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Review Article

Technical-Environmental Assessment of Energy Management Systems in Smart Ports

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Abstract. Shipping is facing huge pressure problems in this 21st century such as climate change and environmental pollution and the depletion of energy resources. Seaports are an important component of the shipping industry architecture. Although there is no common solution, seaports around the globe face the same challenge. Challenges raised include difficulties in integrating new technology into automation, traffic congestion, harmonizing residential communities around the port, quantifying and reducing CO_2 emissions as well as planning for the energy transition. In addition, improving the adaptability of the port infrastructure in the context of increased pressure from market demand, labor shortage, and escalating prices should be considered. In that context, a smart port was born as a necessity. However, the understanding of smart ports is very limited. This review examines the recently published smart port literature to clarify the common concepts of smart ports and their development progress on the way to building a sustainable seaport ecosystem. Although smart port metrics and key port performance metrics are organized around four key performance areas including operations, environment, energy, and safety. However, a comprehensive review of all four key areas is very broad and difficult to cover in a review article. Therefore, this work focuses on analyzing and discussing the approaches and applications of the technology in smart port energy management systems. Our research has shown that different smart port founding perspectives play a decisive role in technology approaches to building a port energy management system including optimizing algorithms for energy consumption, balancing demand and energy production, and comprehensively integrating renewable energy. New findings in this study contribute to the elucidation of smart port concepts based on improving energy use and management efficiency with innovative technologies in the context of sustainable development of the shipping industry.

Keywords: Shipping, Smart Port, Energy Management System, Interner of Things.

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1. Introduction

Transporting approximately 90% of international trade, maritime has always been considered the lifeblood of the global economy (Merk, 2020)(Hoang, 2020)(Hoang & Pham, 2018). This is also an area that is often known for its conservative approach to change and innovative approaches. However, the situation is gradually changing, in which maritime enterprises used to be very dependent on traditional methods (Hoang & Pham, 2019) and skeptical of the application of scientific and technological progress have gradually seen the benefits that technology can bring and take action to adapt to today's digital world (Sun, 2020). As commercial activities are expanded, the demand for transporting goods through ports is constantly increasing leading to a lot of pressure on management levels. Ports are intermodal interchanges in the global supply chain (Ghadge *et al.*, 2020)(Oniszczuk-Jastrząbek *et al.*, 2018). Globalization and sustainable development trends are placing increasing pressures on port and shipping systems and transportation to optimize their economic, environmental, energy and functional performance in reducing CO_2 emissions (Bakır *et al.*, 2022)(Tran *et al.*, 2019). Current ports not only meet the needs of space and equipment but also ensure that goods can be moved most conveniently and efficiently. Furthermore, many current problems to maritime industry such as environmental pollution (e.g. pollution of water, air, and solid waste) (Y. Wang *et al.*, 2021)(Varbanov *et al.*, 2022), operational problems (e.g. operating errors, missing shared information) (Hsu *et al.*, 2021)(Le *et al.*, 2020) or optimization of operation parameters (Pham *et al.*, 2020)(Pham & Hoang, 2020), energy waste (e.g. excessive energy consumption, excessive energy costs and unsustainability of energy sources) (Spadaro *et al.*, 2021)(Hoang, Nižetić, *et al.*, 2022)(Nguyen & Hoang, 2020) and many other problems related to the security and safety of the port are requiring timely

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strategies and action plans (Nguyen *et al*., 2021a)(Gucma, 2019). According to statistics from February 2021 of Innovez One, of 4,900 ports in the world, up to 80% of ports are continuing manual processes and relying on paper to manage their services (innovez-one, 2022). This means that pioneering businesses and ports in the digital transformation race will gain outstanding advantages and become important technology pieces in the current 4.0 race. Faced that growing demand as well as many of those painful problems, the biggest port is no longer the preferred choice but instead the smartest port (Douaioui *et al*., 2018).

The literature review has shown that there are two perspectives on smart ports. The first perspective comes from policy decisions and resource use rather than technology and infrastructure. The remaining perspective on smart ports is based on the application and equipping of recent advanced technologies to meet the requirements of improving port performance as well as energy and environmental issues (Solmaz, 2021). Based on those two points of view, the smart port system is classified as a smart port group based on a multi-purpose initiative and a smart port group based on a targeted initiative (Drosińska-Komor *et al*., 2022). Multipurpose smart port initiatives are often developed by port associations. Their primary objective is to promote the development of efficient port and logistics operations through improved environmental and energy strategies and policies (Pratikto *et al*., 2021). Accelerating the transition to renewable energy and activities that improve the environment and reduce energy consumption are always priority pillars. Prominent smart ports that have been established on this initiative are the Smart Port of Rotterdam, the Smart Port of Hamburg, and the Smart Port of Erasmus Rotterdam.

From the point of view of the targeted initiative, the smart port is a port model that applies automation technologies based on the Internet of Things (IoT), Artificial Intelligence (AI), and Big Data to establish a scientific port management system with optimal performance. Small and medium cargo ports will have the opportunity to effectively compete with larger ports. Besides, with the technology support, port operators can create more value, and improve productivity while reducing costs and other raw materials (Hiekata et al., 2021). Of the many options, AI is the most attractive, because this technology can increase the efficiency of most seaborne trade activities. From autonomous cargo ships, port services, and document handling to safety and environmental issues, AI is showing its ability to radically change one of the oldest fields in the world. AI not only optimizes port services through automation but also makes use of real-time data. Data is collected and aggregated from different sources to estimate the equipment waiting time and immediately arrange the activities of unloading, loading goods, vehicles entering the yard, etc. Thus, equipment downtime is minimized while containers are handled seamlessly (Kovač, 2021). Many seaports around the world have recently succeeded in leveraging AI to digitize processes. The Port of Rotterdam in the Netherlands has developed an application to predict the arrival of ships, while in Belgium, the port of Antwerp has obtained important data on vessel traffic through motion analysis using AI and image processing technology. Combined with an image recognition system, AI can be applied to detect objects in the vicinity, give warnings in case of limited visibility, and minimize collisions between ships (S. Li et al., 2019). Navigation is also easier and smarter because the navigation system can suggest the safest route based on accident data and allows users to locate and track other ships at sea (X. P. Nguyen & Pham Nguyen, 2019).

