



Global green port development models and the assessment of their applicability: A Case study of Vietnam's Southern ports

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ABSTRACT

With 80% of international trade transported by sea, maritime transport serves as the tool through which society navigates the dynamic interaction of supply and demand, featuring its critical role in global commerce. The shipping industry is under growing pressure from current International Maritime Organization (IMO) policies aimed at reducing the impact of climate change and heading towards the bright future of sustainability. Although the maritime industry recognizes green ports as a crucial solution to environmental pollution and climate issues, the progress of green port development, particularly in developing countries, remains limited. Vietnam is making significant efforts to develop environmentally friendly ports, with a vision towards 2050 of connecting the dry port systems with logistics hubs, expecting to serve the increasing demand of container transport and other logistics businesses in numerous localities. However, there are some obstacles to getting everything done properly. This study aims to identify the key factors in building and developing green port models from leading countries in the industry by comparing the differences in port construction and formulation among major designated ports in the world and notable representatives of Vietnam. After that, the study shall assess the hypothesis of applying green port development models in Vietnam in line with global trends. Our research also highlights the support and encouragement for green port initiatives from the government, indicating Vietnam's significant potential in constructing and developing green port models. Additionally, the study figures out current disadvantages and significant challenges in coping with these movements in the future.

1. Introduction

According to the United Nations Conference on Trade and Development (UNCTAD), in recent years, although there was a sharp decrease during the pandemic, maritime transport remains the principal method that moves 80% of all globally traded goods [1]. It enables trade between

countries and continents, giving them access to essential goods and markets all over the world. The shipping industry is facilitating commerce and aiding in economic growth by offering lower freight in transport and presenting cleaner solutions towards sustainability [2].

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Acting as a bridge between sea and land transportation, ports become the integral points optimizing the flow of cargo in an environmentally efficient manner involving reversal of flow and a variety of functional machinery to ensure the seamless transfer of various types of goods. Additionally, in the current world of globalization and supply chain, ports act as the primary nodes for transferring goods between the hinterland and foreland by connecting with the road, rail, or waterways transport depending on the features of the geographic location of a particular port area. Deriving from this essence, port daily operations concentrate on two main sectors, including ship-related and cargo-related services. Ship-related services comprise an extensive range of facilities designed to meet the various demands of vessels. These include navigational services such as pilotage, towage, anchorage, and berthing a ship; and technical services such as ship maintenance, bunkering, repairs, and provisions for ships and their crews. Cargo services can be divided into four segments that are cargo receipt or dispatch and storage.

As Lloyd's report showed that the top 50 ports in the world handled approximately 67% of the global container volume in 2016, therefore, to catch up with the evolution of shipping, ports, which served as the principal connection in supply chains, need to interact with every business partner in the world for the advancement and reinforcement of their services. "Green port" since then was presented as an achievable solution. It has been recognized as an innovative approach to sustainable development in the late 1990s to 2000s by coordinating the balance between environmental effects and economic benefits [3]. The terminology "green port" is a

concept that has evolved over time in response to the growing environmental concerns [4], referring to ports that incorporate environmentally sustainable and responsible practices into their operations, aiming to minimize the environmental impact and contribute to sustainable development by using all resources more efficiently, reducing emissions and waste, and implementing measures to preserve local ecosystems [5]. This includes the use of solar panels, wind turbines, and other green technologies to reduce emissions [6]. By law, regulations, and initiatives, the United Nations (UN), the International Panel on Climate Change (IPCC), the World Health Organization (WHO), and the IMO have set targets for the decarbonization of the world. Overall, CO₂ emissions and their impact on climate change are topics being discussed by individuals, organizations, and entities all over the world.

2. Literature Review

2.1. The impacts to the environment of port operation

Ports are the key link within global supply chains, performing a variety of critical roles from cargo handling and storage to providing value-added services. By serving vessels, handling cargoes, and transporting goods throughout the inland and global markets, there are many sources of pollution arising from port operations, such as air pollution, water pollution, noise pollution, and others.

Vessel: Pollutants and emissions from vessels, along with those from hinterland means of transport and port equipment, contribute a significant amount of pollution in port, including air pollution, water pollution, and noise pollution. Currently, the

global shipping sector's CO₂ emissions, as well as Sulphur Oxides (SO_x), Nitrogen Oxides (NO_x), and other Greenhouse Gases (GHGs) shall grow by 16% from 2018 to 2030 and 50% by 2050 without additional policy action [7]. Water and noise pollution are also considerable concerns. Water pollution stems from various ship operations, such as the discharge of ballast water or the disposal of water from ship activities, which can damage the local marine ecosystem [8]. Ships themselves generate noise due to engine operation, loading/unloading operations, and the use of foghorns [9].

Cargo: Among the variety of cargo types, we focus on non-containerized and containerized cargo. Non-containerized cargo, due to its specific characteristics, carries a higher risk of causing environmental pollution during its handling process. This is often not the case with liquid-based cargo, as the operation occurs within a pipeline system. Dry materials like cement, mineral ores, or mined products are particularly prone to generating dust [10]. On the other hand, containerized cargo, while generally more environmentally friendly than non-containerized cargo, also causes environmental pollution, including air and noise pollution [11]. These pollutants can originate from handling operations as well as the movement of the containers themselves [12].

However, pollution from containerized cargo can be mitigated and monitored more effectively than that from non-containerized cargo by employing alternative fuels that are environmentally friendly, hybrid electric cargo handling equipment, and advanced port technologies [11].

