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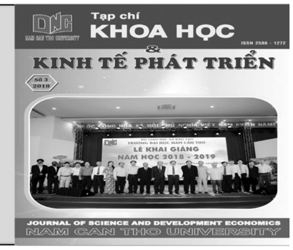

Renewable energy generation and energy efficiency in seaports: a focus on the Malaysian maritime industry

Thiagarajan Marappan[1*], M. Vikneswary Suresh[1]
[1]Malaysia University of Science and Technology, Malaysia
[*]Corresponding author: Thiagarajan Marappan (email: thiagarajan@must.edu.my)

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ABSTRACT

The global maritime industry plays a crucial role in international trade and transportation, with seaports serving as vital hub. In recent years, there has been growing interest in transitioning seaports towards sustainable practices by integrating renewable energy sources for power generation and consumption. Additionally, the global community is witnessing a shift towards a fourth industrial revolution, which has sparked a new wave of energy generation and consumption transformation. Peak shaving can balance load demand and facilitate the participation of small power units in generation based on renewable energy sources. In this regard, many approaches have been introduced, such as solar Power Photovoltaic (PV), wind energy, biofuel, biomass, and Battery Energy Storage (BES) which act as Energy Storage System (ESS). To assess the viability of renewable energy application in ports, various technological solutions and innovative practices will be analysed. Furthermore, this article presents a focused analysis of the Malaysian context, which encompasses a thriving maritime sector, to offer valuable perspectives on the utilisation of renewable energy solutions by seaports in this geographical area. This article seeks to make a scholarly contribution to the ongoing discussion on sustainable port operations within the broader context of the global shift towards renewable energy sources, by conducting a comprehensive examination of technological advancements and sustainable practices.

TÓM TẮT

Ngành hàng hải toàn cầu đóng một vai trò quan trọng trong thương mại và vận tải quốc tế, trong đó các cảng biển đóng vai trò là trung tâm quan trọng. Trong những năm gần đây, mối quan tâm ngày càng tăng đối với việc chuyển đổi cảng biển theo hướng bền vững bằng cách tích hợp các nguồn năng lượng tái tạo để sản xuất và tiêu thụ điện. Ngoài ra, cộng đồng toàn cầu đang chứng kiến sự chuyển dịch sang cuộc cách mạng công nghiệp lần thứ tư, điều này đã tạo ra một làn sóng mới về chuyển đổi sản xuất và tiêu thụ năng lượng. Việc cạo đỉnh có thể cân bằng nhu cầu phụ tải và tạo điều kiện thuận lợi cho các đơn vị điện lực nhỏ tham gia phát điện dựa trên các nguồn năng lượng tái tạo. Về vấn đề này, nhiều phương pháp đã được đưa ra, như Quang điện mặt trời (PV), năng lượng gió, nhiên liệu sinh học, sinh khối và Bộ lưu trữ năng lượng pin (BES) hoạt động như Hệ thống lưu trữ năng lượng (ESS). Để đánh giá tính khả thi của việc ứng dụng năng lượng tái tạo tại các cảng, nhiều giải pháp công nghệ và thực tiễn đổi mới sẽ được phân tích. Hơn nữa, bài viết này trình bày phân tích tập trung về bối cảnh của Malaysia, trong đó bao gồm lĩnh vực hàng hải đang phát triển mạnh, nhằm đưa ra những quan điểm có giá trị về việc sử dụng các giải pháp năng lượng tái tạo của các cảng biển trong khu vực địa lý này. Bài viết này tìm cách đóng góp về mặt học thuật cho cuộc thảo luận đang diễn ra về hoạt động cảng bền vững trong bối cảnh rộng lớn hơn của sự thay đổi toàn cầu hướng tới các nguồn năng lượng tái tạo, bằng cách tiến hành kiểm tra toàn diện các tiến bộ công nghệ và thực tiễn bền vững.