Regardless of the different views on the concept of a smart port, the core structure of a smart port can be established from the intersection of the operational domain (productivity, automation, and smart infrastructure) (Molavi *et al*., 2020), environmental domain (environmental management system, emission and pollution control, waste and water management) (Heilig & Voß, 2017), energy domain (efficient energy consumption, renewable energy production, and supply, energy management) (Durán *et al*., 2019) and safety and security domain (safety management system, security management system, integrated monitoring and optimization system) (Bracke *et al*., 2021). More importantly, although shipping by sea is currently the most environmentally friendly mode (Dulebenets, 2022), the maritime industry is still working to reduce its impact shortly to meet a series of strict environmental and energy regulations (Nguyen *et al*., 2021a). Moreover, the energy demand for port and logistics services is increasing. Traditional energy sources tend to be increasingly depleted and expensive. Therefore, reviewing and evaluating technological approaches to reduce fuel consumption and comprehensively integrate renewable energy is the key to unlocking bottlenecks in energy source limits and port budgets (Hoang, Foley, *et al*., 2022). More interestingly, smart technologies can help calculate factors and make optimal decisions, thereby helping to limit energy consumption and reduce carbon emissions (Sun, 2020).

In this work, smart port concepts and characteristics mainly based on two main pillars, environment and energy is analyzed. Furthermore, discussions and reviews focused on analyzing the possibility of integrating technologies to improve smart port performance indicators. In summary, the rest of this review is organized as follows: part 2 provides the concepts, history, and characteristics of smart ports. Part 3 discusses and evaluates energy and environmental management systems of smart ports to provide approaches to and measurement of energy and environmental indicators. In addition, outstanding technological features equipped in the world's largest smart ports and Vietnam are also discussed. Finally, recommendations and conclusions provide some possible solutions and future research directions on smart and sustainable ports.

2. Smart Port and Features

2.1 Concept and development history of smart port

For a long time, seaports were only operated and monitored by simple machines as well as human power. However, according to the development process of human history, seaports have to greatly increase their operating capacity. As a result, to both reduce the cost of human resources and increase the operational capacity and monitoring of the seaport, people have "upgraded" a normal seaport into a smart port.

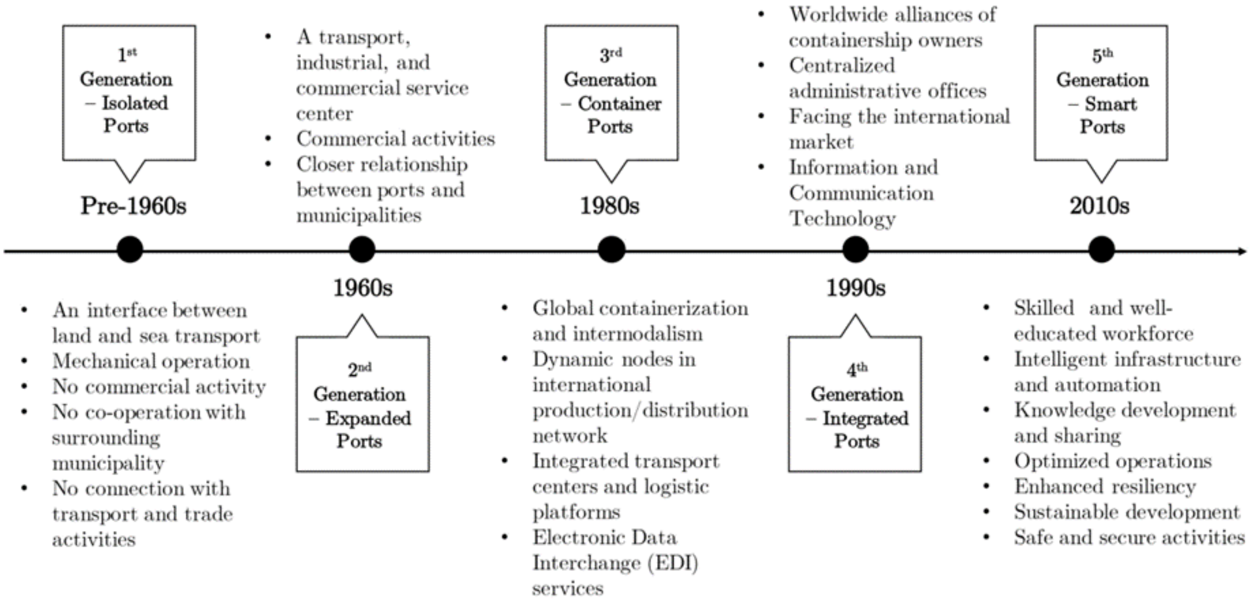

Figure 1 The development path of smart ports (Molavi *et al.*, 2020)

The maritime sector does not seem to have definitions and standards for "smart" in the technical nomenclature. However, in the context of technology, some properties such as self-optimization, self-protection, self-structure, and self-healing dictate the principles of automatic computation which are considered the basis of intelligence (Goddard *et al.*, 1997). In 1990, the term "smart growth" was proposed in the field of urban planning. It has been used in ways to manage development and progress without the negative effects of environmental degradation and the stalemate of adversity (Ye *et al.*, 2005). The term "smart city" has emerged next to describe a trend of urban management and administration originating from the US. The smart city concept has transformed from a concept into an international mainstream over the past decade, helping cities to optimize resources and develop sustainably (Hoang, Pham, *et al.*, 2021)(Kuznetsov *et al.*, 2021). More clearly, intelligence is closely tied to the strategies and policies of the government and public agencies to move towards healthy development and growth with a better quality of life. In terms of facilities, mobile terminals, embedded devices and sensors have been integrated into smart infrastructures such as smart homes, smart hospitals, smart transportation, and smart ports (Winkowska *et al.*, 2019).