The hinterland: The hinterland is the area where traffic demand starts. The port

hinterland is connected to a port by lines of communication or transport routes: roads, railways, pipelines, and rivers/canals [9]. Transport to and from the port could intensively contribute to environmental pollution, especially road transport, because of the flexibility to deliver cargo "from door to door." On the contrary, road transport mode has its limitations, for instance, unit capacity and relatively high engine power used, resulting in high fuel consumption and emissions that are often not optimal compared with other alternatives. The impacts resulting from road traffic are extensive, and the consequences are reflected in fuel leakage, soil sealing, noise, and air pollution. Moreover, referring to land transport, rail transport marks a vital influence in hinterland connection, with more sufficient capacity and less environmental impact compared with road transport for the same quantities of cargo. In some countries with natural blessings, inland waterway transport is their significant advantage by using barges and inland waterway cargo ships, leading to less fuel used for the transportation of the same cargo volumes, generating fewer emissions compared with other transport modes [13].

2.2. The concept of green port

Since 2015, globalization has been moving towards greener and more sustainable practices. The IMO GHGs Strategy [14], adopted at the Marine Environment Protection Committee, sets the target of achieving net-zero emissions from international shipping by or around 2050, employing technology, alternative fuels, and energy sources such as LNG-LPG. Undoubtedly, LPG serves as the kickstart needed to transition towards carbon-neutral fuels [15]. When using LPG, sulfur oxides decrease by approximately 99%, GHGs by

around 15%, and nitrogen oxides by about 10% [16]. Additionally, ships are increasing in size every year to reduce the carbon footprint per unit of cargo. Larger vessels require fewer trips to transport the same amount of cargo, leading to a substantial reduction in overall emissions. Accordingly, the fuel needed for a day of transport per unit of cargo can be reduced by nearly 25% by using 10,000–12,000 TEU ships instead of 5,000–6,000 TEU ships [17].

However, the green transformation of the shipping industry shall be incomplete without embracing the green port concept. Ports need to be equipped with the necessary infrastructure and facilities to support green ships since their reputations are intertwined. Therefore, as ships are becoming environmentally friendly, port authorities would not want to risk tarnishing their name by not adopting green practices. Hence, the concept of a green port is essential for a sustainable future.

Containerized shipping is well-aligned with the green port concept because it simplifies various operational aspects, aiding in the implementation and tracking of green port initiatives. Containerized shipping also offers opportunities for more efficient loading and unloading, reducing the total time spent in port and consequently decreasing emissions at the site. Moreover, with advances in technology, containers themselves can be handled with electric-powered equipment, further minimizing the carbon footprint in operation.

Based on all these pieces of evidence, it can be affirmed that container terminals are appropriate venues for the advancement of green port implementations.

2.3. Regulation and guidelines for global green ports

The trend in maritime transportation is undeniably shifting towards green ports, signaling a collective move towards sustainability in maritime activities. To mitigate environmental impacts, several global organizations have proposed regulations, guidelines, and necessary future objectives for transitioning towards green ports. For example:

IMO: The IMO adopted a strategy to reach net-zero GHG emissions from international shipping by or around 2050 [14], committing to ensure an uptake of alternative zero and near-zero GHG fuels by 2030, as well as indicative checkpoints for international shipping to reach net-zero GHG emissions for 2030 (by at least 20%, striving for 30%) and 2040 (by at least 70%, striving for 80%).

ISO: The ISO has released ISO 14001 certification (which was first published in 1996 and amended in 2015), an internationally recognized standard for Environmental Management Systems (EMS), which is highly pertinent to the establishment of green ports [18]. It outlines a framework for companies to follow to set up an effective EMS, paving the way for ports on their green initiatives. Additionally, ISO 20519, established in 2017, provides specifications for safe bunkering procedures for LNG-fueled ships, aiming to prevent or minimize impacts on the environment during processes. As LNG is seen as a cleaner fuel option in maritime transport, this ISO standard underpins green port practices [19].

APSN: APEC Port Services Network (APSN) is a unique international organization that promotes economically and environmentally sustainable ports for APEC members in the Asia-Pacific region [20]. The APSN initiated the Green Port

Award System (GPAS) in 2011 and officially launched this program in 2016 to set an achievement for ports to encourage green and sustainable development [21].

EcoPorts: They, which was initiated in 1997 and has been integrated into the European Sea Ports Organization (ESPO) since 2011, aim to raise awareness on environmental protection through cooperation and sharing of knowledge between ports by setting two sections about Self Diagnosis Method (SDM) and Port Environmental Review System (PERS), especially PERS, which is the standard for the port sector [22]. PERS is also globally recognized and is now being adopted by numerous international port associations, such as the African Ports Association and the American Association of Port Authorities (AAPA).

Furthermore, the World Bank recognizes the EcoPorts PERS as a global standard for environmental risk prevention for port finance schemes [23].

2.4. The key factors of green ports in achieving sustainable goals

There is a consensus on criteria necessary to establish a list of the key factors to determine a green port:

Port authorities, port management, and pricing: Port authorities play a pivotal role in managing and promoting the ports. Traditionally, port authorities perform roles varying from landlord to regulator to operator of the port. Their role has evolved significantly since the 21st century due to the reforming of port governance, the increasing presence of private operators and owners, and the changing economic contexts and technology. Their key responsibilities include administration, development, management, and port operation, including

ownership, economic exploitation, and long-term development of land, as well as the upkeep of basic infrastructure such as fairways, berths, access roads, bridges, and tunnels [9]. According to ESPO, port authorities should be leaders in driving environmental performance while efficiently managing their ports for socio-economic benefits by promoting best practices, facilitating knowledge sharing, and strengthening networks among their members [24]. On a smaller scale, terminals are typically managed by port operators. Port authorities operating their own container terminal are no longer a priority. Nowadays, port authorities act as landlords by hiring terminal operators to operate their terminals [25].