1. INTRODUCTION

Seaports play a pivotal role in global trade and serve as interfaces between land and sea transportation, facilitating the transfer of cargo from ships to trucks, trains, and vice versa (Gurzhiy et al., 2021) [1]. Seaports generate employment opportunities directly and indirectly, enhance the competitiveness of domestic industries, and foster economic growth by attracting foreign investment and trade (Caliskan, 2022) [2]. Seaports have a strategic importance for national security. They are crucial for the movement of military supplies and personnel during times of conflict or humanitarian crises (Anser et al., 2020) [3]. However, the operations of seaports also present significant environmental challenges posit that seaport activities, particularly those involving ships and trucks, release pollutants into the air, including sulphur dioxide, nitrogen oxides, and particulate matter. These emissions can lead to poor air quality and have adverse health effects on nearby communities. Seaports can discharge pollutants, such as ballast water, oil, and chemicals, into nearby water bodies, causing harm to aquatic ecosystems and marine life (Melnyk et al., 2023) [4]. Inadequate wastewater treatment facilities can exacerbate water pollution (Samsudin et al., 2016) [5]. According to Yadav et al., (2021) [6], addressing these environmental challenges associated with seaport operations requires a multi-faceted approach, including the adoption of cleaner technologies, improved waste management, sustainable urban planning, and regulatory measures to reduce emissions and pollution. In addition, there is a growing emphasis on green port initiatives and the development of eco-friendly infrastructure to mitigate the environmental impact of ports while continuing to support global trade.

2. RENEWABLE ENERGY AND PORTS

Amid the current global climate crisis and the urgent need for energy efficiency, there has been an increase in concerns regarding the environmental impacts of port development and operations. The environmental impact of traditional seaport operations, characterized by emissions from vessel, handling equipment, and energy-intensive facilities, has raised concerns about sustainability. The renewable energy generation and consumption in seaports have gained prominence as an innovative and sustainable solution to address the dual challenges of environmental stewardship and energy security. This transition not only aligns with global effort to combat climate change, such as the Paris Agreement, but also offers numerous perceived benefits. These advantages include reduced carbon emissions, improved air quality, lower operating costs, and increased energy resilience.

The International Maritime Organisation (IMO) is a United Nations specialised agency tasked with the global regulation of shipping. Amid the urgent matter of climate change and its correlation with maritime operations, the IMO has established ambitious objectives to mitigate GHG emissions. IMO has set a goal of achieving a 50% reduction in annual total GHG emissions and a 70% reduction in carbon dioxide (CO2) emissions from transport operations by 2050. Figure 1 illustrate the IMO Strategy on Reduction of GHG Emissions from ships.

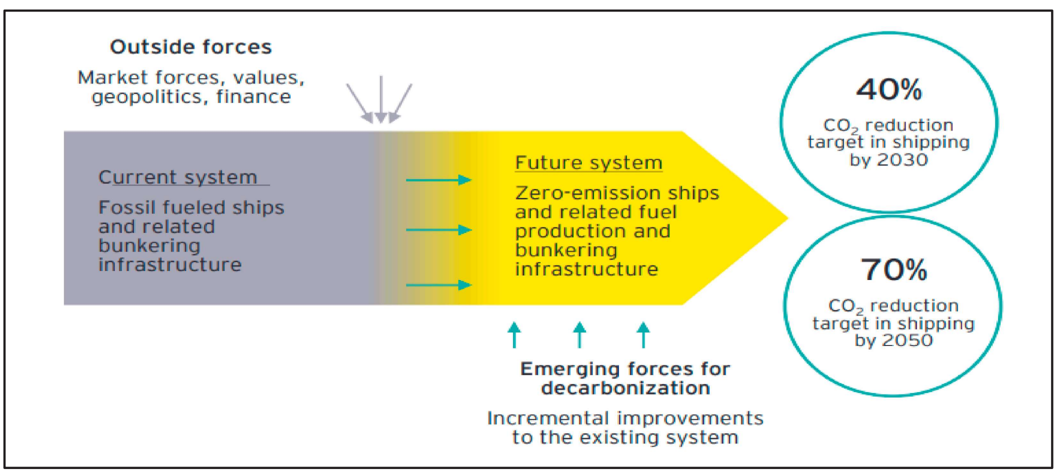

Figure 1. Imo strategy on reduction of ghg emissions from ships

Source: World Economic Forum, 2023

In addition, the European Sea Ports Organisation (ESPO) Report 2022 presents the annual environmental benchmarks for the European port sector, based on data from ports that are members of the EcoPorts Network. The results of an analysis of several environmental performance indicators, which are presented in Figure 2, lead to the conclusion that the most pressing environmental concerns in the year 2019 are related to climate change, air quality, and energy consumption. Therefore, reducing the negative effects that port operations have on the surrounding environment should be the primary motivation for adopting renewable energy sources in ports.