The concept of a smart port has been around since the 2010s, it is considered the 5th generation of port in the history of the port's formation and development (Lee & Lam, 2016). Figure 1 shows the development history of 5 generations of seaports from the years before 1960 to the present day (Molavi *et al.*, 2020). The specifications and services typical of the different generations of ports are also described. This digitization includes import and export activities of ships, transport and storage of goods as well as monitoring and operating the operation of in-port machinery. Port operations algorithms are digitized and precisely calculated using a specialized industrial computer system and a dedicated service system, depicted in Figure 2 (Botti *et al.*, 2017). Intra-port operations take place in a chain, and the productivity and accuracy of the seaport will be greatly improved. This means that the costs incurred by both the port operator and the customer are minimized.

The smart port supports the journey of ships arriving at the port through the provision of necessities, information about the routes, and sea weather. In addition, logistic ports also support checking the load and balance of the ship during the import and export phase. More importantly, with the strict control and calculation thanks to the central server system, the logistics port is capable of supporting and serving ships during the docking process (G. W. Y. Wang *et al.*, 2016). These include services such as speed notices, navigational guidance services, and electronic customs clearance services. On the other hand, transit is the process by which goods are transferred from water transport to road transport before being loaded and unloaded into the warehouse. During this process, the logistics port gives the necessary information and support to the driver about safe and fast transport routes if the customer's warehouse is within the inner port (Gizelis *et al.*, 2020). If the customer's warehouse is outside the seaport, the system also helps transport drivers to easily circulate between the warehouses. From there, the transit time of goods is greatly reduced. This factor is extremely important for goods with high requirements for temperature and humidity standards, which are often only fully met if stored. In general, smart ports have been supporting a lot of global shipping activities. Especially, in the current situation, when the COVID-19 epidemic is complicated, the logistics port ensures the distance between people, thereby minimizing the possibility of cross-infection in the community (Kosiek *et al.*, 2021). As the Covid-19 pandemic subsides, the world is immersed in the price storm of the energy crisis due to the sharp increase in oil prices (Dong *et al.*, 2022). The shipping industry is being strongly impacted by this energy crisis. Port operations need to optimize costs for the energy system (de la Peña Zarzuelo *et al.*, 2020). Smart port models to optimize energy-consuming activities are considered effective solutions (Haidine *et al.*, 2021).

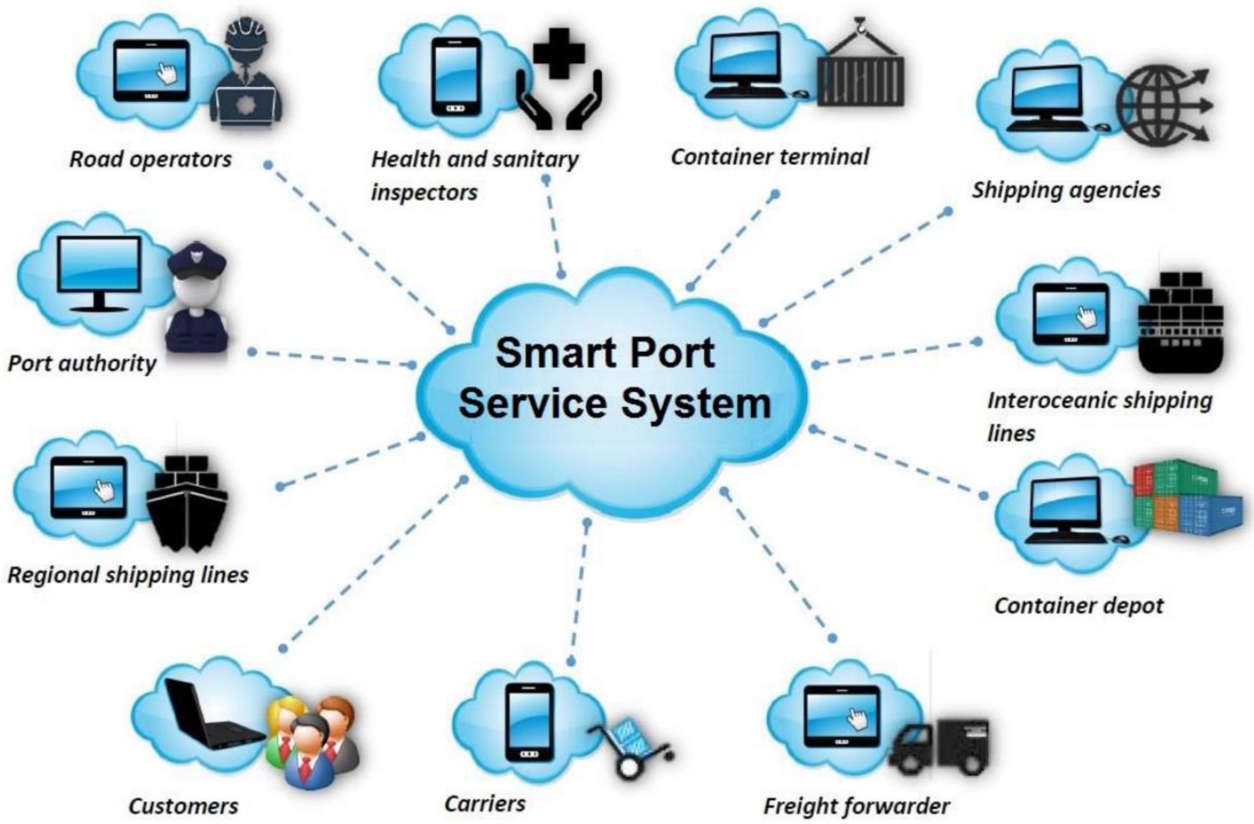

Fig.2 Key components of the smart port service system (Botti *et al.*, 2017)