One efficient green management tool in ports is the pricing strategy. They can be used to boost a port's competitive position, such as lowering charges to encourage green ships to visit [26]. Some ports use the Environmental Ship Index (ESI), which is one of the projects under the World Ports Climate Initiative (WPCI), to identify vessels' performance by assessing the amounts of pollutants [27]. For example:

Port of Busan (Korea): Vessels that ESI score 31 points or higher will be able to receive a 15% discount on port dues in 2014 while staying at the port of Busan [27].

Port of Singapore (Singapore): The Green Port Program is specifically targeted at ocean-going vessels that use approved abatement or scrubber technology or burn clean fuels with a Sulphur content of less than 1.00%. These vessels are offered significant incentives during their time within Singapore Port Limits. For those staying in the port for 5 days or less, a generous 25% reduction in port dues is provided, while vessels at berth can benefit

from a 15% reduction in port dues. Furthermore, the Green Ship Program provides financial benefits to qualifying Singapore-flagged ships. Ships that exceed the IMO's Energy Efficiency Design Index (EEDI) through the adoption of energy-efficient designs benefit from a 50% reduction in initial registration fees along with a 20% rebate on annual tonnage tax. For ships that go the extra mile in environmental responsibility by adopting approved SO_x scrubber technology that exceeds the IMO's emission requirements, these benefits are further increased. A 25% reduction in initial registration fees and the same 20% rebate on annual tonnage tax are the rewards for these ships. Even better are the benefits for ships that combine both energy-efficient designs and approved SO_x scrubber technology. These ships are given a substantial 75% reduction in initial registration fees and a 50% rebate on annual tonnage tax [27].

Port of Tokyo (Japan): Vessels that achieve certain ESI scores are eligible for reductions on port dues. Specifically, vessels with an ESI score of 20.0 to 29.9 can qualify for a 30% reduction. The reduction increases with the ESI score, with a 40% reduction applicable to vessels that have an ESI score in the range of 30.0 to 39.9. Lastly, vessels that attain an impressive ESI score of 40.0 or higher can benefit from the maximum reduction, a significant 50% off on their port dues [27].

Technical Infrastructure: Technical infrastructure plays a significant role in providing the physical and technical foundations for implementing green solutions at ports. By improving and innovating technical infrastructure, ports can significantly reduce the environmental impact of port operations while

simultaneously providing more efficient and safer harbor services. Several technical infrastructure solutions have been recommended to address specific issues frequently encountered in ports, such as managing air pollution, ship waste, and improving energy efficiency and transitions [28]. Investment in appropriate infrastructure and collaborative efforts with shipping companies and other stakeholders enhances the efficiency and sustainability of cargo handling. The net effect not only leads to substantial cost savings but also promotes environmental protection, underpinning the vital role of green ports in building sustainable global supply chains.

Shore power: It is a method employed at ports to supply electricity to docked ships from an external source, such as a shore-side electricity grid. This action allows the ship to shut down its engines while remaining fully operational [25]. The benefits of shore power are manifold. Using significantly reduces the emission of GHGs and other pollutants like CO₂ (reducing emissions by up to 85%), SO_x (by 88%), NO_x (by 94%), and PM (by 95%) from a container terminal's ship emissions inventory, as well as particulate matter from the ships, leading to improved air quality around the ports [29]. Additionally, onboard energy consumption is lowered, thereby increasing energy efficiency. Shore power also reduces noise pollution, as the ship's own engines no longer need to operate while docked [30]. Lastly, if shore-side energy is sourced from renewable power plants, shore power can contribute to green shipping solutions and a more sustainable maritime industry.

Water treatment: This includes facilities designed to effectively collect, treat, and recycle water waste or pollutants discharged from ships and port activities [24]. This

helps protect precious biodiversity and maritime ecosystems. Furthermore, efficient treatment of water waste aids the port in adhering to environmental regulations, avoiding legal ramifications, and saving costs by reusing. Lastly, this infrastructure enhances the port's reputation in operation and environmental protection in the industry as well as in the community.

Cargo handling and facility: Automated cargo handling systems ensure logistics efficiency by estimating accurately the time in ports, reducing waiting times, therefore lowering the level of environmental. The use of digitalization and automation in cargo handling reduces operational inefficiencies caused by human negligence, enhancing speed and overall process [31]. The use of energy-efficient and low-emission equipment, including hybrid or electric cranes and Automated Guided Vehicles (AGVs), reduces the carbon footprint.

GHGs emission inventory: A GHGs emission inventory is a crucial tool used at green port to manage and reduce their environmental impact. It provides a thorough account of all energy use, fuel use, and other port-related activities that contribute to GHGs emissions. With this comprehensive understanding of the emission sources, port authorities can identify areas for improvement, such as enhancing energy efficiency or upgrading port operations to reduce their environmental footprint. Furthermore, this inventory serves as a foundation for the development and implementation of effective emission reduction measures. The benefits are substantial; by obtaining a clear and detailed emission profile, sustainable strategies can be tailor-made for the port, leading to better environmental performance [28]. In the long run, this not

only helps reduce the impact but also contributes to the attainment of global sustainability goals, making the ports more socially responsible and economically viable.