	1996	2009	2013	2018	2019	2020	2021	2022
1	Port development (water)	Noise	Air quality	Air quality	Air quality	Air quality	Air quality	Climate change
2	Water quality	Air quality	Garbage/ Port waste	Energy consumption	Energy consumption	Climate change	Climate change	Air quality
3	Dredging disposal	Garbage/ Port waste	Energy consumption	Noise	Climate change	Energy efficiency	Energy efficiency	Energy efficiency
4	Dredging operations	Dredging operations	Noise	Relationship with the local community	Noise	Noise	Noise	Noise
5	Dust	Dredging disposal	Ship waste	Ship waste	Relationship with the local community	Relationship with the local community	Relationship with the local community	Water quality
6	Port development (land related)	Relationship with the local community	Relationship with the local community	Port development (land related)	Ship waste	Ship waste	Water quality	Relationship with the local community
7	Contaminated land	Energy consumption	Dredging operations	Climate change	Garbage/ Port waste	Water quality	Ship waste	Ship waste
8	Habitat loss/ degradation	Dust	Dust	Water quality	Port development (land related)	Garbage/ Port waste	Dredging operations	Garbage/ Port waste
9	Traffic volume	Port development (water)	Port development (land related)	Dredging operations	Dredging operations	Dredging operations	Port development (land related)	Port development (land related)
10	Industrial effluent	Port development (land related)	Water quality	Garbage/ Port waste	Water quality	Port development (land related)	Garbage/ Port waste	Dredging operations

Figure 2. Top 10 Environmental Priorities of the Port Sector over the Year

Source: ESPO

3. RENEWABLE ENERGY TECHNOLOGIES IN PORTS

Renewable energy technologies in seaports have gained significant attention and implementation in recent years. To ensure sustainability, a port must effectively monitor and reconcile three fundamental aspects: environmental quality, economic prosperity, and societal well-being. According to Sarmento et al. (2018), the economic benefits of renewable energy, such as reduced energy costs over time, are a significant motivation for ports to transition to cleaner energy source. This is also supported by Guo et al., (2019) that the use of renewable energy in ports can improve energy security by lowering reliance on fossil fuels and increasing the availability of diverse energy sources. The following are the technologies that offer various benefits, including reducing GHG emissions, lowering operational costs, enhancing energy security, and promoting sustainable development (Rajaram et al., 2019).

3.1 Power Photovoltaic

Power Photovoltaic (PV) has gained prominence in many ports as a clean and sustainable energy source. Ports with extensive rooftop areas, such as the Port of Los Angles, have installed solar panel to generate electricity for their operations. In addition, floating solar farms on water bodies within port premises, such as those seen in the Port of Singapore, are emerging as viable option for maximizing solar power generation. Solar energy is the most promising source of clean, renewable energy and has the greatest potential to solve the world's energy problems. An energy source that uses the radiant light emitted from the sun is called solar energy and can be converted into electrical energy using a device called photovoltaic cell (Ong., H.C et al., 2011). Photovoltaic cells convert sunlight directly into electricity without creating air or water pollution. Solar energy has been identified the cleanest renewable energy source.

3.2 Wind Energy

Wind turbines have found their way into seaport area, taking advantage of the often-windy coastal locations. The Port of Rotterdam, Europe’s largest port, features a dedicated wind farm that supplies renewable energy to the seaport's infrastructure. These turbines not only provide clean energy but also serve as iconic landmarks in the port landscape.

3.3 Biomass and Biofuels

Several seaports are exploring the use of biomass and biofuels to replace traditional fossil fuels. The Port of Gothenburg in Sweden has invested in biogas-powered trucks and machinery for cargo handling. In addition, biofuel blends are becoming increasingly common for vessels docking at ports worldwide, reducing emissions from marine transportation. Biomass is the mass of combustible materials of organic origin from any source such as plants, bio wastes or process wastes (Acciaro et al., 2014) [7]. Biomass gives energy via different conversion technologies in the form of heat or electricity, or into other forms such as liquid biofuel or combustible biogas. The conversion technologies for solid biomass resources into heat, power and combine heat and power (CHP) can be classified into two general groups, i.e., combustion and gasification. Another method for conversion of solid biomass is anaerobic digestion. Biomass also provides transportation fuels such as bioethanol and biodiesel.

3.4 Battery Storage

Battery Energy Storage System (BESS) are gaining popularity in ports to store excess renewable energy for later use. These systems help ensure a stable and reliable power supply, particularly during peak demand periods or when renewable generation is low. The Port of Los Angeles, for instance, has deployed a significant BESS to enhance grid stability (Green Ports Gateways to Europe, 2020) [8].