2.2 The integration of 4.0 technology platforms in smart ports

The recent explosive industrial revolution 4.0 has redefined the concept of Smart Ports where all devices are connected in a technological ecosystem of the Internet of Things (IoT). Accordingly, an intelligent infrastructure system consisting of sensors, wireless devices, and intelligent communication connected to the synchronous data center to provide port services in the fastest and most efficient way to improve port efficiency metrics. The preeminent features of the laser encoder and measurement system with intelligent obstacle and positioning algorithms have been deeply integrated by Pratama *et al.*(Pratama *et al.*, 2016) into the autonomous guided vehicle (AGV). A stable working sliding mode observer with the support of micro-mechatronics, virtual sensors, and a thermal positioning algorithm was designed by Xia et al. (Xia *et al.*, 2018). Koop *et al.* used accelerometers to track the motion behavior of container cranes based on structural strength tracking of a 3-D finite element model which has been designed to simulate the static displacement of the crane under different loads (Kaloop *et al.*, n.d.). An ultrasonic sensor for measuring deviations from the ground to points has been proposed by Carullo and Parvis (Carullo & Parvis, 2001) for a motor vehicle. Computer vision with image sensors was used by Mi et al. (C. Mi *et al.*, 2021) to determine the position of a container in the horizontal plane.

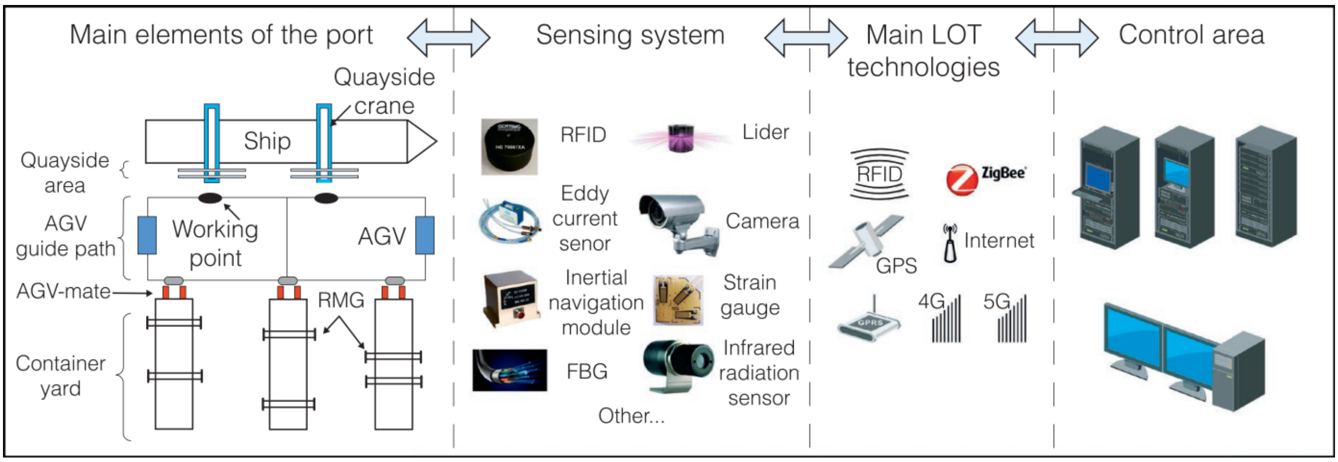

Fig. 3 Components of IoT system in automatic port terminal (Yang *et al.*, 2018)

IoT hardware solutions applied in smart ports include a cluster of checkin devices, face recognition devices, cruise monitoring devices, station information display devices, and temperature and humidity monitoring devices, they are depicted in Figure 3 (Yang *et al.*, 2018). Checkin equipment cluster includes technology devices with algorithms that support port staff attendance by card quickly and efficiently. Facial recognition devices are monitoring devices that make traveling safer than ever with the ability to identify driver behaviors such as not wearing seat belts, sleeping, smoking, etc (Rajabi *et al.*, 2018). Cruise monitoring equipment helps port businesses manage their vehicles professionally, improve the quality of transport services and ensure driver safety (Yau *et al.*, 2020). Moreover, AGVs are flexibly used to transport import and export containers to delivery stations by truck or train. Information display devices at bus stations include Smart Electronic Boards displaying bus station information in real-time, supporting users to actively and flexibly travel time (Min, 2022). Information from equipment such as rotary cranes, autonomous vehicles, and yard cranes is updated in real-time to ensure the safest and most reliable operations. Smart sensors monitor cold storage temperature and humidity, ensuring to provide the most accurate information about equipment status in real-time (Fernández *et al.*, 2016). Developments in the areas of fiber optics, highly sensitive magnetic sensors, and MEMS inertial measurement units enable interoperable wireless protocols including 4G and 5G technologies (Zhong *et al.*, 2019). They allow for extend the Internet connectivity of sensor systems installed in port logistics and handling facilities. As such, they present great opportunities for new developments in the smart port sector.

Solutions that apply AI and Big Data to the management and operation of port operations such as navigation algorithms, face recognition algorithms, and vehicle arrival time algorithms. The navigation algorithm helps drivers choose safe and time-saving journeys (W. Mi & Liu, 2022). The face recognition algorithm allows face recognition and provides information such as gender, age, and physical characteristics, ... The algorithm calculates the time the vehicle arrives at the station to assist users in optimizing the journey plan and managing the time in the best way. Prediction and optimization algorithms using data from automatic identification systems aid in navigation detection and port operations. They allow ports to compare and evaluate the environmental and economic impacts of different modes of transport at the port. Furthermore, energy and environmental management plans are also supported based on such data (Ozturk *et al.*, 2018). Integrated development contributes to enhancing port competitiveness as well as solving sustainability issues with artificial intelligence and Big Data. Smart technologies such as Big Data, IoT, AI, and other forms of smart technology methods have been improving the efficiency, economic competitiveness, and energy and environmental sustainability of ports.