The hinterland: The important part that makes a port green is its hinterland. It is known as the effective market, or the interior region served by the port. The hinterland transportation system enables load units to be transhipped between seaports and inland destinations. The logistics related to the hinterland involve many actors and activities and require intense collaboration and coordination to work effectively and efficiently. The hinterland transportation system consists of rail, road, and inland waterways to transport goods. In the concept of a "green port", the hinterland is also known as the efficient factor [32]. For example, the Japanese shipping company ONE recently expanded its hinterland range, primarily offering the main service by rail, cutting around 80 percent of CO₂ emissions compared to truck transport. TFGeco, ONE product, completely covers the power requirement for rail transport with renewable energies. While in other continents, in the infras survey review, it was found that using rail transport saves 80% of CO₂ emissions compared to road transport, while inland waterways also save 70% of CO₂ emissions compared to road transport. Additionally, the cost of using rail or inland waterways is less than 50% of the external cost of road traffic. This is because rails and barges can move a large amount of cargo in a single trip, reducing the number of individual trips that would be necessary if the same quantity of goods were transported by road [33].

3. The relevant case study of green port development

3.1. Bremen/Bremerhaven Port

The Sustainability Strategy of the Ports of Bremen/Bremerhaven: The twin ports of Bremen, situated in Bremen and Bremerhaven, are overseen by Bremen ports GmbH and Co. KG, representing the Free Hanseatic City of Bremen. Bremerhaven, positioned nearer to the North Sea, focuses on container ships, car carriers, and specialized vessels, while Bremen's terminals, located approximately 60 kilometers south, primarily handle general cargo and bulk commodities. In line with the aim of transitioning towards sustainability, the Ports of Bremen implemented a variety of policies, technologies, and measures and provided several green services to ships calling at its ports. They developed measures and integrated environmental objectives into their planning and operational structures. This pursuit includes technical infrastructures, such as a necessary waste reception infrastructure established in the early 2000s to receive and process all kinds of waste from ships and vessels that call at the port [34].

Port authorities, port management and pricing of the Port of Bremen/Bremerhaven: The port authority of the Port of Bremen has taken active steps in protecting the environment and public health and mitigating the impact of operations and port/environment development on climate change. Referred to as a “green port”, this port has implemented various policies, technologies, and measures to transition towards sustainability, incorporating environmental goals in planning and operational structures. For instance, as per an EU directive, Bremen Port developed a waste reception infrastructure to process various kinds of waste from ships and vessels since the early 2000s [28]. The port authorities have also focused on reducing air

emissions to improve air quality, enhance energy efficiency, and minimize impacts on climate change. To encourage ships to reduce their emissions, the port introduced the ESI tool in 2012, offering a bonus scheme for vessels that use low-sulfur fuels. Also, since 2012, the port has doubled its energy intake from renewable sources. To manage the entire process, the port authority established the office of environment and sustainability affairs in 2008, began publishing its “green port” sustainability strategy since 2009, and even registered its “green port” label as a global brand for companies wanting to promote sustainability in the logistic chain. Therefore, the port is committed to sustainable development, not only to protect the environment and public health but also to improve the port's competitive position. The Port of Bremen in Germany has implemented a pricing policy aimed at promoting environmental sustainability in shipping. Under this policy, a total of 25 ships with an ESI score of 30 or higher are eligible for discounts. Ships with an ESI score between 30 and 40 will receive a 5% discount per port call, while those with a score of 41 or higher will receive a higher discount of 10% per port call [27]. This initiative encourages ships with lower emissions and better environmental performance to frequent the port by offering them reduced fees, thereby incentivizing environmentally responsible shipping practices and contributing to overall sustainability efforts in the maritime industry.

Technical Infrastructures: In compliance with EU Directive 2000/59/EU and Bremen law on port reception facilities for ship waste and cargo residue, the port established waste reception infrastructure in the early

2000s [35]. Since 2010, efforts have been made to reduce air emissions, improve air quality, enhance energy efficiency, and mitigate climate change impacts. Renewable energy-generated electricity is provided for inland vessels and port operations.

Shore power: A total of 18 shore power connectors have been installed to enable inland vessels docked at the port to utilize clean energy, facilitating the shutdown of their auxiliary engines that would otherwise run on diesel generators. Meanwhile, options for onshore power supply for maritime shipping are under evaluation [28]. Since 2012, the port has significantly increased its use of renewable energy, aiming to double its reliance on sustainable sources. Plans are underway to introduce innovative technologies like green hydrogen by 2024, aligning with broader efforts to reduce GHGs emissions and meet evolving air quality regulations. EU directive 2014/94 mandates the prioritization of renewable energy and alternative fuels in ports, pressuring EU ports to comply.

Water treatment: The Federal Land of Bremen has taken proactive steps by establishing regulations and issuing guidelines for treating ship-generated wastewater, aimed at providing clarity on requirements for shipping, ports, and public authorities. Additionally, guidelines for issuing permits for underwater hull cleaning at the ports of Bremen were published in November 2021. Furthermore, efforts to reduce nitrogen oxide emissions, which contribute to water eutrophication, have been supported by the ports of Bremen. Initiatives include developing an information campaign on proper medication disposal, particularly for seagoing vessels, and exploring measures to implement IMO biofouling recommendations.

The hinterland: Ports like Bremerhaven and Hamburg have shifted to rail shuttles to reduce emissions and congestion, while others rely on barges for hinterland transport. The Port's first carbon footprint analysis in 2012 has guided efforts to monitor and mitigate its environmental impact, aiding in the development of targeted sustainability strategies.