3.5 Electric Vehicles (EVs)

Many ports are electrifying their vehicle fleets by introducing electric cargo handling equipment and establishing EV charging infrastructure. This reduces emissions from port activities and contributes to the electrification of transportation within the port vicinity (National Energy Transition Roadmap, 2023) [9]

Seaports are major sources of GHG emissions because of the heavy use of diesel-powered equipment, such as cranes, trucks, and ships. Thus, transitioning to renewable energy sources, such as wind, solar, and hydroelectric power, can significantly reduce carbon emissions associated with seaport operations. However, alongside the promising benefits, there are also perceived risks and challenges associated with the integration of renewable energy into seaport operations. These include initial capital investments, grid integration complexities, variability in energy production, and potential disruptions to established supply chains. Therefore, a comprehensive understanding of dynamics, opportunities, and potential risk of renewable energy adoption in seaports is crucial for stakeholders in the maritime industry, policymakers, and researchers (Yang et al., 2021) [10].

4. RENEWABLE ENERGY ADOPTIONS SEAPIRTS

The need for renewable energy solutions in seaports is driven by the imperative to reduce carbon emissions and enhance sustainability in the maritime industry. However, the high level of activity in seaports also leads to significant environmental impacts, primarily due to the reliance on fossil fuels. Renewable energy solutions offer a way to mitigate these impacts. Therefore, using renewable energy for electricity generation and electrifying seaport equipment can reduce local air pollution by eliminating diesel emissions.

Seaports are required to meet global and regional regulations, such as the International Maritime Organization's (IMO) sulphur cap and emissions reduction targets, require seaports and ships to reduce their environmental footprint (Ariffin et al., 2022) [11]. Furthermore, renewable energy adoption in seaports can position them as leaders in sustainable maritime operations, attracting environmentally conscious shipping companies and shippers while bolstering their reputations as responsible stewards of their local ecosystems.

Notable case studies such as port of Los Angeles and port of Rotterdam demonstrate the feasibility of these initiatives as well as the benefits that can be gained from participating in them. Even though there are still obstacles to overcome, the overall outlook for renewable energy in seaports is optimistic, which is in line with efforts being made all over the world to combat climate change. This overview provides insights into the state of renewable energy adoption in seaports globally, drawing upon recent developments and notable examples.

Table 1. Current Ongoing Renewable Energy Projects in Ports

Country	Port name	Technologies
United Arab Emirates (UAE)	Port of Jebel Ali	Solar Photovoltaic
Sweden	Port of Gothenburg	Hydrogen production facility

Country	Port name	Technologies
Australia	Por of Brisbane	The Solar Energy Initiative
The Netherlands	Port of Rotterdam	Wind farm & Biofuel refinery
Finland	Port of Helsinki	Wind Power
Germany	Port of Hamburg	Solar Photovoltaic
New Zealand	Ports of Auckland	Solar Photovoltaic
China	Port of Qingdao	Hydrogen
Italy	Port of Genoa	Solar, biomass, wind, geothermal energy
Fiji	Ports of Fiji	Solar Photovoltaic
Sri Lanka	Port of Colombo	Solar Photovoltaic

Source: Author

5. RENEWABLE ENERGY AND EVIDENCE FROM MALAYSIAN SEAPORT

Malaysia is one of the world's fastest-growing, competitive economies with a significant position in the Southeast Asian region attributed to its location at the confluence of the intercontinental and intra-Asian maritime trade routes going through the Strait of Malacca. Hence, it is no surprise that Malaysia houses one of the biggest port facilities in the world. It is also a transshipment hub of the Asian region and a preferred point of entry into the Southeast Asian Market. Boasting a highly developed maritime shipping sector, Malaysia has been ranked by UNCTAD as the fifth-best linked country in the world, in terms of shipping trade route connectivity, better than the developed economies of Germany and the Netherlands. There are six major ports in Malaysia that are currently being identified as the major trade route for international trade namely, Port Klang, Port of Tanjung Pelepas, Port of Johor, Port of Bintulu, and Port of Kuantan.