3. Energy management system at Smart Port

3.1 Typical energy management models of typical smart ports

From an environmental and economic perspective, energy efficiency is a very important factor in the assessment of port performance indicators. The current general trend for modern ports is to optimize the energy flow at the port. Therefore, it is urgent to apply the cutting-edge advances of the Internet of Things in energy balance modeling at ports to enhance energy efficiency, reliability, and port capacity (Vo *et al.*, 2021). To solve that problem, it is necessary to quantify both energies consumed and supplied to ensure balance in the context of complex industrial processes. The optimal calculation based on AI algorithms for deep integration of local renewable energy sources into the port power supply system has always been considered a key module(Sharma *et al.*, 2022). This has not only allowed port planners and authorities to determine the amount and type of energy, but also to assess the level of emissions of associated pollutants from the port. Thus, port and energy managers can make the best decisions about energy management plans at ports (Iris & Lam, 2019).

The establishment of an energy management strategy at ports is considered an indispensable and most important step to building a sustainable and smart port system. The first step of the energy management plan is to clearly define the port's vision for energy system management. Furthermore, the port energy management plan should be based on the general port energy mapping and consumption assessment methodologies presented in Figure 4 (Boile *et al.*, 2016). With a 6-step process-based approach that includes (1) Energy Mapping (based on essential performance indicators and a benchmarking process to assess port energy performance), (2) Determining the void that needs to be treated to achieve the energy-saving goal, (3) Establish preliminary recommendations for addressing such gaps, (4) Recommendations and solutions are communicated to stakeholders at focus group meetings to reach a common consensus, (5) Energy restructuring is carried out after actions to address gaps are clearly defined, (6) An energy management plan will be established to improve the energy efficiency of ports, The plan also identifies how to calculate, monitor and evaluate the port's energy consumption for the next cycle.

An efficient energy management system at smart ports is often linked by domains including efficient energy consumption, renewable energy production and supply, and optimal energy management (Ga Bui *et al.*, 2021). An energy management system is typically a set of computerized tools used by operators of electrical facilities to monitor, control, and optimize the performance of equipment or transmission systems (Nguyen *et al.*, 2021b). Various computer-aided tools are implemented from short-time control modules to planning or committing of power generation units on a day/week basis. An energy management system whose goal is to maximize system performance with monitoring and control functions requires a centralized data collection system and decision-making process. Energy consumption at a smart port usually includes direct energy consumption and indirect energy consumption. The lighting system in port areas and office facilities, garages is a direct source of energy consumption. Meanwhile, the crane systems, and the internal fleet at the port are the components of seasonal energy consumption. Therefore, the improvement and monitoring of energy-consuming equipment, directly and indirectly, contributes to reducing energy loss, thereby improving energy efficiency and lowering costs (Hoang, Sandro Nižetić, *et al.*, 2021).

The potential for deploying renewable energy sources at ports is huge (X. P. Nguyen *et al.*, 2021)(Lamberti *et al.*, 2015). Possible forms of renewable energy include wind power (Chen *et al.*, 2021)(Chen, Wang, *et al.*, 2022), solar energy (Sirohi, Pandey, Ranganathan, *et al.*, 2022)(Nižetić, Jurčević, *et al.*, 2021), and biodiesel (Nayak *et al.*, 2022)(Murugesan *et al.*, 2021)(Veza *et al.*, 2020). Wind power systems are often fitted to electric crane systems and electric forklifts. Vehicles such as garages and offices can use photovoltaic energy. The fleet and internal container transport vehicles can use biodiesel fuel (Sirohi, Pandey, Nižetić, *et al.*, 2022). Indeed, the use of machine learning and ANN optimization algorithms combined with advanced techniques in biofuel production helped reduce energy costs in biomass pretreatment processes. Efficient pretreatment techniques such as liquid hot water (Chen, Nižetić, *et al.*, 2022), and microwaves (Nižetić, Ong, et al., 2021), combined with acid pretreatment (Hoang, Nizetic, *et al.*, 2021) have improved production yields, reduced energy consumption, and environmental pollution. In addition, the refining processes in the biorefineries have been especially supported by energy management and environmental control systems to produce sustainable fuel additives such as DMF (Pham & Hoang, 2021) and HMF (Hoang *et al.*, 2020). Thus, achievements in the production of alternative fuels from waste sources (such as biomass and waste) and strategies to optimize combustion in internal combustion engines have brought high expectations in the development of a green transport system at the port (Wu *et al.*, 2020)(Veza *et al.*, 2022).

The adoption of energy management plans in the largest ports in the world has contributed significantly to the implementation of the port's performance indicators for the environment and energy. Improvements in technology systems in energy management at the world's 3 largest smart ports have shown numbers of automatic, intelligent, and optimal energy consumption at Shanghai International Port, Singapore Seaport and Port of Rotterdam are very impressive (Acciaro *et al.*, 2014).

In 2018, Shanghai International Port Group (SIPG) built 14 billion yuan worth of automatic cargo terminals in the deep-water port area, thereby increasing the capacity of Yangshan Port by about 6 million TEUs (Luo, 2019). All processes are operated automatically, adding 7 deepwater berths, bringing the total number to 30 berths with the capacity to handle up to 13 million TEUs. The total capacity of Shanghai Port has surpassed 40 million TEU. SIPG aims to reduce energy consumption by 70% and reduce emissions to zero by developing a special port operating system (L.-L. Li *et al.*, 2021). SIPG's research and development team of 200 people has set up a set of standards for the future of China's entire seaport automation platform. Indeed, a pioneer in efforts to reduce traffic congestion and speed up the transit of trucks, at the port of SIPG installed the TREK-723 computer system on their container trucks. As a result, those ports can easily and efficiently manage equipment and cargo, saving management costs thanks to the real-time nature of the data system and eliminating manual steps. The TREK-723 has built-in WWAN communication that transfers all necessary data including license plates, container numbers, and driver's licenses in real-time to a computer located at the gate (Y. Li, 2021)(Hayakawa *et al.*, 2021). When the vehicle approaches the gate, the system immediately confirms the driver's identity and grants access to the port. The harbor system then transfers all duties in real-time to the TREK-723 and directs the driver to the correct cargo location, confirming the location and parking of the container through the pre-installed GPS on the truck.