The implementation of the green port model by the Port of Bremen has yielded significant efficiency and achievement. One notable success lies in their endeavor to reduce carbon emissions. With a target of achieving carbon neutrality in port infrastructure by 2023, the company has made remarkable progress. From 2011 to 2021, they have successfully reduced CO2 emissions from 7000 tons to 1,115 tons, representing an impressive relative reduction of 84.1%. Furthermore, the Port of Bremen's commitment to sustainability has been recognized through prestigious awards for eight consecutive years. Especially in 2021, the shipping company Holwerda Shipmanagement, with its vessel MV Freya, stood out as a beacon of eco-friendliness. The MV Freya achieved an outstanding ESI score of 56.11 points, securing both the "Most Eco-friendly Vessel" and "Most Eco-friendly Fleet" awards. This recognition not only underscores the Port of Bremen's dedication to environmental excellence but also serves as a testament to the tangible successes realized through their green port initiatives [34].

3.2. Shanghai International Port Group

Port authorities and port management of SIPG: Sustainable development, as an important element of their strategy, reflects Shanghai International Port Group's (SIPG) relentless pursuit of economic, environmental, and social development. SIPG focuses on technology development and actively trains and educates employees to adopt an environmentally conscious mindset [36].

Economic: SIPG is ranked among the top three major terminal operators worldwide and maintains the No. 1 ranking in container throughput in the world [36].

Environmental: SIPG aims to improve the capacity and efficiency of technological innovation. They focus on shore-power supply projects, RTG hybrid power transformation projects, and the use of technologies in management and paperwork to enhance the green hinterland [36].

Social development: SIPG continues to develop the waterway hinterland [36].

Technical infrastructure:

Shore power: In January 2020, Guangdong successfully supplied shore power to the "COSCO Sagittarius," a 20,000 TEU ultra-large container ship. The charging lasted for 6 hours, totaling 13,200 kWh. It was the first time in the world that this class of ultra-large container ships was successfully charged using shore power [36].

Cargo handling and facility: Optimizing the port of entry by building platforms: The feeder service platform and e-DOC platform for the Yangtze River [36].

E-EIR platform in the port of Shanghai: This platform helps improve the efficiency of the port of Shanghai, making it an information hub, innovating in port logistics,

and enhancing the port environment. The platform operates 24 hours a day, 365 days a year, transmitting over 3 million EIR documents daily, or nearly 1.5 billion per year [36].

E-truck platform: This platform centralizes the scheduling of container loading space, yards, docks, and fleets, reducing resource waste and achieving optimal resource allocation [36].

In 2019, in line with the requirements of the Central Government and Shanghai on cross-border trade facilitation, SIPG further optimized its port environment by improving customs clearance and logistics efficiency. The e-B/L went fully online on November 6, following the launch of the last e-Doc after the e-EIR and e-loading list. Under the instruction of the Shanghai Municipal Office for Port Services, SIPG began a test run for e-B/L in November 2018 and established a task force to collaborate with shipping companies, shipping agents, customers, and other relevant parties to promote the use of this paperless document. Within a year, e-B/L had been expanded to cover all containers in the Port of Shanghai [36].

Yangshan Port Phase IV Automated Terminal: The capacity of the Yangshan Phase IV terminal is 150,000 tons. This phase is characterized by intelligent and unmanned operations throughout terminal handling, horizontal transportation, and stacking yard management. This approach is crucial for reducing terminal operating costs, enhancing operational efficiency and safety, and promoting green and low-carbon terminal development. By the end of 2019, the Yangshan Phase IV terminal had 16 quay cranes, 88 Automated Rail- Mounted Gantry (RMG) cranes, and 80 Automated Guided Vehicles (AGVs), with an annual throughput

capacity of 4 million TEUs. Long-term plans include expanding to 26 quay cranes, 120 RMG cranes, and 130 AGVs, with an annual throughput capacity of 6.3 million TEUs. The Yangshan Phase IV project covers a total land area of 2.23 million square meters, featuring 7 container berths and a total quay length of 2,350 meters. It currently stands as the world's largest automated container terminal with fully independent intellectual property rights, completed in a single phase. This terminal serves as a model for smart, green, efficient, and technologically advanced ports, demonstrating SIPG's commitment to innovation and sustainability in port development. Cargo handling at the port includes a 90% application rate of LNG for infield truck tractors and an 87% proportion of green-power Rubber-Tired Gantry Cranes (RTGs) [36].

The hinterland: SIPG focused on the inland waterways of the Yangtze River and railways:

Sea-rail intermodal transportation: SIPG, together with the subsidiaries of COSCO SHIPPING Group, China Railway Shanghai Bureau, and China Railway Container Transport Co., Ltd., established an equity joint venture, Shanghai Port Sea-Rail Intermodal Transport Co., Ltd., to vigorously expand the sea-rail intermodal transport business. Throughout 2019, the container throughput of sea-rail intermodal transport at the Port of Shanghai exceeded 147,000 TEUs, an increase of 86.1% year on year [36].

Yangtze River Delta: Implementing the national strategy for the integrated development of the Yangtze River Delta region is one of Shanghai's three new major tasks. On December 1, 2019, the CPC Central Committee and the State Council issued the Outline of the Plan for the Integrated

Development of the Yangtze River Delta Region, which clearly outlined the future integrated development of the region.

The outline proposes focusing on enhancing international competitiveness, strengthening cooperation between Shanghai and Zhejiang in Hangzhou Bay, deepening capital cooperation on Yangshan development between Shanghai and Zhejiang, and expanding and strengthening the role of the Shanghai International Shipping Center as a container hub port. The company has taken active actions to fully promote the integrated development of the Yangtze River Delta with higher quality [36].

4. The case of Vietnam

4.1. Vietnam's seaport system

Vietnam has over 3,200 kilometers of coastline in a busy international maritime route, marking Vietnam as an ideal country for seaport business, an important gateway to the sea for neighboring countries. Vietnam has 286 berths, classified into 5 groups with a total length of about 96,000 meters of quays, over 1 million square meters of warehouses, and more than 2.2 million square meters of yards [37].