Malaysia is located between 1 degree and -7 degree in North latitude and between 100 degree and 120 degree in East longitude, which is second largest solar radiation region (Samsudin et al., 2016) [5]. Therefore, there is a large potential for photovoltaic energy to be absorbed by photovoltaic cells in Malaysia. The average daily solar radiation in Malaysia is within the range of 4.12 – 5.56 kWh/m^2. The highest solar radiation was estimated to be 6.8 kWh/m^2/day in August and November, whereas the lowest was found to be 0.61 kWh/m^2/day in December (Mansor, 2014). According to the International Energy Agency, it is estimated that approximately 141 GWh of electricity was produced in 2013, which 0.1% of the total electricity generation in Malaysia. The installed capacity of solar energy in Malaysia is 0.07 GW (Mekhilef et al., 2014).

In terms of, the wind speed is generally low over Malaysia and there is no remarkable electricity has been generated using wind energy in Malaysia (Bose et al. 2019). However, some areas of Malaysia have experienced a considerable wind speed for wind power generation.

Table 2. Wind speed and power density in few prospective areas of Malaysia

Area	Power density (W/m^2) at 10 m height	Power density (W/m^2) at 65 m height	Probity of speed above 2.5 m/s (%)	Turbine operating hours
Kota Bharu	11.058	45.015	38.79	3398
Kuala Terengganu	7.367	30	28.37	2485
Langkawi Island	5.822	23.7	20.75	1818
Mersing	17.013	69.257	58.04	5084
Miri	7.197	29.298	28.85	2527

Source: Samsudin et al., (2016) [5]

Power generation in Malaysia heavily relies on three fossil fuel sources, namely coal, natural gas, and fuel-oil. However, the current power generation pattern is not sustainable due to the adverse environmental impacts and the depletion of fossil fuel reserves. Fortunately, Malaysia possesses abundant renewable energy resources, particularly biomass, solar, small hydro, and ocean energy. Considering this, the utilization of renewable energy and the implementation of energy efficiency measures emerge as crucial tools in achieving sustainable energy solutions.

The reserves of the main fossil fuel sources in Malaysia are estimated at 1.94 billion tons for coal, 0.64 billion tonnes for crude oil, and 2784 billion cubic meters for natural gas. The reserves of fossil fuels will be completely exhausted in the near future, e.g. natural gas by 40 years and oil by 29 years from now. Although the country has a relatively big amount of coal reserves, they are concentrated in Sarawak and Sabah which have inadequate infrastructure and high extraction cost. Malaysia endowed with huge hydropower resources that can generate as much as 29,000 MW of electricity. Malaysia produces large amount of palm oil biomass annually, which can be the major contributor of renewable energy. The wind speed is generally lower over Malaysia and there is no remarkable potential of wind energy (Samsudin et al., 2016) [5].

While the adoption of renewable energy in ports is growing, challenges remain. High upfront costs, regulatory hurdles, and the intermittency of renewable sources are among the key obstacles. However, as technology advances and economies of scale are realized, these challenges are likely to diminish. The global trend toward decarbonization and the imperative to combat climate change ensure that renewable energy adoption in ports will continue to expand (Samsudin et al., 2016) [5].

Malaysia Government Initiatives:

The 12th Malaysia Plan, spanning the years 2021 to 2025, and the National Energy Policy 2022-2040, have laid the groundwork while the NETR will ensure Malaysia forges ahead in this transformative journey. Against the backdrop of a dynamic global energy landscape mired with the energy trilemma of security, affordability, and sustainability at its core, the world is racing for solutions. Malaysia too is resolute in overcoming these challenges and the NETR demonstrates our unwavering determination in this regard. Reducing Malaysia's carbon footprint is one of the catalysts to transforming the economy on a more sustainable path. It is also an agenda to generate new sources of growth, creating business and trade opportunities, and consequently, knowledge workers (National Energy Transition Roadmap, 2023) [9]. Malaysia's transition to a low-carbon, climate resilient economy is driving industry leaders to prioritize focus on reducing greenhouse gas (GHG) emissions and investing in low emissions technologies. In supporting the global decarbonization initiatives, Malaysia has set a reduction target of up to 45% of GHG emission intensity to GDP by 2030 and this demands the participation of economic stakeholders across all sectors (National Energy Policy, 2021) [12]. Malaysian ports can benefit from collaborating with international ports that have successfully adopted renewable energy solutions. Participation in international initiatives and organization can provide access to funding and expertise. The Malaysian government can further promote renewable energy adoption in ports by offering incentives, subsidies, and clear regulations. Encouraging partnership between port authorities and private companies can facilitate investment in renewable energy projects. Ten flagship catalyst projects of the NETR, which cover six energy transition levers namely, energy efficiency (EE), renewable energy (RE), hydrogen, bioenergy, green mobility, and carbon capture, utilisation, and storage (CCUS) was launched in July, 2023. These flagship projects are expected to attract investment of more than RM25 billion, create 23,000 job opportunities and reduce GHG emissions by more than 10,000 Gg CO2eq per year (National Energy Transition Roadmap, 2023) [9].