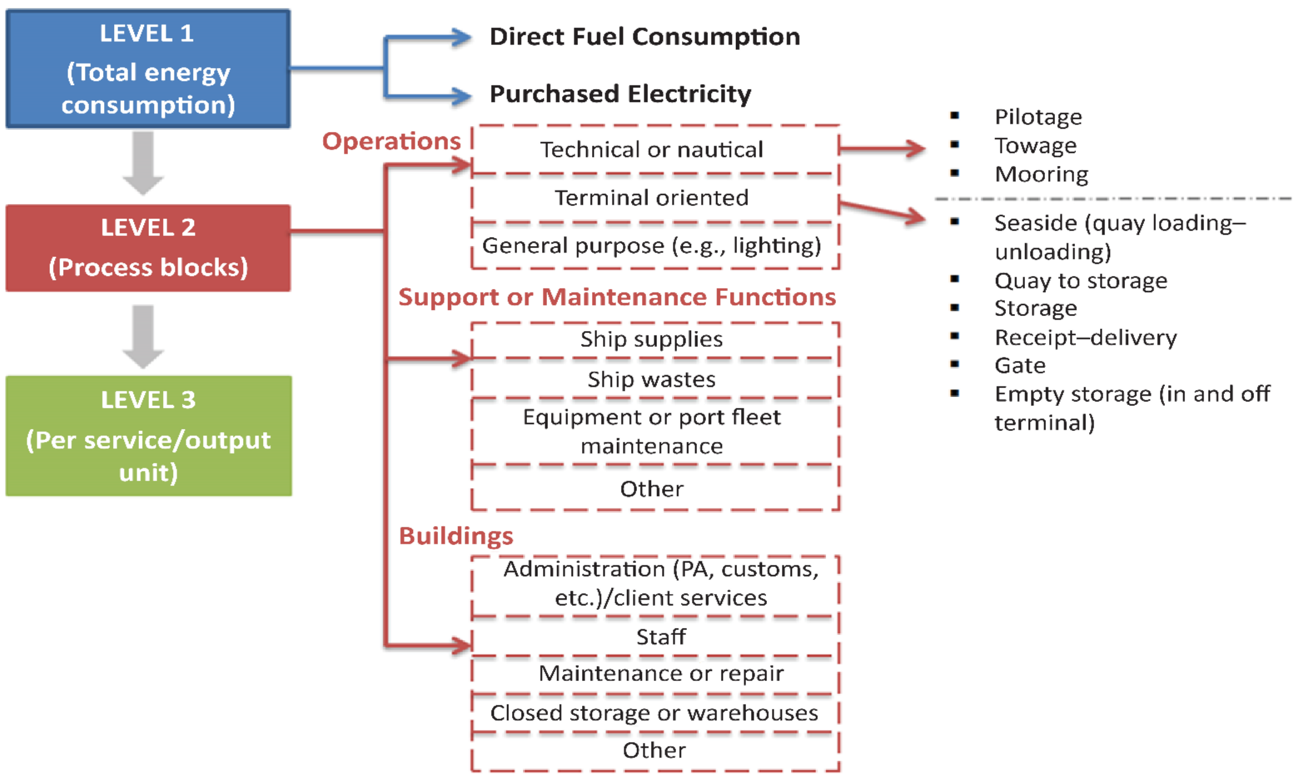

Fig. 4 Generic energy mapping and consumption assessment methodology (Boile et al., 2016)

In April 2018, the Maritime and Port Authority of Singapore (MPA) announced a strategy to regain the title of "seaport hegemon" from Shanghai, a digital platform to optimize productivity and efficiency. It is expected to overtake Shanghai to become the world's largest automated seaport (Osundiran *et al.*, 2021). Besides investing in the superport, MPA has also contacted 7 partners to develop seaport activities, focusing on connectivity, the ability to research - develop technology as well an innovate port business culture. Of these 7 agreements, the most important is the cooperation with ST Electronics (France) and Kongsberg Norcontrol (Norway) to develop a new generation of ship traffic management systems (Zhou *et al.*, 2021). $7.5 million will be invested to build a laboratory dedicated to research into maritime safety and security as well as operational aspects of the new port transportation system. MPA has also partnered with Finland's Wartsila Group to develop cybersecurity and smart port operations, in conjunction with marine technology startups and universities and academies. MPA is also developing the Singapore Marine Data Center as a one-stop data repository to support the development and testing of cutting-edge digital services and applications for the Maritime industry (Ilin *et al.*, 2022).

Rotterdam is the preeminent maritime trade center in the 4.0 revolution in Europe. The Port of Rotterdam has the ambition to build a self-propelled fleet by 2025 - 2030. Accordingly, Rotterdam is adding more sensors, software, and artificial intelligence at the port to create a digital system that can set up, operate, track and run all shipping operations and port infrastructure management based on weather and water depth analysis data (Wester, 2021). The Port of Rotterdam handles more than 140,000 ships a year, and the operation of the port in and out is very complicated. As a result, understanding navigation and environmental metrics can improve profitability for freight operators. Environmental data at the port, including wind, visibility, and tidal information were collected to discern optimal conditions and times for vessel mooring and navigation (Vakili *et al.*, 2022). The port also provides clearance elevation guidance for ships, increasing vessel capacity based on clearance elevation to increase revenue per vessel entering the port. The TRECK-688 computer system is applied with RFID technology to ensure that there is a separate RFID tag for each vehicle (Nadi *et al.*, 2021). This system has many outstanding advantages in design. They have a rugged design that is suitable for harsh industrial environments. With its compact design, the TRECK-688 has low power consumption and rich I/O (T. H. Nguyen *et al.*, 2021). The system maintains consistent performance for all data acquisition and computation even in harsh environmental conditions at ports. This solution, when applied at seaports, has limited unnecessary human errors, moreover, the vehicle inspection process takes place more quickly, ensuring all vehicles circulate smoothly and efficiently without having to wait long (Arulananth *et al.*, 2021).