Port governance: Vietnam's government has focused on developing its transportation system, especially ocean shipping, as part of the open economic policy. A number of special policies have been issued to enhance the country's fleet and improve our seaport systems, including infrastructure and services. This has led to significant changes in Vietnam's seaports, driven by growing imports, exports, and economic growth. Vietnam aims to develop a modern, synchronized maritime infrastructure that ensures safety, security, and efficient connectivity. They plan to use seaports as key hubs for international cargo

transportation to reduce logistics costs. By integrating with economic and urban development spaces and utilizing natural conditions, they aim to harmonize port development with environmental sustainability. Additionally, the port governance is committed to embracing and applying Fourth Industrial Revolution achievements in construction, management, and operation. This includes developing green seaports, promoting energy-saving practices, and efficiently utilizing natural resources along coastlines and water bodies. Through these efforts, the port governance aims to make seaports the leading contributors to Vietnam's maritime economy, supporting its growth into a strong maritime nation and a developed country with a higher GDP by 2050 [38].

Objectives by 2030: Develop a modern seaport system meeting all needs in economic, social, and military defense; increase cargo capacity to 1,423 million tons; prioritize the development of key international gateway ports and strategic seaports.

Vision by 2050: Develop a modern seaport system meeting global standards, emphasizing environmental sustainability. Play a leading role in the country's maritime economy, contributing to Vietnam becoming a strong maritime nation and a developed, high-income country.

The infrastructure of Vietnam's seaport system: Vietnam's seaport system has experienced significant growth since the first development plan was approved in 1999. This plan, authorized by the Prime Minister in Decision No. 202/1999/QD-TTg on October 12, 1999, marked the beginning of several improvements. The system has progressed through two main stages: Stage I, from 2000 to 2010, and Stage II, from 2010

to 2020, as outlined in Decision No. 2190/QD-TTg on December 24, 2009, and adjusted in Decision No. 1037/QD-TTg on June 24, 2014. In two decades, Vietnam's seaport infrastructure has expanded significantly. In 2000, the national seaport system was only about 20 kilometers long, handling 82.4 million tons of cargo. Recently, there are approximately 92.2 kilometers of wharves, with a capacity of over 550 million tons per year, showing an increase from 6 to 7 times since the start of the development plan. This growth has been accompanied by the improvements in technology and cargo handling practices, with many ports adopting modern management technologies. Major modern ports in Hai Phong and Da Nang are currently being further developed to meet the increasing demands of import and export activities across all regions of North, Central, and South Vietnam. The adjustment made in Decision No. 1579/QD-TTg dated 22 September 2021 and Decision No. 442/QD-TTg dated 22 May 2024, further underscores the commitment to enhancing the seaport system. The decisions divide the system into five groups, aligning with the plan for the system's development until 2030 [39].

Cargo handling: Tan Cang - Cai Mep International Port (TCIT) has focused on enhancing its cargo handling operations by investing in modern, environmentally friendly equipment. This includes electric cranes that reduce CO₂ emissions compared to traditional diesel-powered equipment; LED lights on all the cranes to develop harmonic filter system for stable grid power; and utilizes excess crane power to strengthen its offices and container yards; and cargo handling machinery, such as 8 STS cranes, 18 RTG cranes, and feeder cranes. These investments have allowed TCIT to

handle cargo more efficiently and sustainably. The E-RTG cranes, for example, use 100% grid electricity and feature semi-automated operations, flexible load control technology, and intelligent control cabins. Combined with the DGPS system and CATOS port management software, these advancements have made TCIT a preferred choice for shipping lines seeking environmentally conscious partners [40].

Water treatment: Gemadept has implemented various water-saving measures, including regular inspection and maintenance of water supply systems and equipment, timely repairs of leaks, and the replacement of old equipment. They also monitor water usage daily and have replaced faucets with automatic shut-off faucets. Furthermore, the company provides water-saving training for employees and reminds them to use water efficiently. Gemadept also encourages customers and employees to use water sparingly and avoid waste. Additionally, they have installed toilets with dual flushing functions to reduce water consumption. In 2022, Gemadept measured the water consumption of major companies in their Port and Logistics system, totaling 190,090 cubic meters. Gemadept is also upgrading its fleet technology to comply with International Maritime Organization (IMO) environmental standards, including the Energy Efficiency Existing Ship Index (EEXI) and the Carbon Intensity Indicator (CII), with a goal of achieving net-zero emissions by 2050 [41].

GHGs emission inventory: To reduce GHG emissions, Gemadept is installing an Emission Control System (EPL) in 2022 to regulate ship engine capacity and prevent overloading, which can increase GHG emissions. This system aims to reduce GHG emissions and promote sustainable

practices in the shipping industry. Gemadept is also the leader in conducting inventory and reporting on GHG emissions, with Nam Dinh Vu Port and Gemalink Port being the first two ports in their ecosystem to officially implement an ISO 14064 GHGs inventory, recognized by the British Standards Institution (BSI) [41]. Through efforts to build and develop in line with global tendency, Vietnam's seaport system has seen some ports honored with the award of green port and various important certifications: Green Port Award by the APEC Ports Service Network (APSN) Council: Tan Cang Cat Lai Port (2018), Tan Cang Cai Mep TCIT (2020); ISO 4001:2015: Dinh Vu Port (2023), Gemadept Dung Quat International Port (2019); ISO 45001-2018: Dung Quat Port (2019).