6. CONCLUSION

The adoption of renewable energy sources in ports is a multifaceted process driven by environmental concerns, cost savings, and energy security considerations. While there are challenges related to initial costs, intermittency, and grid integration, ongoing advancements in technology and supportive policy frameworks are encouraging ports to make the transition. As research in this field continues to evolve, it is essential to explore innovative solutions and share best practices to further promote the sustainability and environmental performance of ports. Over the next three decades, Responsible Transition pathway sets the direction to meet growing energy needs and reduce GHG emissions. Malaysia will focus on improving energy efficiency, enhancing RE and bioenergy, reducing GHG emissions, greening mobility, accelerating innovation to commercialise hydrogen and CCUS technologies as well as strengthening energy infrastructure. These actions will be accompanied by strategies to unlock capital flows in support of the energy transition with energy security as the cornerstone. In terms of prospects, it is expected that the use of RETs in green ports will continue to increase in the coming years. This trend will be driven by the growing awareness of the need for sustainable development, decreasing the installation cost of RETs, and the availability of supportive policies and incentives. The development of innovative technologies such as floating solar panels, wind-powered shipping, and green hydrogen production will also open new opportunities for the application of renewable energy in green ports. Additionally, the integration of RETs with smart port technologies and digital solutions such as artificial intelligence, blockchain, and the Internet of Things will enable better monitoring, management, and optimization of energy consumption in green ports.

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REFERENCES

[1] Gurzhiy, A., Kalyazina, S., Maydanova, S., & Marchenko, R. (2021). Port and City Integration: Transportation Aspect. *Transportation Research Procedia, 54*, 890–899. https://doi.org/10.1016/j.trpro.2021.02.144

[2] Caliskan, A. (2022). Seaports participation in enhancing the sustainable development goals. *Journal of Cleaner Production, 379*, 134715. https://doi.org/10.1016/J.JCLEPRO.2022.134715

[3] Anser, M. K., Yousaf, Z., & Zaman, K. (2020). Green Technology Acceptance Model and Green Logistics Operations: "To See Which Way the Wind Is Blowing." *In Frontiers in Sustainability* (Vol. 1). Frontiers Media S.A. https://doi.org/10.3389/frsus.2020.00003

[4] Melnyk, O., Onyshchenko, S., & Onishchenko, O. (2023). Development Measures to Enhance the Ecological Safety of Ships and Reduce Operational Pollution to the Environment. *Scientific Journal of Silesian University of Technology. Series Transport, 118*, 195–206. https://doi.org/10.20858/sjsutst.2023.118.13

[5] Samsudin, M. S. N., Rahman, M. M., & Wahid, M. A. (2016). Akademia Baru Power Generation Sources in Malaysia: Status and Prospects for Sustainable Development. *Journal of Advanced Review on Scientific Research ISSN* (Vol. 25, Issue 1).

[6] Yadav, H., Soni, U., & Kumar, G. (2021). Analysing Challenges to Smart Waste Management for a Sustainable Circular Economy in Developing countries: A fuzzy DEMATEL study. *Smart and Sustainable Built Environment, 12*(2), 361–384. https://doi.org/10.21203/rs.3.rs-263855/v1

[7] Acciaro, M., Ghiara, H., & Cusano, M. I. (2014). Energy management in seaports: A new role for port authorities. *Energy Policy, 71*, 4–12. https://doi.org/10.1016/j.enpol.2014.04.013

[8] Green ports gateways to Europe. (2020).

[9] National Energy Transition Roadmap. (2023).

[10] Yang, L., Danwana, S. B., & Yassaanah, F. L. I. (2021). An empirical study of renewable energy technology acceptance in ghana using an extended technology acceptance model. *Sustainability*

(Switzerland), 13(19). https://doi.org/10.3390/su131910791

[11] Ariffin, Z. Z., Isa, N., Lokman, M. Q., Ludin, N. A., Jusoh, S., & Ibrahim, M. A. (2022). Consumer Acceptance of Renewable Energy in Peninsular Malaysia. *Sustainability (Switzerland), 14*(21). https://doi.org/10.3390/su142114627

[12] National Energy Policy (2021).