also influence the adoption of public strategy, especially the current strategy, which emphasizes efficiency rather than labor and communities. For instance, Xibei's chairman was "open" and "transparent" about his belief in the "715" work culture. However, this transparency was exactly what triggered a PR disaster. Because the public's values (work-life balance) clashed with management's values (extreme output), openness became a weapon against the brand. The governance challenge faced by Yangshan Port lies in finding a "dynamic balance point": it needs to learn from Busan Port's technical transparency, such as environmental indicators and carbon reduction data, to meet international financial requirements, while also avoiding the management transparency trap of Xibei, especially avoiding directly exposing the strict labor substitution logic.

3.2. Focus on EESG at the national scale

Yangshan port demonstrates higher efficiency, technology, and scale than many global ports. However, to become truly sustainable, Yangshan Port cannot stop at technological innovation and automation. Sustainable port performance is determined not only by economic indicators, such as cargo volume and automation ratios, but also by detailed operational indicators, including labor protection policies, environmental management, and impacts on local communities. As illustrated by Busan port, systematically managing and disclosing detailed information to the public, such as annual ESG reports, plays a crucial role in enhancing policy credibility and consistency. From a national perspective, such practice cannot remain an individual exemplar, but should be institutionalized as a national ESG evaluation policy applied across the entire port industry. Ongoing monitoring of detailed indicators and long-term data accumulation will improve allocative efficiency, strengthening the Yangshan port's sustainable development and national competitiveness.

Nevertheless, certain inefficiencies are unavoidable. Given limited resources, keeping up a high level of both efficiency and detailed operational standards is challenging. From an economics perspective, allocating additional resources to labor protection, environmental management, and social accountability may reduce short-term efficiency gains. This trade-off represents an opportunity cost that Yangshan Port should accept to support long-term, sustainable development.

4. Conclusion

From an economic perspective, Yangshan Port has a significant advantage over Busan in terms of scale and efficiency. Its comprehensive automated equipment and large-scale AI application enable Yangshan Port to achieve economies of scale and lower long-term production costs. However, the pursue of efficiency also causes challenges in labor displacement and social adaptation. In contrast, Busan port has competitive advantages in innovation, social stability, and performance in governance capacity. From a governance perspective, Busan Port achieves significant carbon reduction through the use of renewable energy and diversified experimental technologies. In addition, Busan Port has a strong labor union participation and transparent governance for the public. These features promote stable governance structures and develop environmentally beneficial processes. It has greater long-term potential benefits. The comparison implies that the Yangshan port must make an unavoidable trade-off. Finally, although with certain limitations, this essay suggests that Yangshan Ports should allocate additional resources to ESG initiatives and call for a national strategy to improve the national EESG performance.

Acknowledgement

If any, should be placed before the references section without numbering.

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