The hinterland: Based on Vietnam's geography, it can be seen that hinterland transportation develops unevenly across the nation. Specifically, the North includes many mountainous terrains and steep rivers, so transportation mainly relies on roads and railways. At the same time, in the south, based on the delta terrain, many gateways, and the Mekong River system, inland waterway transportation will be more developed than railways. However, the connection of seaports to all logistics centers mostly relies on road transport [42].

Road transportation: Currently, there are 1,822 km of highways across the country, with an additional 1,071 km under construction. Most of these highways are concentrated in the two main economic hubs, Ho Chi Minh City and Hanoi. According to the Road Network Planning for the period 2021-2030, with a vision to 2050, the highway system will include 41 routes, totaling 9,014 km, and the national road system will consist of 172 routes, totaling

29,795 km. In 2023, Vietnam continues to complete and put into operation many highway projects, such as 7 component projects with a total length of 411.6 km. Meanwhile, 5 important national projects will be under construction, including the Bien Hoa-Vung Tau highway, Ring Road 4 project in Hanoi Capital, the Ring Road 3 project in Ho Chi Minh City, and others.

Railway transportation: According to the current state of the railway system, we can see that the Vietnamese railway system has not been evenly invested in and developed, with a concentration in the Northern region. In the past, the railway used to connect to many large seaports, but these connections

were removed, such as the railway to Cua Lo port, Song Han port, Quy Nhon port, and Saigon port. Currently, there are only two seaports directly connected to the railway system: Hai Phong port and Cai Lan port in Quang Ninh [43]. According to the plan being implemented, railways connecting to transport hub areas will be invested in, such as the Ho Chi Minh City-Can Tho railway, Bien Hoa-Vung Tau lines connecting to Cai Mep-Thi Vai international seaport, and Hanoi-Hai Phong lines connecting with Lach Huyen international seaport. According to conclusion No. 49-KL/TW, it is determined to complete the Yen Vien-Pha Lai and Ha Long Cai Lan railways by 2030.



Figure 1. The Vietnam highway system by 2025 [44].



Figure 2. Vietnam Railway map.

Inland waterways transportation: Vietnam's inland waterways have developed rapidly, contributing to the growth of green ports, thanks to its geography featuring two large deltas—the Red River Delta in the North

and the Mekong River Delta in the South—which help limit emissions into the environment. According to data from the Vietnam Inland Waterways Administration, in the northern region, 7 out of 17 routes

have been renovated and upgraded, covering a total length of 949.5 out of 2265.5 kilometers, reaching about 41%. In the Central region, 1 out of 10 routes has been renovated and upgraded, covering a total length of 63.5 out of 480.5 kilometers, reaching 13%. In the southern region, 9 out of 18 routes have been renovated and upgraded, covering a total length of 2303.9 out of 3426.4 kilometers, reaching 67%. The government is focusing on the development of inland waterways to support road transport. The four major projects include the Cho Gao Canal upgrading project phase II, the project to upgrade waterway

corridors and logistics in the Southern region, the Duong Bridge air clearance upgrading project, and the project to enhance air clearance of road and railway bridges crossing the national inland waterway route. Gemadept is actively developing inland waterway transport to create a green logistics system. They are researching the Cai Mep transport route in the Mekong Delta, aiming to contribute to Vietnam's inland waterway transport development. Improvements are needed in signaling, bridge systems, and connectivity to optimize goods transport [41].



Figure 3. Inland waterway in the Mekong Delta region map.

4.2. Measures within the key factors

In the following section, we will compare Vietnam's seaports with other ports that we named above based on the three factors mentioned in the literature review section. The goal of this comparison is to identify opportunities for improving green ports within the measures already implemented in Vietnam's ports. It is important to emphasize the focused clustering approach to highlight areas that still require action. [Table 1](#) presents the field of authorities and management in ports to demonstrate the

differences between the main green goals of the three ports and how they are put into action. [Table 2](#) demonstrates how the port authorities actualize the green port goals through technical infrastructure. The aim is to examine the primary areas of focus for application and improvement within the port. The hinterland plays a crucial role in the development of green ports. In [Table 3](#), the study aims to achieve how ports optimize air quality by replacing road transportation with railway and inland waterway transportation, considering land features.

Table 1. The comparison among the Port of Bremen/Bremerhaven, and Shanghai International Port.

Key factor(s)	<i>Port of Bremen/Bremerhaven</i>	<i>Shanghai International Port Group</i>	<i>Vietnam's seaport</i>
The guidelines	ESPO	Shanghai government	Vietnam Maritime Administration
Notable Policy	Encouraging technical infrastructure for waste reduction; Enhancing operation among ports; Applying favorable port fees for green ships.	Developing technology for efficient port operation; Educating environmentally conscious mindsets for port employees.	Developing infrastructure of port and hinterland; Leveraging natural blessing. Educating environmentally conscious mindsets for port employees.
Pricing scheme	Published	Not clear	Not clear

Table 2. Comparison among Port of Bremen/Bremerhaven, SIPG and Vietnam's seaports in terms of technical infrastructure.

Key factor(s)	<i>Port of Bremen/Bremerhaven</i>	<i>Shanghai International Port Group</i>	<i>Vietnam's seaport</i>
Shore power	Wind & solar power	Wind & solar power	Ongoing project
Water treatment	Efforts to reduce nitrogen oxide emissions	Not provided in the report	Ongoing project
Cargo handling and facility	Promoting Bremen freight village (GVZ) Building Bremen high-bay warehouse; Applying Auto Terminal.	Building E-Platform and Automated Terminal; Using LNG for infield truck tractors and green-power RTGs.	Applying electronic shore and yard cranes; Developing a harmonic filter system for stable grid power; Utilizes excess crane power to energize its offices and container yards.
Greenhouse gas emission inventory	No	No	Yes

Table 3. The comparison among the Port of Bremen/Bremerhaven, and Shanghai International Port.