3.2 A typical case in Vietnam

In the context of integration and development, building and developing a smart port model is one the right direction, is the top priority of maritime nations in the world and Vietnam is no exception. With the emergence of the IoT, ports and functional areas are considered too busy and large to adopt full digitalization. However, recent technological innovations and movements have transformed port operations, accelerating the adoption of integrated processes. Besides, the application of Blockchain technology is also a breakthrough in the strategy of digitizing seaports and logistics services. Innovation around early planning and predictive data enable increased advance planning at gateway ports, resulting in reduced transaction costs and improved delivery cycles. Recent planning methods have provided early visibility, allowing for more precise initialization for mapping freight movements. It can be affirmed that smart ports represent a radical change to the supply chain that has positively impacted the marine economy. With reduced cycle times, predictable movements, and reliable data about network activity have been delivering unprecedented processing efficiency in the shipping and logistics industry.

In Vietnam, Phenikaa MaaS Company has launched a Smart Port technology solution package using artificial intelligence (AI) to help optimize management activities at cargo port areas, as shown in Figure 5 (Phenikaa MaaS, 2021). The product is expected to upgrade the management ability of the cargo port operator for vehicles and operations inside the port area in a smart way, saving time and costs as well as accelerating the digital transformation process in the transportation industry. Smart Port is a solution package using AI on the Edge technology developed by Phenikaa MaaS, providing container number recognition (ACCR) and vehicle control plate (ALPR) Its role is to support the development intelligent management systems at enterprises and cargo ports, helping to automate manual processes and improve operational efficiency as well as speeding up the digital transformation process in the transportation industry. Smart Port is capable of recognizing ACCR, ALPR, and driver's face and behavior (bHub) in AI Box devices manufactured by Phenikaa MaaS, also turns ordinary cameras into AI cameras with ACCR, ALPR, and driver face detection (T. S. Le & Hieu, 2021). These features have supported automatic counting and identification of the number of container trucks and drivers entering and leaving the port daily at the gate, detailed statistics of license plates and container numbers, driver identification, recording date and time of vehicles entering and leaving the port and automatically taking pictures of each vehicle in and out. In particular, this technology is effective even when license plates and container numbers are dirty, rusty, or discolored, harder to read than regular license plates. Real-time identification information is processed and synchronized with the port's management system in real-time at millisecond intervals, then the port's management system can automatically calculate the position of the container and notify the loading and unloading position of the container the driver at the port's entrance.

The application of the Smart Port solution reduces the time the container truck has to stop at the gate and do manual checks as well as traffic congestion at the port, thereby overcoming the problem of congestion in areas inside and outside the port at peak times. The automatic identification system is also built-in to push information into the common management portal of the unit. Currently, Phenikaa MaaS has piloted the Smart Port solution at one of the entrances at Tien Sa Port, Da Nang. Positive results show that when it comes to automating the process and shortening the time to check containers at the entrance. Feedback from the authorities at Tien Sa port shows that Smart Port's support, it saves 80% of container stopping time at the port (Phenikaa MaaS, 2021). In the future, the Smart Port solution package will continue to expand this model at all remaining ports of Tien Sa Port. In addition, at Saigon New Port, ALPR and ACCR solutions have been implemented to count the daily number of containers entering and leaving the port, shortening the time and inspection process when stopping and parking at the entrance.

The trend of digital transformation in the transportation industry, especially in container forwarding and cargo ports, becomes essential and urgent in the context of the complicated developments of the Covid-19 pandemic and the global economy has been going through a recessionary cycle since 2008 (Huynh *et al.*, 2021). Governments and businesses of developing countries, including Vietnam, have been promoting digital transformation to develop the digital economy and digital society. Besides, it helps domestic enterprises in the transportation industry. Vietnam has built green and smart port system that ensures ships operate 24/7, reducing the time it takes for ships to wait for a wharf to a very small amount. While many major ports in the world are congested, Vietnam's seaport system is still operating efficiently