Key factor(s)	<i>Port of Bremen/Bremerhaven</i>	<i>Shanghai International Port Group</i>	<i>Vietnam's seaport</i>
Road	50%/60% of total hinterland transport	Shanghai-Hangzhou Highway (A8), Shanghai-Nanjing Highway (A11), Highway A20, Highway A2 - East Sea Bridge	Mainly focus on road transportation, developing the highway and national road system
Railway	47%/37% of total hinterland transport	Pudong city railway	Ongoing project
Inland waterway	3%/3% of total hinterland transport	Shanghai-Hangzhou railway Shanghai-Nanjing railway	The Red River in the North and the Mekong River in the South

5. Conclusion

The green port concept represents a harmonious blend between environmental sustainability and economic development, emerging as a strategic trend in the global maritime industry. Its inception aims to mitigate and eradicate adverse environmental impacts stemming from port activities. Leading port nations like Germany, Singapore, and China have successfully implemented green port development, demonstrating significant reductions in emissions. While green port development is a prevailing trend, its implementation in developing countries, particularly Vietnam, encounters various challenges.

Research indicates Vietnam's suitability for embracing the green port development model, given the government's encouragement and support for green port initiatives in recent years. The government has set objectives to make seaports leading contributors to Vietnam's maritime economy, supporting the country's growth into a strong maritime nation and a developed, high-income country by 2050. In Vietnam, transportation infrastructure is increasingly being invested in and expanded, especially with a series of major highways facilitating cost and time savings for transportation businesses. The maritime port system is also being improved and continuously invested in, providing access to advanced, modern, and environmentally friendly transportation services. Moreover, Vietnam, with its potential for inland waterway exploitation through its network of rivers, canals, and major ports, has been investing in inland waterway development to expand the port ecosystem and maximize available resources. Furthermore, Vietnam benefits from abundant foreign investment

capital for developing maritime port infrastructure. Over the past decade, many foreign investors have poured capital into building seaports in Vietnam. In the southern region, Ba Ria-Vung Tau is the locality that attracts the most foreign investors to construct ports, including major corporations such as PSA (Singapore), investing in SP-PSA Port; APMT (Denmark), investing in CMIT Port; Hutchison Port Holding (Hong Kong), investing in SITV Port; and shipping companies like Mitsui O.S.K Line (Japan) and Wanhai Lines (Taiwan), investing in the operation of the international container terminal Tan Cang - Cai Mep.

With these substantial potentials, Vietnam promises to be at the forefront of building and developing green ports. However, Vietnam faces challenges in developing green ports, including the lack of consistency in criteria, technological limitations, and significant initial capital requirements. One of the major challenges facing Vietnam in the development of green ports is the lack of consistency in criteria. Different regions and organizations may propose varying criteria for green ports. This lack of uniformity can pose difficulties for ports, particularly those in developing countries, in efficiently identifying the key factors they need to prioritize to foster the growth of their green port. Consequently, considerable time and financial investments may be required to establish an appropriately tailored set of criteria for a specific port. Moreover, Vietnam's journey toward developing green ports encounters a significant hurdle in adopting cutting-edge technology for environmentally friendly shipping and port infrastructure, known as technical development. While various advanced technologies such as cold ironing,

seawater filters, alternative energy sources, and monitoring systems have been suggested for green ports, their implementation in Vietnam is hindered by limited access to these technologies. Most ports in Vietnam rely on outdated equipment that fails to meet modern environmental standards. Consequently, the deployment of green technologies, including cold ironing and seawater filters, which have the potential to reduce GHGs emissions and pollution, is restricted. Additionally, port operators in Vietnam face pressure to secure substantial initial capital for the construction of green ports. These financial barriers encompass all costs related to the facility before, during, and after development. To comply with emission reduction criteria, modern technologies such as cold ironing systems, seawater filters, alternative energy sources, and monitoring systems must be installed. As can be seen, the expense associated with deploying such systems is substantial.

Nevertheless, the Vietnamese government and port enterprises are persevering daily in the green transformation process to contribute to achieving the goal of reducing net emissions to zero in Vietnam. Specifically, green ports in Vietnam will be developed based on six main criteria with specific scoring scales, including awareness of green ports (maximum score of 5 points), resource utilization (maximum score of 15 points), environmental quality management (maximum score of 50 points), energy usage (maximum score of 15 points), information technology application (maximum score of 5 points), and emission reduction, climate change adaptation, and sea-level rise response (maximum score of 10 points). According to the roadmap after 2030, the

application of green port criteria will be mandatory for port development, and to be considered for green port recognition, ports must achieve a minimum of 60% of the total points across all criteria (achieving a minimum total score of 60 out of 100 points) [45].

Contributions of authors in this article

Tran Thi Anh Tho: Methodology, Data management, Formal analysis, Investigation, Validation, Grant acquisition, Feedback on peer review, Writing – original manuscript, Manuscript Editing. **To Thi Bich Ngoc:** Data compilation, Data analysis, Investigation, Verification. **Lam Nguyen Thai Hoang:** Writing – original manuscript, Investigation, Validation, Visualization. **Le Huy Nhat Tai:** Writing – original manuscript, Investigation, Validation, Visualization, Data management.

Declaration of competing interest and dedication to copyright

The authors declare the absence of any potential conflicts of interest from this study and affirm that the paper has not been previously published.

Data available

Data will be provided upon request.

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