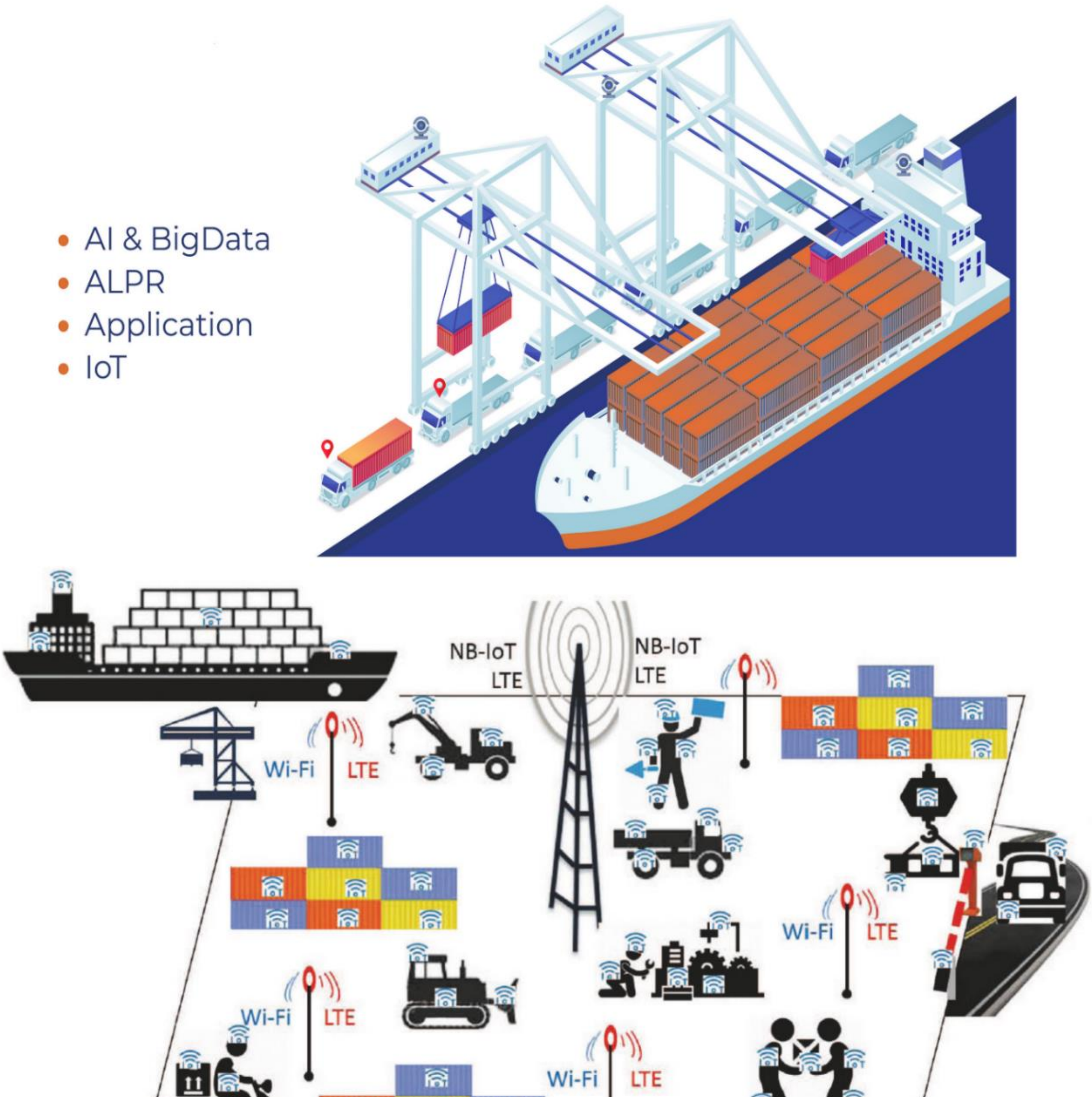

Fig. 5 Application of Smart Port solution package at some typical ports in Vietnam(Ozturk et al., 2018) (Phenikaa MaaS, 2021)

In 2021, goods through Vietnam's seaports reached more than 706 million tons, up 2% compared to 2020, of which container cargo volume reached 24 million TEUs, up 7%. In general, the strategy for sustainable development of Vietnam's marine economy to 2030, with a vision to 2045, aims to turn Vietnam into a strong maritime nation, including the task of developing the seaport system. Therefore, to ensure the sustainable development of the seaport system, the maritime industry needs to make the most of the achievements of the industrial revolution 4.0, towards building and developing a smart seaport model by providing orientations for deploying marine strategies in each region.

4. Conclusion and perspectivesves

The smart port was born in the context of industrial revolution 4.0. With the great role and potential of the smart scene in the trend of sustainable development, port countries have all established thorough and sustainable development and orientation strategies for the smart port system. However, researchers' interest in smart ports is limited. Therefore, more efforts are needed to clarify the comprehensive concepts and in-depth characteristics of smart ports as well as to discuss and collectively evaluate the current development trends of smart port systems. This review focuses on a key pillar of the port structure framework, the relationship between port energy management systems and advanced integration technologies. Document research has shown that smart ports built on the approach to information technology penetration are increasingly focused to take advantage of the outstanding achievements of the 4.0 industrial revolution in IoT, AI, and Big Data. Although, a comprehensive smart port must incorporate the automation and sustainability of the four pillars including operations, energy, environment, and safety and security. However, the energy and environmental pillars are the most important because it determines the sustainability of the port. Ports in Europe take a more holistic approach, both in policy and technology, to improving the energy and environmental pillars. Meanwhile, ports in Asia often take a biased approach to prioritizing the application of technology to improve energy efficiency and the environment. In this work, typical applications of technology in the energy sector are highlighted. IoT and AI technologies have greatly contributed to optimizing port energy consumption to reduce energy consumption and waste costs, and promote the deep and comprehensive integration of sustainable renewable energy sources in all port facilities and operations.

In the future, issues related to the remaining 2 pillars including safety and security, and human resources at smart ports need to be considered more thoroughly. Although technology plays a huge role in the innovation of port automation and smart port capacity, it cannot replace the role of port human resources. In addition, the main human resources team can solve governance issues, harmony with the community, and partnerships to ensure development goals and strategies are implemented synchronously and sustainably. Finally, although the technology can increase speed and huge data reserves, it cannot handle security and privacy-related situations. Incident situations on the network security system are always threatening and permanent to the smart port system. Therefore, the improvement of the network security system is a vital task for the stable development of the smart port.

In the context of Vietnam, to continue to study the development planning of an automated inland port system - an extension arm of a seaport to support services of a smart port, also contribute to the efficient organization of the intelligent transport network in the future. The maritime industry needs to review and complete the master plans for the development of the seaport system in the direction of strongly moving to the sea, minimizing limitations on channels, and getting closer to international shipping routes in the East Sea. Port construction investment strategies need to be associated with building an advanced port management model to optimize investment in port operation. Moreover, it is very important to promote the systematic and synchronous database connection of seaports throughout the country. Finally, strengthening the policy of developing a smart seaport system in line with international trends is imperative in the global sustainable development strategy.

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